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Human Factors Analysis of Operational Activities

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RAMS

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Master Thesis

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Preface

This Master Thesis is written as a study program of International Master's Program in Reliability, Availability, Maintainability and Safety (MSc in RAMS) under Production and Quality Engineering Department (IPK) at Norwegian University of Science and Technology (NTNU), Trondheim, Norway. This thesis work is attached with one of NTNU's ongoing project MIRMAP (Modeling Instantaneous Risk for Major Accident Prevention). The report is about assessing human and organizational factors in major accidents. And the main aim of MIRMAP project is also to analyze the risk of major hazardous events.

The reader of this report should have some primary knowledge on risk analysis or equivalent knowledge of the course TPK-5160-Risk Analysis at NTNU.

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Ridwan

Muhammed Ridwanul Hoque

Acknowledgement

There are several people I would like to thank for their help and support throughout my Master thesis.

At first, I want to thank my supervisor, Stein Haugen. With his great guidance and help, I continued my work with my own interest. Stein helped me to find out relevant documents about the thesis topic and he was constantly there with his ideas and helping hand.

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In the end, special thanks to my family and friends to support me throughout this whole period of my study at NTNU.

Abstract

Investigation of major accidents shows that along with technical factors, human factors can influence operational activities as well. In spite of this, existing quantitative risk analysis are utilized broadly for technical safety systems. The purpose of thesis work is to emphasize on human factors and how it can influence operational activities and risk associated with the activities. For the sake of assessment of human factors influence on operational activities a model is proposed. The proposed model deals with barrier failures and finds out the basic events for the failure. Then it goes further down and analyzes the reasons for each basic event. Some risk influencing factors are identified which affect the basic events and for each risk influencing factors some indicators are identified as an influencing factor. Hot work has been selected as the work task to analyze and operational steps of hot work are identified to understand the risk associated with each work task or activity. After that, each of the work tasks is assessed for the hazardous event 'ignition' and relevant RIFs are extracted. A few RIFs are selected from the identified RIFs and evaluated thoroughly to understand their impact in hot work. The intention of the author is to analyze the work task activities, risk on the task, possible barrier failure, the relation between the cause of failure and risk influencing factors as well as include some indicators to analyze the risk factors.

Contents

Acronyms

BBN	Bayesian Belief Network
BORA	Barrier and operational risk analysis of hydrocarbon releases
CSB	US Chemical Safety Board
ETA	Event Tree Analysis
FAR	Fatal Accident Rate
FTA	Fault tree analysis
HC	Hydrocarbon
HCL	Hybrid Causal Logic
HRA	Human Reliability Analysis
HSE	Health and Safety Executive
MIRMAP	Modeling Instantaneous Risk for Major Accident Prevention
PSAN	Petroleum Safety Authority Norway
PPE	Personal Protective Equipment
ORIM	Organizational Risk Influence Model
OTS	Operational Condition Safety
PSA	Probabilistic Safety Assessment
QRA	Quantitative Risk Analysis
REWI	Resilience-based Early Warning Indicators
RIF	Risk Influencing Factor
Risk_OMT	Risk modeling- Integration of Organizational, Human and Technical factors
RNNP	Risk Level in the Norwegian Petroleum Activity
SoTeRiA	Socio-Technical Risk Assessment
SJA	Safety Job Analysis
TTS	Technical condition safety

Chapter 1

Introduction

1.1 Background

Risk analysis has been dealing with the associated risks in industry for many years. Quantitative risk analysis (QRA) is used in oil and gas industry to quantify the risks mostly related to technical aspects of design and it has been proven very efficient. But the existing methods related to QRA reflect limited work in operational and organizational issues. Only a few qualitative approaches are present for operational and organizational issues but these show a weak link to the risk. PSAN states that there is a significant influence of maintenance and related simultaneous activities on the risk levels in operations (Edwin, 2015). This has become a motivation now to improve the methods to handle operational and organizational issues and develop some methods that are not confined only to qualitative aspects but only can contribute quantitatively.

In the last few years, there has been some important research in modeling the effect of human, technical and organizational factors on risk in nuclear industry as well as oil and gas industry. Although in oil and gas industry, using human and organizational factors is a quite new concept but it is gaining importance day by day because of some severe incidents like Piper Alpha and so on which clearly refers to the human error impact on major accidents.

Øien, K. (2001a) first made an effort to develop a method/ model termed as Organizational Risk Influence Modeling (ORIM) for organizational factors analysis through risk indicators. The shortcoming of this method is that it did not give explicit knowledge on failure causes. Following that Aven et al. (2006) developed a new model named Barrier and Operational Risk Analysis (BORA) focusing on the barrier failures with the help of fault trees and risk influence diagrams. But BORA cannot link the basic events and disregard the interaction between basic events. Afterward, Røed et al. (2009) have improved the BORA method considering the interactions between basic events and indicators with the help of Bayesian belief network (BBN) and termed it as HCL. Sklet et al. (2010) have developed another qualitative method next year called Operational Condition safety (OTS) that emphasizes the impact of human and organizational factors on barrier performance. Later on, Vinnem et al. (2012) improvised a new method Risk modeling -Integration of Organizational, Human and Technical factors (Risk_OMT) combining the two methods BORA and OTS. It represents the risk influencing factors (RIFs) into two levels- an organizational level which has a direct influence on basic events of failure and management level which has an influence on an organizational level. But this method is very difficult to practice because of its time consumption and it needs to moderate the existing QRA. Apart from these human and organizational factors related methods, Mogaghegh et al. (2009) has developed another method Socio-Technical Risk Assessment (SoTeRiA) to combine both of the social and technical aspects of the risk assessment. With the development of all these methods, the concept of 'indicator' in the risk analysis has come in front vividly and indicates its impact on total risk of the facility. But yet no concrete method is identified to measure all types of subjective and objective indicators.

All these above methods that have been developed to analyze operational activities in risk analysis but there are some limitations in each of them. The purpose of this thesis to analyze an operational activity and its related human factors for risk analysis. Besides, a further analysis on the indicators of RIFs is carried on and discussed how these indicators influence on the risk level.

1.2 Objectives

The main objectives of this Master thesis are:

1. Select a specific work task and go through in details of this task by describing task analysis or equivalent method. Find out relevant failures/errors/failure modes (focus on human errors)
2. Identify RIFs for failures based on the breakdown of work task steps in the first objective. Also, describe why these RIFs influences the task performance.
3. Build a model for the work task.
4. Select some RIFs from the previous identification. From the literature survey describe potential indicators for the RIFs and how they influence on the work task.
5. Describe non-linearity and how we can model non-linear effects.

1.3 Limitations

The implementation of this thesis is limited to hazardous process plants. Although some accidents related to onshore plants are discussed in Chapter 6, but it can be applied to offshore plants as well with little modifications.

The concern of the study is to increase human safety and avoid major accidents. Of course, this concern's implementation is related to cost analysis. But any type of cost analysis is ignored in this study concentrating only on health, safety and environment.

Unavailability of data is not new in human factors analysis. In this thesis work, it is also clearly evident. Many data are assumed due to lack of available sources.

1.4 Approach

With the project knowledge of autumn semester of 2015, a detailed literature review is done. Along with that, a detailed knowledge of the specific work task is also searched in several sources. Afterward, a model has been proposed and implemented for the specific task. At the last, some further work has been suggested. Throughout the thesis work, the author is monitored by the supervisor and advised time to time. The thesis work approach is illustrated in Figure 1.1.

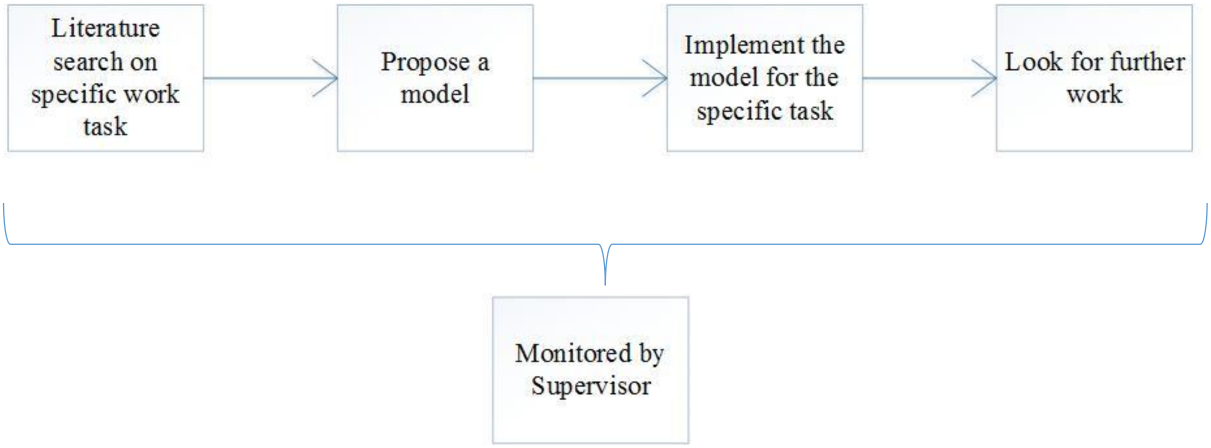


Figure 1.1 : Approach of the thesis work

1.5 Structure of the report

The structure of the report is as follows:

- Chapter 2 presents a brief summary of the literature that has been reviewed.
- Chapter 3 contains a detailed discussion of Bayesian Belief Network.
- Chapter 4 gives a details discussion about the specific work task (in that thesis work, it is hot work), steps of the work task.
- Chapter 5 represents the RIFs related to hot work steps.
- Chapter 6 discusses some accidents in hot work operation and a proposed RIF model for the hot work.
- Chapter 7 explains some of the selected RIFs identified in chapter 5 and evaluate these selected RIFs.
- Chapter 8 describes non-linearity and present models' stand in dealing with it.
- Chapter 9 discusses key points of the thesis work and proposes some further work.
- Chapter 10 concludes the thesis work with the findings.

Note: While giving a reference, in most of the cases, the reference is given either in the beginning of a text and paragraph or the reference is given at the end of the text and paragraph. If any text or paragraph is not given any reference then it is the author's understanding and opinion.

Chapter 2

Literature Review

This chapter starts with some basic definition of risk analysis. Following that, sources that helped in the study are discussed briefly. Some other relevant sources are mentioned in the later chapters while discussing the topics adapted from them.

Definitions

Major accident

A major accident is defined as an acute incident, such as a major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets. (PSA)

Risk influencing factor

A risk influencing factor is an aspect of a system/activity that affects the risk level of that system/activity. (Wagnild, 2015)

Risk

The risk associated with an activity means the combination of possible future incidents and their consequences and associated uncertainty. (PSA)

Modeling instantaneous risk for major accident prevention, Task 1: Analysis of decisional situations (Petter Almklov)

‘Average risk’ is a popular term in risk analysis and is quantified in the Quantitative Risk Assessment (QRA). Average risk indicates to the average risk of a plant or a platform over a 12 month period. On the contrary, the expression ‘instantaneous risk’ is quite confusing because of its imprecise definition. Generally, it refers to the risk of a shorter period like one day, one shift, one hour etc. In the QRA approach, the average risk is expressed as Fatal Accident Rate (FAR) values over a year. But the instantaneous risk is not expressed as FAR values, rather it is expressed by some other values on a relative scale.

Safe Job Analysis (SJA) is a preferred method to analyze activities in a short duration. But it is evident that SJA has a tendency towards occupational injury risk instead of major accidental risk(Leistad & Bradley, 2009). SJA is not a convenient method to use while considering complex operational situations and their impact on risk. Rather it is more suitable when there is only one hazard situation at a time and to identify relative solutions.

There exists another term as 'living risk analysis', mostly popular in the nuclear industry, also addresses to the 'instantaneous risk'.

Indicators for risk of major accidents (S. Sklet, Hahnsen, E., Bosheim, S., Seljelid J., Haugen. S., & Nyheim O. M. , 2011)

Much research is performed in the field of safety indicators, both in personal and process risk indicators. Among these two process risk indicators relates to major accident risk indicators. There are manifold definitions of the term indicator. According to Øien (Knut Øien, 2001b), "An indicator is a measurable/operational variable that can be used to describe the condition of a broader phenomenon or aspect of reality". But the noteworthy fact is that an indicator is the operationalization of a theoretically variable which cannot be directly measured or observed. In the case of major accidents, these indicators are used as a medium to control and monitor the overall plant condition. Indicators in the view of risk approach are "a risk indicator is a measurable/operational definition of a RIF" (Øien 2001).

Indicators are categorized into two types: (a) leading and (b) lagging indicators. Leading indicators work as proactive and preventive tools as they reveal conditions those are declining the effect of safety measures. Pointing out the leading risk factors requires intensive monitoring and checking of the safety critical activities and relevant systems. On the other side, lagging indicators work as reactive as they are exposed after the accident or undesirable incident happens such as a number of leaks in the hydrocarbon facility last year.

There is already much research on lagging indicators e.g. rates of accidents or near misses. Yet the lagging factors are the result of the incident, it cannot predict any early warning. To get early warnings, it is inevitable to look into the causal chains of accidents, fault trees, and risk influencing factors. But it is a challenge to select appropriate indicators as they are quite difficult to identify and cannot be measured according to traditional analysis approach. Nevertheless, the more the knowledge is acquired the more chance for early prediction. Different methods have been developed to identify major accident risk indicators. Some of these are described below:

Health and Safety Executive's (HSE & Association, 2006) guideline propose 6 steps to implement a process safety measurement system. One of the main concepts is ‘dual assurance'. This recommends the combination of leading and lagging indicators for measuring the status of each risk control system within the process safety system. In this way, the leading indicators will provide early warning if there is any deviation in the safety system as well as lagging indicators will continuously monitor the status of safety systems by checking whether it is operating as it is intended or not.

Reiman & Pietikäinen (Reiman & Pietikäinen, 2012) proposed three categories of safety performance indicators. One is the lag indicators to measure the outcome of an activity and the rest two types are for lead indicators; indicators for driving and for monitoring. Outcome indicators simply measure the result of any activity like accident rate or leak frequency. Driving indicators indicate safety policies taken by the organization i.e. communication and management changes. Monitoring indicators describe management related activities like work practices, human resources etc. (Reiman, Pietikäinen, Kahlbom, & Rollenhagen, 2010)

SINTEF’s Building Safety project (K Øien, Utne, Tinmannsvik, & Massaiu, 2011) also contributes to developing leading indicators and it suggests a) incident based and b) resilience based indicators. Incident-based indicators are based on well-known scenarios and resilience based indicators relates to such factors that are important to recovery and prevention of incidents.

The literature review on indicators (S. Sklet, Hahnsen, E., Bosheim, S., Seljelid J., Haugen. S., & Nyheim O. M. , 2011) discusses the idea of indicator, the definition, categorization of indicators and different methods to identify these indicators. As indicators influence risk situation vitally, it is of great interest for the researchers. With the help of this literature, MIRMAP project can also be benefitted with risk analysis. Much research is going on to develop more ideas about indicators and how they can be identified.

Building Safety indicators: Part 1 – Theoretical foundation (Knut Øien, Utne, & Herrera, 2011)

Most of the recent research on safety indicators are based on leading and lagging indicators. Nonetheless, it should not hinder the development of early warnings about potential major accidents. Authors have been defining safety indicators or indicators differently since the start. OECD (OECD, 2003) defines, safety performance indicator means to measure the changes over time considering safety (related to chemical accident prevention, preparedness, and response) as a result of actions taken. Holmberg et al. (Laakso, Holmberg, Lehtinen, & Johansson, 1994) state, "A safety indicator is an observable characteristic of an operational nuclear power plant unit, presumed to bear a positive correlation with the safety of the reactor. The safety indicators have been selected, among other means, for the purpose of supervision of safety. The safety indicators can be related to defense lines according to defense-in-depth such as physical barriers and safety functions".Øien (Knut Øien, 2001b) describes risk influencing factor as an event or condition of a system that affects the risk level of the system. But Hellevik (Hellevik, 1999) prior to Øien's (Knut Øien, 2001b) research has discussed the fact about measuring the problem of some a RIF e.g., organization factor. According to Øien (Knut Øien, 2001b), the RIF should have a theoretical definition so that in can be measurable. Figure 2.1 shows Øien's (Knut Øien, 2001b) concept of RIF.

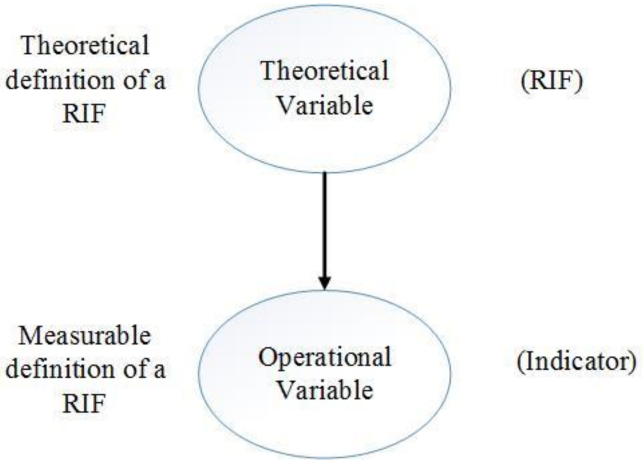


Figure 2.1: General measurement model (Knut Øien, 2001b)

This paper emphasizes into two main perspectives. Firstly, the development of causes of accidents, focusing on the organizational causes rather than technical causes. Secondly, emphasize on the comparison of predictive and retrospective view. It's to predict the possibility of having a major accident tomorrow including all possible causes (in predictive view) and not sticking to the idea of only establishing the causes after the event (in retrospective view). Based on these two perspectives, a conceptual model has been developed to differentiate the approaches of these two perspectives. Figure 2.2 shows the conceptual model and it includes some key topics of quantitative risk assessment (QRA) such as fault tree analysis, event tree analysis (ETA), human reliability analysis (HRA).

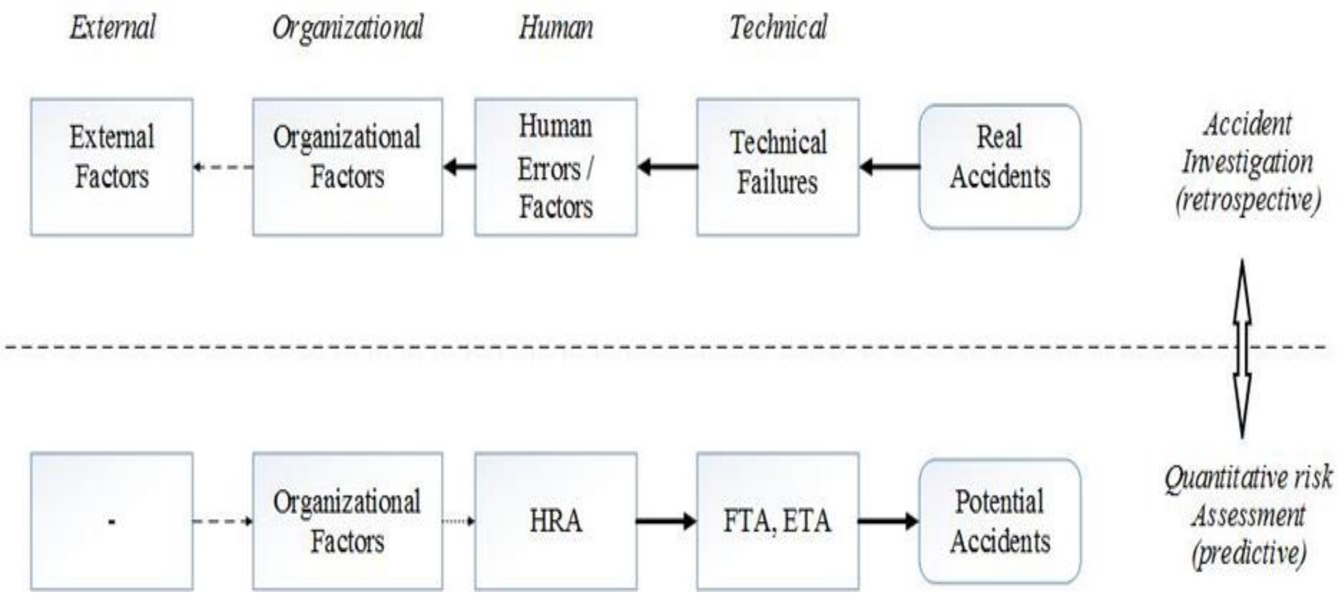


Figure 2.2: Accident investigation versus predictive assessment (K Øien, 2001)

An indicator is a measurable aspect. This aspect could be safety or risk. Safety indicators and risk indicators should be clearly distinguished unless it is clearly explained what is risk indicator. Safety indicator is based on assumed relations or correlations and risk indicator is based on causal connection through a risk model. In the previous works, risk indicator is referred as a probabilistic indicator or a PSA-based risk indicator.

Major Accident Indicators in High-Risk Industries - A Literature Review (Kilskar et al., 2016)

The focus of this paper is to improve the knowledge of safety relevant indicators related to major accidents. For this purpose, the writers emphasize into three main key topics: (a) relationships between indicators and major accident risk, (b) the effect of the use of indicators and (c) the impact of surroundings on the reliability of the indicators. And for each topic, it has been researched further considering some key themes.

(a) Relationships between indicators and major accident risk

Some key themes have been identified from the literature review to discuss the relationships: relationships through correlations, logically explained relationships (versus assumptions) and relationships through the retrospective analysis of accidents.

Relationships through correlations, As there had not been many major accidents, the relationships between indicators and the number of mishaps or precursors had been analyzed.

Vinnem et al. (J. E. Vinnem, Hestad, Kvaløy, & Skogdalen, 2010) used linear regression to analyze the different data related to hydrocarbon leaks frequency and conclude that there are potential relations between the number of hydrocarbon leak and safety climate factors.

Zohar (Zohar, 1980) described safety climate as the safety program effectiveness judged by the safety indicators. In addition, it is the perception of workers towards management attitudes about safety and perception regarding the safety in the general production process.

Kongsvik et al. (Kongsvik, Johnsen, & Sklet, 2011) add, ”The statistically significant relations found, support the hypothesis that the safety climate indicator could serve as a leading indicator for HC leaks”. Grabowski et al. (Grabowski, You, Song, Wang, & Merrick, 2010) identified potential safety factors or leading indicators that have significant correlations with accidents. Some of the indicators are formal learning systems, safety orientation, communication etc. Likewise, research of Bergh et al. (Bergh, Ringstad, Leka, & Zwetsloot, 2014) identifies the impact of psychological risk indicator on the variation of HC leaks. Several indicators such as workload, cooperation, support from co-workers etc. have been included.

Logically explained relationships (versus assumptions) Øien et al.(Knut Øien et al., 2011) proposed that if a major accident is modeled using the total risk analysis of potential accidents, it is possible to identify indicators that are logically related to the major accident risk. Haugen et al. (Stein Haugen, Seljelid, Mo, & Nyheim, 2011) have added that the risk model includes relevant factors which influence the risk of major accidents.

On the contrary, Roberson (ROBERSON, 2012) argues that determining the relationship between an indicator and major accident risk is not the same as to predict a major accident. He warns that, “There is no way to identify a metric that can reliably predict a particular future outcome; don’t even try”. But rather he comments that leading indicators can help to identify and avoid accident-prone situations.

Relationships through the retrospective analysis of accidents The third theme is to find relationships by analyzing the previous accidents. Øien & Nielsen (Oien & Nielsen, 2012) apply a method of resilience based early warning indicators (REWI) on the Deepwater Horizon accident and concluded that one could have been gained necessary early information if the factors had been followed-up using relevant indicators. If the early warnings had been responded with proper consideration then the REWI method could have prevented the accident.

Thorsen (Thorsen, 2013) analyzed several accidents reports and interviews and found that indicators were used in order to identify risk influencing factors. All the indicators were assessed against several criteria and indicators need to fulfill some prerequisite before providing information to predict the risk of major accidents. Some indicators got a high score that may be used to provide warnings of changes in the risk.

(b) Effects of use of indicators

The key themes that have been followed in this topic are effects on the result, effects on activities and processes, unwanted and unintended effects.

Effects on the result, Øien (Knut Øien et al., 2011) and Herrera (I. Herrera, 2012) comments that the effect of the indicator values on the risk of major accidents can be understood by the use of risk analysis or risk model given that the indicators are used in the risk model. Besides, the limitation of the model should be considered. Van der (Van der Wielen, 2012) states it is difficult to establish the relationship between indicators and major accident risk and the indicators seldom used in the risk models.

Effects on activities and processes, Like the effects on the result, the effects on activities and processes is hard to identify. As a result, most of the authors discuss assumed effects. For instance, indicators contribute to maintaining awareness which influences in preventing major accidents (J. E. Vinnem, 2010), indicators shows limits for acceptable operations which increase system efficiency (I. A. Herrera, Nordskag, Myhre, & Halvorsen, 2009) and so on.

Unwanted and unintended effects, Indicator establishment has both positive and negative effects. But most of the authors are interested in discussing the negative effects and why indicators are established. Waefler et al. (Waefler, Binz, Gaertner, & Fischer, 2012) give an example how the target of reducing maintenance backlog can lead to low quality of maintenance. It could increase the indicator value but could reduce the safety level. Delatour (Delatour, Laclémence, Calcei, & Mazri, 2014) argued about the measurement variability. They questioned what could the method to change the value of indicators with the evolution of standards and the continuous management considering the long-term comparison.

(c) The impact of surroundings on the reliability of the indicators

The themes that are followed to describe the impact of surroundings on the reliability of indicators are event occurrence, adequate reporting, comparability across installations and companies.

Event occurrence, In several documents, it is stated that the occurrence of events affects the reliability of event based indicators. Although, these documents do not give any concrete example. Vinnem (J. E. Vinnem, 2010) commented it has been seen that major hazards precursors appear once per year per installation. Such frequency is not enough to work as an incident based indicator on an installation level.

Adequate reporting, It is a question how to develop a method that can provide data as one wants to observe. For example, Vinnem (J.-E. Vinnem, 2014) found it difficult to measure the real numbers of hydrocarbon leaks. If the limit of leaks is set to be high, one will get only a few registrations, and on the contrary, a lower limit will give more registrations but less reliable ones. In the end, Vinnem (2010, 2014) proposed to improve the reliability of an indicator by limiting event-based data collection in the range of medium to high severity.

Comparability across installations and companies, Indicators are not only used for any specific installation but for several installations and companies. The indicators should be identical means that the reporting methodology should be identical at each location. Herrera et al. (I. A. Herrera et al., 2009) and Herrera (I. Herrera, 2012) suggest, the indicators used in the industry should have a common meaning so that the results in different installations have the same basis.

A generic method for identifying major accident risk indicators (S Haugen, Seljelid, Nyheim, Sklet, & Jahnsen, 2012)

A generic method is developed to identify the risk indicators of a major accident. A risk model containing a set of risk indicators that influence the probability of occurring an event is developed. These factors could be technical, operational or organizational. Also, these factors refer to root causes, background etc. The model links all the factors to the end event directly so that the influence of these factors in risk can be measured.

The factors are classified into three layers: 1) activity factors, which can be controlled by the operating organization of the installation. 2) planning and coordination factors, that are considered and accepted in the operation planning i.e. operational planning, maintenance procedures, competence plans etc. 3) preconditions factors are those whose conditions are predetermined and very unlikely changes i.e. company policy, the design of the plant, environmental conditions.

The operating status of the factors is measured by the indicators. But it is true that to measure all the aspects of a factor is not possible all the time. So only a fraction of factor can be measured by the indicators and the rest is uncertain. While identifying the indicators, some properties i.e. validity, measurability, comprehensibility, reliability need to be considered. By using these invariable properties, the user can influence the status of indicators and it needs to keep in mind that the gathering of data should not be too excessive compared to the benefit achieved from these indicators. This paper suggests some criteria for the selection of a complete indicator- a) size of the indicator set, b) dual assurance, an indicator set that consists of both leading and lagging indicators, c) alarm and diagnosis, a combination of indicators that reflects what is wrong and tells us what is wrong is optimal, d) frequency of measurement.

This method suggests a way to identify the risk indicators following some criteria. However, the method cannot give any quantitative result of whether the risk is increasing or decreasing.

The contribution of human factors to accidents in the offshore oil industry (R. P. Gordon, 1998)

Accidents in several offshore and onshore industries i.e. Piper Alpha disaster, which is a combination of technical, operational, human and organizational, managerial, environmental etc. several factors, shows human factors have some significant contribution to these undesired events. Again, there exists another term ‘human error' that is slightly different from human factors but closely linked together.

The term ‘human error’ and ‘human factor’ are often ambiguous in the industry because of unclear definition. In the work of Gordon, he defines, “human factors is the scientific study if the interaction between man and machine” (Gordon 1998) This definition was later extended to individual, group and organizational factors. Human errors were defined by Rasmussen as “human acts which are judged by somebody to deviate from some kind of reference act... they are subjective and vary with time” (Rasmussen 1993).

Human Error (J. Reason, 1990b)

Reason outlines human error into four types human failure : slips, lapses, mistakes and violations.

Slips mean the faulty action execution where action do not proceed according to plan. In this case, the person knows exactly what to do but he/she unintentionally makes a wrong move in the task. For example, typing mistake of an official person even though he/she types similar type of document every day correctly.

Lapses are associated with the failure of memory. Again the intention is correct but something else then the task sequence occupies the person's mind while working and he forgets a usual task to do. For example, a worker always uses earplugs before the start of grinding operation. But suddenly one day he took other personal protective equipment (PPE) but forgot to take the earplug.

Mistakes happen when the execution is perfect but the plan itself fail to meet the objectives. May the plan was inappropriate or something happened unintentionally but the plan was not robust to the situation and does not notify the worker about situation change. For instance, misdiagnosing between various process variables and then carrying out incorrect actions.

Violations occur when the operators deliberately carry out actions that go against the organizational rules and regulations. It is not that the operation is stopped or the violators want to make harm. But the fact is that may be the operational task goes against the interest of worker or there is some procedural steps which the operator think not safe enough. For example, the procedure might be out of date or impractical.

Human Reliability Assessment (Kontogiannis & Embrey, 1992)

Kontogiannis and Embrey summarize human errors in a different way:

- *Action errors*: there is no action taken or the wrong action is taken or the right action taken in the wrong object.
- *Checking errors*: there is no checking or the wrong checking or the right checking in the wrong object.
- *Retrieval errors*: no information is available or the information retrieved is wrong.
- *Transmission errors*: when the information needs to be transferred either no information transmission or the wrong information transmitted or the right information transmitted in the wrong place.

- *Diagnostic errors*: when the undesired event arises, the situation is misinterpreted.
- *Decision errors*: when the situation is interpreted correctly, but a wrong decision is taken.

Chapter 3

Bayesian Belief Network

A Bayesian belief network is the graphical representation of the causal relationships between factors (causes) and final result(s) of the system. There are two main components of BBN: (1) node, (2) directed arc. Node describes the state or condition and arc indicates a direct influence. Arcs are also called links, arrows, vertices, and edges. Bayesian network diagram is also called as influence diagram (Rausand, 2013).

Probabilities can be included in the Bayesian network to find the probability of the outcome i.e. in the fault trees. Bayesian network sometimes called as a causal network or belief network. A Bayesian network is used for qualitative, quantitative or both as the analysis scope. Bayesian network is a comprehensive method and can be used for several purposes (Rausand, 2013). In this project work, it is used to represent the causal relationships between factors along with fault tree and event tree for risk assessment.

3.1 Fundamentals of BBN

A Bayesian network consists of following (Nielsen & Jensen, 2009) :

- A set of variables and directed arcs between variables.
- Each variable possesses a finite set of mutually exclusive states.
- The variables together with the directed arcs build a directed acyclic graph (DAG); a directed acyclic graph means the graph is not cyclic. Hence, if the directed arc shows a relation such as A1→ ………→ An, then in DAG A1 ≠ An .
- Each variable has a conditional probability table.

3.2 Method Description

(Rausand, 2013)

A Bayesian network consists of directed acyclic graph with probability tables. The graph is presented by nodes and arcs. An arc written as ‹ A, B › that means that an arc goes from A to

B. A and B are the two nodes in the graph. The nodes can be drawn as oval or circular and the arcs as arrows. Each node is presented as random variables with discrete values. It is not impossible to use continuous values, but then it becomes more complex. The value of the node or random variable is presented as a state. There could be more than one state of a variable. But the suggestion is to consider as less state as possible to avoid complicacy.

Suppose, two variables A and B are represented as node A and B. An arc from A to B denotes statistical dependencies between these variables. The arrow from A to B indicates that the value of B depends on the value of A or that the variable A has a direct influence on variable B. the Bayesian network is illustrated in Figure 3.1.

Figure 3.1 A simple Bayesian network (Rausand, 2013)

In Figure 3.1, A node is connected to B node as stated. A is called as parent node and B is child node. A node has no parent node. So it is called root node. The nodes from which A can be reached on a direct path are called the ancestors of A and the nodes that can be reached from A on a direct path these nodes are called the descendants of A. As Bayesian network is a directed acyclic graph so, no node can be its own descendant or ancestor.

Suppose A denotes the condition of weather, it is raining or not and B denotes the condition of a job, it is successful or failure. Let,

A = 1, raining	B = 1, job is successful
A= 0, not raining	B = 0, job is not successful

Then the joint probability distribution of A and B is presented by,

$\Pr (A = a \cap B = b) = \Pr (A = a) \times \Pr (B = b \mid A= a).$

Now, if $\Pr (A = 1) = 0.15$ and $\Pr (A = 0) = 0.85$ then the conditional probability table be like,

Table 3.1 Conditional probability table

a	$\Pr (B = 1 \mid A= a)$	$\Pr (B = 0 \mid A= a)$
1	0.10	0.90
0	0.70	0.30

With this table, we can calculate the probability of successful job (B= 1).

$\Pr(B = 1) = \Pr(B = 1 \mid A = 1) \times \Pr(A = 1) + \Pr(B = 1 \mid A = 0) \times \Pr(A = 0)$

$= 0.10 \times 0.15 + 0.70 \times 0.85 = 0.61 = 61\%$

The prime objective of Bayesian network in risk analysis is to develop a model that will illustrate the influences of factors in the major accidents. The factors influence the accident scenario are the risk influencing factors (RIFs).

3.3 Assumptions

(Rausand, 2013)

Some assumptions are made in the Bayesian network while quantifying the probabilities. This is discussed with the help of the following Figure 3.2.

1. A node is assumed to be independent of the state of its ancestors when the state of its parents is known. In Figure 3.2, the state of node *F* is independent of the state of node *A* if the state of node *D* is known. That mean that, $\Pr(F \mid A \cap D) = \Pr(F \mid D)$
2. In Figure 3.2, the node *D* and *E* seems to have some dependencies as they are both influenced by node *B*. In Bayesian network, to calculate the probabilities it is assumed that each node is 'conditionally independent' if the state of their parent(s) are known. Hence, if we know the state of node *A*, *B*, *C* then node *D* and *E* are 'conditionally independent'.
3. If there is no arc between two nodes then there are no dependencies between them, which means they are 'conditionally independent'.

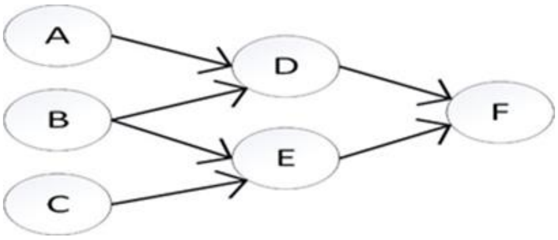


Figure 3.2: Bayesian Network (Rausand 2013)

3.4 Conditional probability

(Rausand, 2013)

Each node must be associated with one conditional probability table. The root nodes who have no parents they will be associated with marginal probabilities. In Figure 3.2, node D and E are influenced by its parents A, B and C. Therefore, both node D and E will have a separate conditional probability table. Considering the marginal probabilities of node A and B, an example of a conditional probability Table 3.2 for node D is given below.

In this table different condition probability of node *D* of its failure and success is given as an example according to its parent’s status.

Table 3.2 Conditional probability table of node *D*

Parents		**Pr (*D* = *d* | Parents)**	
A	*B*	1	0
0	0	0.10	0.90
0	1	0.25	0.75
1	0	0.50	0.50
1	1	0.95	0.05

3.5 Bayesian Networks and Fault trees

(Rausand, 2013)

One of the important aspects of the Bayesian network is its relation to fault trees. A fault tree analysis can be transformed into the Bayesian network. After the transformation, we can easily apply the formulas of BBN to evaluate the respective Bayesian network diagram. Irrespective of the type of the fault tree it can be converted to Bayesian network. That means whether it is a fault tree and the relation between the top event and basic event is based on AND gate or OR gate it can be transformed to BBN. But then, a conditional probability table indicating the relation between parent node and child should be provided. The transformation of a fault tree with AND gate and OR gate to a BBN are illustrated.

Figure 3.3 and 3.4 illustrates the transformation of the AND gate and OR gate fault trees to a Bayesian Network. The top event in the fault tree denoted as the outcome node C in the BBN. And we have to include the conditional probability table to measure the BBN. An example of a conditional probability table for the AND gate and its respective BBN is shown Table 3.3.

$$\text{Suppose, } A = \begin{cases} 1 \text{ if basic event A occurs} \\ 0 \text{ if basic event A does not occur} \end{cases}$$

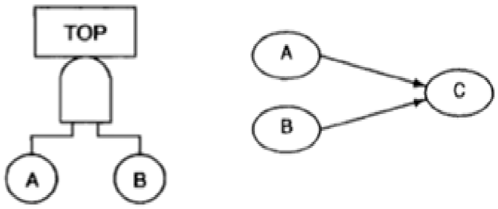


Figure 3.3: Fault tree with AND gate and corresponding Bayesian network

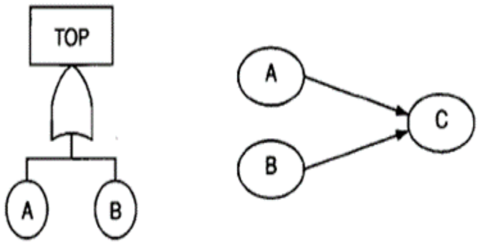


Figure 3.4: Fault tree with OR gate and corresponding Bayesian network

Both for the basic event B and C it is also the same. So the conditional probability will look like the table below.

Table 3.3 : Conditional probability table corresponding to the fault tree with single AND gate and BBN

Basic events		Top event *C* Pr(*C*=1)
A	***B***	
0	0	0.00
0	1	0.00
1	0	0.00
1	1	1.00

Because of the AND gate, the outcome probability is 1.00 when both of the root node A and B occur.

3.6 Causality and BBN

Causality plays an important role in the procedure of constructing a BBN model. In models where the representation of decisions is needed, causal relationships are used there. In BBN, the directed links represent the causal relationship. And to represent the dependence and independence among the variables it is useful to use the causal relationships in term of directed links between them denoting causes to effect. Let us assume, X is the cause of event Y. So the causal relationship between them is X→Y. If we use the opposite relation (i.e. Y→X) then the model does not represent the proper dependence and independence relationships between the variables.

There are three types of connection between variables: a) serial connection (Figure 3.5), X has an influence of Y and Y has an influence on Z. So it is evident that X has an influence on Z and vice versa. If we come to know the state of the middle variable, Y then X and Z become independent of each other. b) diverging connection (Figure 3.6), the influence can pass between all the child nodes unless the state of the parent node is known. That means information can be transmitted into Y, Z from X unless the state of X is known. c) converging connections (Figure 3.7), information can be transmitted through the connection Y→X←Z if there is evidence on Y or one of its children is available (Kjaerulff & Madsen, 2008).

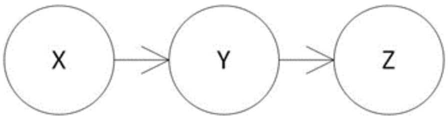


Figure 3.5: Serial connection(Kjaerulff & Madsen, 2008)

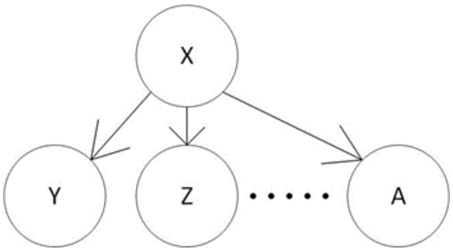


Figure 3.6: Divergent connection(Kjaerulff & Madsen, 2008)

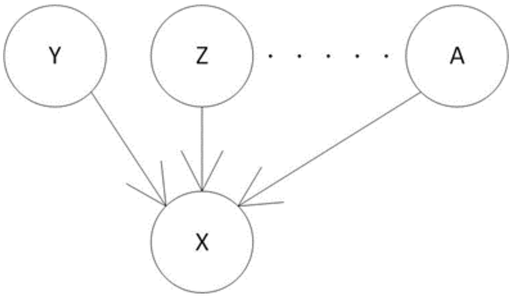


Figure 3.7: Converging connection(Kjaerulff & Madsen, 2008)

This is a brief description of Bayesian network and related topics to BBN. Although there are many discussions with BBN, but here some selected topics are discussed that are related to the thesis work.

3.7 Independence Assumption

Independence assumption is an important aspect of Bayesian network. Generally, if there are *n* variables then $2^{\mathrm{n}} - 1$ joint probabilities should be considered. But in the practical example, fewer probabilities are considered. This is because of independence assumption. Independence assumption suggests if there are three variables related to each other, then if the state of the middle variable is known then the first and last variables are independent of each other. That is how we consider a few probabilities instead of considering all the $2^{\mathrm{n}} - 1$ variables. For example, in the case of 5 variables even though there should be $2^{\mathrm{n}} - 1 = 31$ probabilities, but instead of the independence assumption it could be sufficient enough to consider only 10 probabilities. (Charniak, 1991)

With the knowledge of chapter 2 and chapter 3, a specific task is going to be selected and analyzed further in the later chapters.

Chapter 4

Hot Work

As per the first objective of this thesis work, the author selected hot work as the specific task and decided to work further on with this topic.

This chapter presents a detail information about hot work activities and procedure to perform hot works in the industry according to HSE guide. The discussion is to give an illustration of tasks in hot work to comprehend whether there are any associated risks or not.

4.1 What is Hot Work?

Hot work means any process where an ignition source is present with a flammable material or it can be a fire hazard regardless of the flammable material in the work environment. Mostly the processes that are considered as hot work are welding, soldering, cutting and brazing. With the presence of flammable material processes like grinding and drilling are also recognized as hot work.

4.2 Standards of Hot work

Hot work involves potential hazards both for equipment and personnel. Hence, it needs to be controlled very carefully and closely. Several standards are present to control the hot work operation such as *OSHA* provides general requirements for welding, cutting and brazing operations, *API RP 2009*: Safe Welding, Cutting, and other Hot Work Practices in the Petroleum and Petrochemical Industries, *API Publ. 2201*: Procedures for Welding and Hot Tapping on Equipment in Service, *HSE Hot Work Guide* etc.

In the following discussion, the welding operation is discussed as a representative of hot work operation and procedures of welding operations are described as an example of hot work procedure.

4.3 Procedures for welding operations:

The *HSE Hot Work Guide* (Mannan & Lees, 2012) describes the procedure of welding operation under the headings: (1) initial planning, (2) site preparations, (3) stand by services, (4) preparation of the equipment, (5) fitting alignment, (6) welding procedure, (7) action prior to welding, (8) action during welding, (9) checking the completed welding and (10) final completion.

1. The *initial planning* involves inspection of regulatory requirements and company codes; to give notice to the external interested figures, reviewing the process condition, fittings, and consumables, the site conditions; making a list of fittings, requirements and services required; work sketches; plan for emergency procedures; preparing the permit.

According to Factories Act 1961, any plant, vessel or tank that contains or has contained any flammable or explosive material shall not be subjected to any (Mannan & Lees, 2012) :

- Welding brazing and soldering operation,
- Cutting operation that uses the application of heat,
- Operation that involves application of heat to take apart or removing the plant, tank or vessel or any part of it;

  Until necessary steps have been followed to remove the substance or fumes arising from it, or to render them nonexplosive or non-flammable; and if any plant, vessel or tank is used to any such operation, no explosive or flammable substance shall be entered to the plant, vessel or tank until the metal has been cooled sufficiently to ignore any risk of ignition.

2. The *site preparations* are the precautions that need to be followed in the welding site to avoid any accident from the ignition source, particularly in the location or hazardous area around welding operation.

- The welding site should be clear from flammables whether gases, liquids or solids. The atmosphere to a radius of 15 m and a height of 2 m above the ground level should be free of flammable gas. Surrounding equipment’s surface should also be free from flammable materials. No flammable liquid is allowed within the radius of 15 m. Drains and weld spatter container should be covered and shielded.

- The equipment to be worked on needs to be vacated and cleaned, tested for flammables and inspected before welding. There are some exceptional procedures, but this general rule cannot be ignored anyhow.
- Access to the welding site for the welders and emergency services should be good enough. Suitable lifting up equipment and scaffolding should be provided for elevated locations. For proper safety, lighting should be adequate. For underground welding, an excavation of adequate shoring, the ladder should be designed.
- For welding in confined space, sufficient ventilation for dispersion of fumes should be provided, including an excavation.
- Protective clothing should be provided for all personnel working in the welding operation. A ‘fire watch’, at least one person, should be present with fire extinguishers and dry powder in the spot all the time. First aid equipment such as resuscitation equipment and breathing apparatus should be present as well.

3. The *stand by services* are the above precautions that need to be ensured besides site preparations.
4. The *preparation of the equipment* includes checking the material, removal of insulation, surface cleaning, roundness checking, measuring the thickness, testing the external condition and internal condition, grinding flush any external weld which might interfere with a flush fitting.

5. *Fittings alignment* demands that the fittings are accurately positioned and aligned, the weld preparation and clearances are checked. Welding cables should be free of flammable gases and liquids and the cables should be close to the weld point.

6. *Welding procedure* indicates the working process and the competence of the welder. The welder must be trained enough to do the hot work operation as it is required. Moreover, he should have proper knowledge about his own safety. He needs to have adequate training to detect any deviation of operation that can cause a serious hazard and accident.

7. *Actions immediately prior to welding* are the tasks such as, to ensure the identity of the equipment to be welded, operating conditions of the equipment, the welder and welding

supervisor’s understanding of the work to be done, temperature of the equipment and fitting, current used for welding and its compliance with the permit.

8. *The actions during welding* are to check and monitor the operating conditions and the flammables’ condition in the environment.

HSE Hot Work Guide (Mannan & Lees, 2012) provides some limitations and prohibitions during welding operations:

- No welding should be carried in a metal thickness of which is less than 0.2 in (5 mm), on the external surface of a tank at a point that is less than 3 ft (1 m) below the liquid surface or on an equipment at a temperature below 7°C.
- Welding on an equipment should not be carried out where the temperature and pressure exceed the metal strength.
- Welding should not be undertaken in vent and blowdown system unless it is certified safe to do so. Such kind of systems should not be isolated during operation before some alternative arrangements have been made.
- Welding should not be done where the equipment contains a flammable mixture or the welding can create one after the operation; the equipment contains compressed air or an oxygen-enriched mixture together with hydrocarbons.
- Precautions should be taken before welding on equipment containing pure liquid or gaseous oxygen as any accident can cause an extreme hazard. For example, welding on equipment containing ethylene gas can be carried out at a temperature up to 150°C and at a pressure up to 400 psi. Hence, while welding in an ethylene container the temperature and pressure must be controlled to avoid any kind of hazard.

9. *The integrity of the completed weld* means that it should be able to withstand any operating conditions to which the equipment is subjected to the predefined temperature and pressure. There are many suitable ways to test the integrity of the weld such as hydraulic pressure testing, pneumatic leak testing and non-destructive testing. In the pressure testing, proper care should be taken to avoid over pressurizing.

10. The final completion consists of the usual termination procedure such as checking the site is free of hazards after welding, notifying the interested organization or party that the work is done and sign off the work permit (Mannan & Lees, 2012).

Figure 4.1 illustrates the steps that are followed in the hot work task.

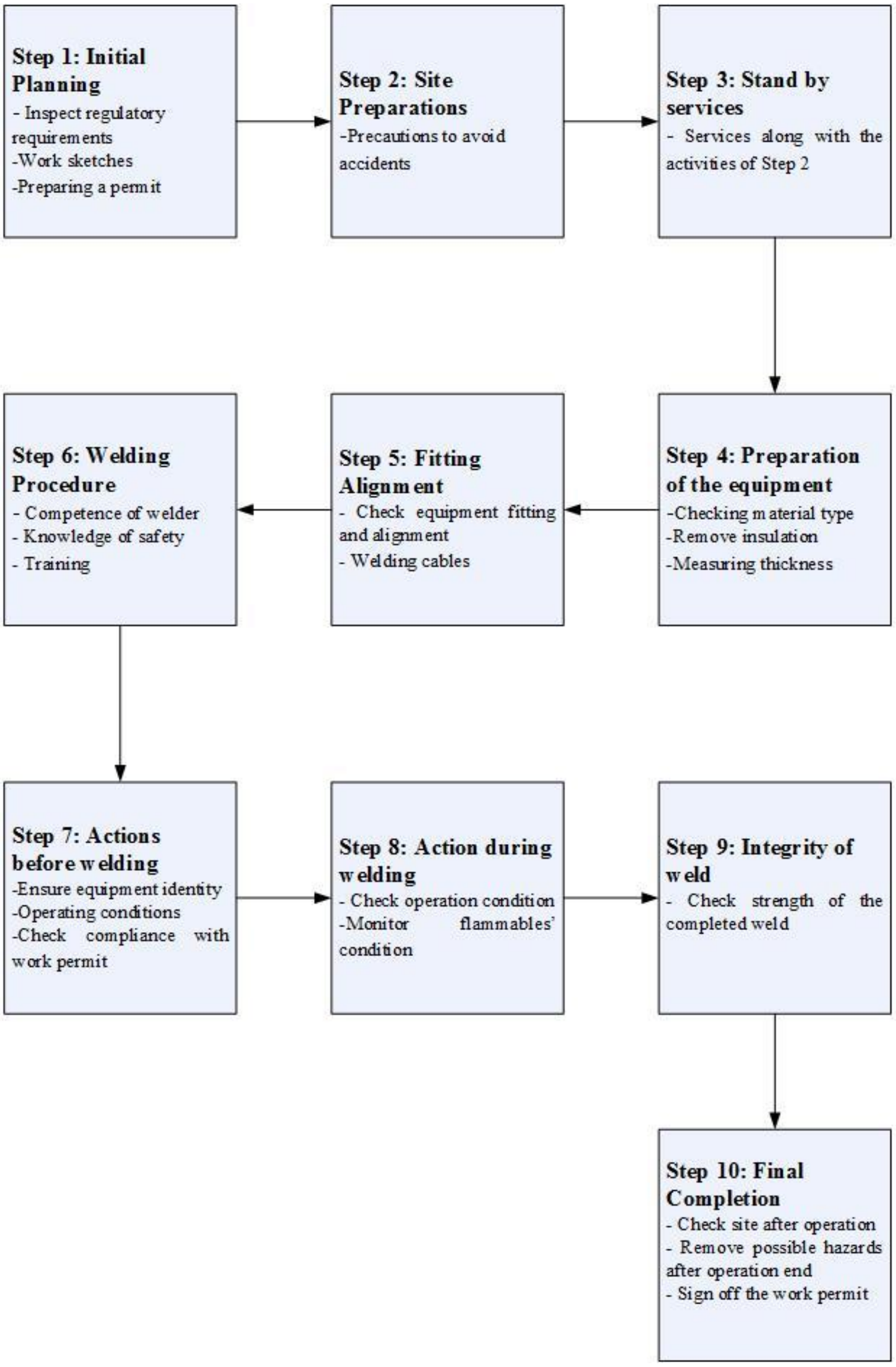


Figure 4.1: Steps in Hot Work

This chapter gives an overview of hot work procedure and the tasks related to it. With this conception, RIFs are identified according to operational steps of hot work in chapter 5.

Chapter 5

RIF Identification

Risk Influencing Factor (RIF) is the basic unit of any accident. Most of the work on RIF identification is for specific accident or event. An alternative approach needs to be developed for operational activities. This chapter discusses a summary of the principles followed for RIF identification from literature and recommends a process to RIF identification for operational activities.

5.1 Theory

5.1.1 Definition

Rausand (Rausand, 2013) expresses RIF as a relatively stable condition that influences the risk. Vatn (Vatn, 2013a) defined RIFs in connection with the QRA and clarifies that a RIF is a factor or condition that influences the risk and it is of three types, (i) RIFs that equal a QRA parameter, (ii) RIFs which influence a QRA parameter (iii) RIFs which do not explicitly influence a QRA parameter (A QRA parameter is factor that influences the risk and is included as a unit in the QRA risk model. These events could be the basic event in the fault trees e.g. probability of ignition, gas detection system etc.).

5.1.2 Classification

According to Haugen et al. (S Haugen et al., 2012), a RIF may be classified as technical, operational and organizational factors. A deeper understanding is essential to identify all types of RIFs. The following discussion about technical, operational and organizational factors is adapted from Edwin (Edwin, 2015).

Technical Factors

Technical factors mean the systems or processes that have been implemented to prevent or reduce the effect of an event or prevent it from occurring (S Haugen et al., 2012). These factors must not be confined to and cover only the technical barriers. Technical factors are more comprehensive and deal with the technical aspects as well as with factors of same characteristics. This is not only equipment, hardware and software aspects (Johansen & Rausand, 2015), but also equipment design, condition, process complexity etc.

Operational Factors

Haugen et al. (S Haugen et al., 2012) refer the operational factors as the aspects related to safety-critical operations such as maintenance and inspection. They involve human and task-related factors.

Organizational factors

Haugen et al (S Haugen et al., 2012) stated organizational factors as the structural and managerial aspects that influence the risk. These factors construct the concept of safety amongst the employees in an organization and may be either dormant or active (J. T. Reason & Reason, 1997). They also involve administrative issues that are governing aspects which ensure smooth implementation of safety procedures. For example, the organizational factors are supervision, communication, leadership, procedures, task documentation, change management etc.

In this thesis work, ‘Hot Work’ related activities are analyzed in details and human factors are specifically emphasized. Hence, further work will be associated only with human factors analyses in ‘Hot Work’ operation.

Crowl (Crowl, 2007) in his book, published by Center for Chemical Process Safety (CCPS), has identified some key topics on human factors. A wide range of human factors is covered in a concise and systematic format. This identification is followed by available tools in industry applications. These topics are categorized under three headlines: (1) Facilities and Equipment, (2) People and (3) Management Systems. These categories are quite similar to technical, operational and organizational factors respectively. Therefore, the RIFs that will be pointed out in the forthcoming discussion will be categorized according to these headlines.

5.2 Measurement

The measured value of a RIF is defined as its score and is the realization of its underlying value(Vatn, 2013c). According to Mohaghegh and Mosleh (Mohaghegh & Mosleh, 2009), a RIF may be measured in three ways(Edwin, 2015) :

- Objectively, observing a set of indicators which directly or indirectly measures the RIF score.
- Subjectively, from the result of interviews, surveys etc.
- Hybrid, with the combination of objective and subjective methods.

Objective measurement of RIFs using observable indicators presents quite a few discussions in the literature. For instance, leading vs lagging indicators , indicator coverage limitations (S Haugen et al., 2012) etc. These discussions are not explained in this presentation. It is assumed that all RIFs are measurable and are represented by their scores.

The scoring method for the RIFs varies from researcher to researcher. For instance, if ‘r’ is the score of the RIF, in the ORIM method (Knut Øien, 2001a) r = 1 in the best case and r = 5 for the worst case. The BORA (Aven, Sklet, & Vinnem, 2006)and Risk_OMT (J. Vinnem et al., 2012) methods define the scale from A to F or 1 to 6. Similarly, a scale can be designed referring r = -1 as the worst case and r = 1 as the best case. Thinking about all these measurement scales. Vatn (Vatn, 2013b) recommended a uniform scale of measurement for all RIFs. A uniform scale of measurement will aid to treat all the RIFs within a single framework for the purpose of risk model calculation. Moreover, if a RIF is measured through a set of observable risk indicators, a mapping of the risk indicators to the uniform scale is a must. This is not easy owing to coverage limitations for risk indicators (S Haugen et al., 2012). That is why, in the case of insufficient information about RIFs, the uncertainty in the RIF score must be appropriately represented. BBN can be a solution in this regard (Edwin, 2015).

5.3 RIFs related to operational activities

With the insight of definition, classification and measurement of RIFs, this section describes some processes of RIF identification for operational activities. Section 2.1 presents a framework to identify RIFs relevant to a particular operation.

5.3.1 Selection of RIFs

Edwin (Edwin, 2015) has discussed the details of RIFs selection and the approaches for that. Section 2.1 is discussed from his work.

A structured method is needed to identify the set of RIFs for the selected work task operation. Two possible approaches are present for that - (a) a process-based approach and (b) a system-based approach.

The process-based approach does a detailed task-wise break down of an operation (i.e. task analysis) and analyzes what can possibly go wrong for each of these tasks or steps. For instance, the Risk_OMT (Vatn, 2013c) performs detailed task analysis to mark out the critical steps in HC equipment work execution. Later on, the event sequences and failure causes are modeled using event and fault trees. This approach illustrates a better understanding of work processes and thereby identifies relevant RIFs for each step of the work process. Instead of that, one can model all major scenarios that influence ignition, escalation, loss of containment etc. and by doing so the model becomes so detailed and broad that it cannot be applied effectively in actual analysis work (J. E. Vinnem, Aven, Hauge, Seljelid, & Veire, 2004).

On the other hand, system approach identifies accident scenarios related to the chosen activity. Afterward, these scenarios are classified by observing the barrier impairment or degradation. This approach upholds an explicit qualitative understanding of issues that could directly or indirectly lead to a degradation in barrier performance during work process execution.

Both approaches pinpoint the same hazards but result in very different analysis. This can be easily comprehended by comparing a Hazard and Operability Study (HAZOP) with a Failure Mode and Effect Analysis (FMEA) conducted on the same system. The first one is a process approach and the second one is a system approach. Both approaches indicate the similar hazards but provide different results and recommendation to decision makers. This addresses the importance of the right choice of approach depending on the context and objective of the analysis.

5.3.2 Chosen Approach

Both of the approaches are utilized in this report. At fist, the system-based approach is used to identify the RIFs related to the hazardous event. Then process-based approach is adopted to identify RIFs related to the work task. As the purpose of this thesis work is to analyze the work task steps and risk associated with these steps of the work task, the process-based approach has given more priority.

In this study, ‘hot work’ is the work task operation and the selected hazardous event is ‘ignition’. Table 5.1 presents the RIFs sorted out from the system-based approach for the hazardous event. Then process-based approach is discussed in details in section 5.3.2.1.

Table 5.1: RIFs related to '*Ignition in hot works*'

Facilities and Equipment	People	Management System
Process equipment design	Training	Safety culture
Labeling	Communication	Behavior-based safety
Nature of gas	Environmental Factors	Procedures
Frequency of gas detection	Time pressure/Stress	Maintenance
Facilities and work station design	Documentation design and use	Safe work practices and Permit to work system
Work area	Manual materials handling	Competence management
Work place accessibility	Shiftwork Issues	Safety systems
		Management of change

5.3.2.1 Process-based approach for RIF identification of operational steps

An outline of the process-based approach is illustrated in Figure 2.

Step 1: Analyze the work operation and its procedure

Understand the operational work thoroughly and mark out each procedural steps of the operation. Furthermore, it is important to sort out the sequence of the working procedure. Analyzing the sequence makes it easier to understand which operational steps could be crucial for further consideration.

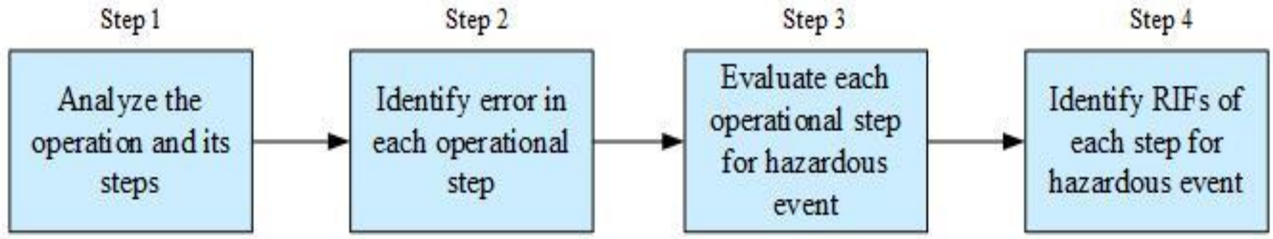


Figure 5.1: Outline of Process-based approach for RIF identification of operational steps

Step 2: Identify the possible error that can happen during the corresponding step.

Step 3: Evaluate each operational steps for selected hazardous event.

After analyzing each operational steps, all the steps needs to be evaluated for our selected hazardous event. Following that, we can understand which operational steps need further research and emphasize.

Step 4: Identify RIFs related to each operational step for the hazardous event

Identify RIFs that are related to all of the steps for the proposed hazardous event. In this step, we can find out which factors influence more in the hazardous event.

Table 5.2 illustrates the identified RIFs.

Table 5.2: RIFs related to '*Hot work'* steps

Hot work operational steps	Error	Hazardous Event	Facilities and Equipment	People	Management System
Step 1: Initial Planning	Fail to remove combustible fuel	Ignition	Process equipment design	Environmental Factors	Safety culture
			Labeling	Time pressure/Stress	Maintenance
			Facilities and work station design	Documentation design and use	Competence management
				Shiftwork Issues	Safety systems
Step 2: Site Preparations	Fail to remove combustible fuel	Ignition	Work area	Training	Procedures
			Work place accessibility	Communication	Safety systems
			Facilities and work station design	Manual materials handling	Safe work practices and Permit to work system
				Environmental Factors	Management of change
Step 3: Stand by Services		Not applicable			
Step 4: Preparation of equipment	Mishandling of equipment	Ignition	Labeling	Communication	Procedures
				Manual materials handling	Safe work practices and Permit to work system
				Training	
Step 5: Fitting alignment		Not applicable			

Hot work operational steps	Error	Hazardous Event	Facilities and Equipment	People	Management System
Step 6: Welding Procedure	Not following welding manual	Ignition	Facilities and work station design	Communication	Safety culture
			Frequency of gas detection	Environmental Factors	Management of change
			Nature of gas	Training	Procedures
				Time pressure/Stress	Safety systems
				Shiftwork Issues	Safe work practices and Permit to work system
					Behavior-based safety
					Maintenance
Step 7: Actions before Welding	Fail to detect gas	Ignition	Facilities and work station design	Manual materials handling	Procedures
				Environmental Factors	Safe work practices and Permit to work system
					Competence management
Step 8: Actions during Welding	Not following welding manual, Fail to detect gas	Ignition	Frequency of gas detection	Environmental Factors	Safe work practices and Permit to work system
			Process equipment design	Time pressure/Stress	Safety culture
			Facilities and work station design	Training	Safety systems
				Result interpretation	Procedures
				Communication	Management of change
Step 9: Integrity of weld		Not applicable			
Step 10: Final Completion		Not applicable			

Table 5.2 summarizes all the possible RIFs for the corresponding operational steps of hot work considering the error that can happen in the step which error may eventually result in the hazardous event (ignition). In chapter 6, a model is proposed considering ‘combustible gas not detected’ which is relevant to step 8. Therefore, the impact of RIFs only in step 8 is discussed below.

The influence of the selected RIFs on step 8 is easily perceivable. If there is no proper facilities and equipment it is possible that the employee will fail to detect gas prior to hot work. Time pressure, training, communication and other RIFs in the ‘people’ category also relevant as they are directly connected to personnel’s action. In addition, management system related RIFs are added since the management rules always plays an important role on employee’s performance.

This chapter identifies all the relevant RIFs for the corresponding operational steps of hot work. All the steps are analyzed thoroughly and RIFs are extracted. After knowing the RIFs, now we can make a model for the RIFs and analyze further. Chapter 6 describes the modeling process.

Chapter 6

Accidents in Hot Work and RIF Modeling

Accidents in hot works happen occasionally in several industries. Some of them result in severe accidents and some do not, except for some minor accidents. In this chapter, two hot work accidents are described which caused death and environment losses. Following that, RIF modeling in hot works is presented keeping in mind the severity of hot work accidents.

6.1 Accidents

Accidents in hot works have been happening all over the world regardless of industry. It is not confined to only oil and gas industry. Some other companies like packaging, foods processing companies are also included in this. For example, the accident at the Packaging Corporation of America in Tomahawk, US and ConAgra Foods I Boadman, US Chemical Safety Board (CSB, 2014). These are typically not related to oil and gas, yet accidents during hot works caused due to unawareness and unsafe acts. In this section, two hot work related accidents are discussed with a view to analyzing these accidents, what could get wrong in the operation and what could be the end result. The two accidents are (1) Partridge-Raleigh Oilfield Explosion and Fire and (2) Motiva Enterprises Sulfuric Acid Tank Explosion.

6.1.1 Partridge-Raleigh Oilfield Explosion and Fire

CSB (CSB, 2007) has done an investigation on this accident and provided a report about the sequence of the incident and what were the failures in this. The purpose of hot work was to join a pipe between a production tank and a storage tank. An extended pipe was there in the storage tank and welding was supposed to perform in the production tank and join a pipe in between these two tanks.

CSB (CSB, 2007) report adds more - a task of flammable gas checking (although it was very unsafe and unreliable technique of checking by using an oxy-acetylene torch) was done in the production tank prior to welding. But unfortunately, there was no flammable gas checking in the storage tank. Therefore, as the day went by, flammable gas started to produce in the storage tank and started coming out through the extended pipe. On the other hand, the ongoing process of welding in the production tank created sparks. As a result, sparks ignited flammable vapor spreading it through the storage tank and explosion was the end circumstance.

CSB (CSB, 2007) summarizes some key facts that contributed to the happening or severity of the accident i.e. (a) only production tank was tested for flammable or combustible gas ignoring the other storage tanks beside the production tank, (b) no use of flammable or combustible gas detector, (c) not capping the extended pipe through which the flammable gas came out.

Following Wagnild et al. (Wagnild, 2015) Barrier Grid model and example of Edwin (Edwin, 2015), the sequence diagram of this accident is drawn in Figure 6.1.

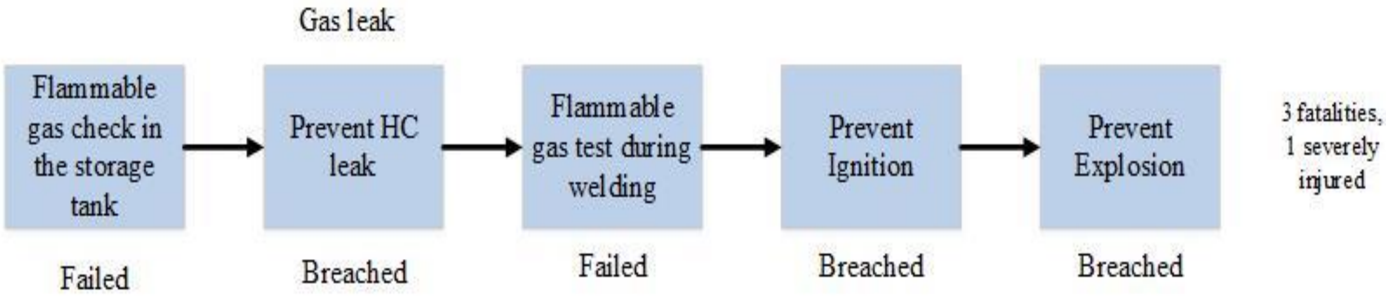


Figure 6.1: Sequence of events of Partridge-Raleigh Oilfield Explosion and Fire

6.1.2 Motiva Enterprises Sulfuric Acid Tank Explosion

CSB (CSB, 2002) has performed an accident investigation about the accident and provided an accident report. The following information is added according to the report.

The task was to repair a catwalk above a sulfuric acid tank farm. The repair work required cutting. Hence, the contractors were using electric arc cutting system. For safety purpose, a combustible gas testing was done before commencing cutting operation and no combustible gas was detected. But for the contractors, it was totally unknown that the tank was severely corroded and there are holes in the roof and shell of the tank. Besides, after the first check of combustible gas prior to the operation, there was no more checking throughout the whole day.

The contractors started to perform the cutting operation. And as the day was passing, because of the temperature rise there started creating some flammable vapor inside the nearby sulfuric acid tank. During the cutting operation, sparks from cutting went through the holes of the corroded roof inside the sulphuric acid tank and ignited the vapor. An explosion happened killing 1 contractor and 8 badly injured. And the hydrocarbon that flowed to a nearby river killed fish and aquatic life.

From the accident analysis and report of CSB, we can conclude on several failures that were present in this incident : (a) No prior checking of the storage condition before cutting, (b) no continuous combustible gas testing, (c) no consideration of environmental effects.

Like the first accident, a similar sequence of events has been drawn in Figure 4.2 for this accident.

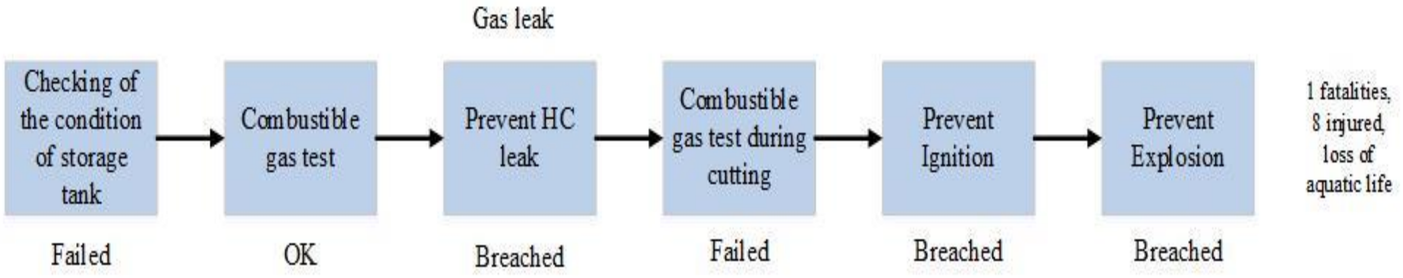


Figure 6.2: Sequence of events of Motiva Enterprises Sulfuric Acid Tank Explosion

From the discussion of these accidents, we can comment that after all the failure in hot work tasks, even if the ignition could have been prevented, then the consequence may not be such severe. Therefore, in the next discussion of RIF modeling the focus is on ignition and related reasons of ignition is scrutinized while modeling.

6.2 RIF modeling

RIF modeling means to give the case study a structured look like. The main objectives of RIF modeling are:

a. To understand the sequence of accidents.
b. To identify the RIFs and find out any relationships or dependencies between them.
c. To find out the basic events.
d. To identify the barriers and barrier deviations if there any.
e. To analyze the case both qualitatively and quantitatively (if needed).

Yang Xue (Yang, 2013) has summarized different models according to their qualitative and quantitative aspects of risk assessment. From Xue's formulated summary some methods i.e.

ORIM, BORA, HCL, Risk_OMT are included. In addition, the aspects of proposed model for the case study (ignition in hot works) is included.

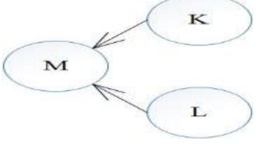
6.2.1 Qualitative aspects

Table 6.1: Qualitative compare results between models (Yang, 2013)

Framework	Industry	Source of RIFs	Levels of RIF Structure (Bottom-up)	Link to risk models	Modeling technique
ORIM	O&G	Leak events data sources Accident and incident report system	1 level RIF OFs -> Leak frequency (Note: intermediate levels of human error and component are removed for simple quantification)	Leak frequency parameter in QRA	Bayesian networks Regression based technique
BORA	O&G	Accident investigation, HRA	1 level RIFs Human factor + organizational factor + operational factor + technical factors -> IE and barrier performance	Effect of plant specific conditions on initiating events and barrier performance to update QRA	Influencing diagram
Risk-OMT	O&G	OTS project and theoretical model	2 levels RIFs Indirect RIFs (Management)-> direct RIFs to human errors	Update failure probability of basic event in FT and ET	Bayesian networks
HCL	O&G	BORA	Full Bayesian belief network	Same to BORA	Bayesian networks
Proposed model	Process Industry	BORA, HCL	1 level RIFs Human factor-> barrier performance	Effect of plant specific conditions on initiating events and barrier performance	Bayesian networks (using risk influence diagram)

6.2.2 Quantitative aspects

Table 6.2: Quantitative compare results between models (Yang, 2013)

Model	**Rating process**	**Weighting process**	**Common cause**
ORIM	Using indicators to get assessed rating values of OFs. $r_k = \sum_{j=1}^{n_k} v_{kj} r_{kj}$ Note: convert indicator measurement to state 1 to 5	*Weight of indicators:* Expert judgment *Weighting of OFs:* Cox-proportional hazard model to get coefficients as weights (Data-driven and expert based method)	Not considered
BORA	Scores of RIFs (A-F) are from -RIF audit -TTS result -RNNS result Note: No attempt to use risk indicators	Expert judgment Use scale 2-4-6-8-10 to evaluate relative importance	Not considered
RISK_OMT	Use score to denote the summarized information regarding the RIFs from interview, surveys, etc.	Expert judgment in Hybrid method	-Closeness in time -Similarity of crew -Stress -Complexity
HCL	Scores of RIFs (A-F), same to BORA Rate based on – TTS – Expert evaluation	*Assign weights:* 1. Determine by expert judgment the relative change in E (M), when one parent is changed from A to F, the other parent is locked to C. 2. Same procedure to the other parent. 3. Normalize the result 	HCL algorithms developed in Groen and Mosleh are designed to correctly account for dependencies between basic events introduced by common causal roots in BBN
Proposed model	Using indicators to get assessed rating values of OFs. $r_k = \sum_{j=1}^{n_k} v_{kj} r_{kj}$	Expert judgment in Hybrid method	Not considered

In this thesis work, ‘hot work’ is the case study and all the RIFs related to ‘ignition’ in hot works are identified. From the previous discussion of accidents, it is evident that in most of the cases hot works incident could end up to ignition and can cause a major accident. This is the main reason to select ignition as a topic to study further. This proposed model is built with the combination of BORA and HCL model. Hence, some aspects of these two models are followed while modeling the case (ignition in hot work).

6.2.3 Proposed model

The proposed model consists of barrier block diagram, event tree, fault tree, and BBN. It is described in details.

6.2.3.1 Barrier Block Diagram

The first step is to create a barrier block diagram for ‘ignition’ in ‘hot work’. The prime purpose of barrier block diagram is to identify, illustrate and describe the scenarios that may lead to ignition. In Figure 4.3, the block diagram is illustrated.

From the study of US Chemical Safety Board (CSB), most of the accidents happened during hot work are related to unawareness of combustible gas in the work area. That is the reason to consider ‘combustible gas created in or near hot work job’ as the initiating event.

A barrier block diagram consists of an initiating event, arrows that show the event sequence, barrier functions realized by barrier systems and possible end event. A horizontal arrow indicates that the barrier system fulfills its function. On the contrary, an arrow downwards indicates the failure of the barrier system. In that case, the undesired end event is ‘ignition’. A barrier block diagram corresponds to an event tree and this event tree can be used for quantitative analysis as well if needed. Figure 4.4 illustrates the event tree for this case.

An initiating event is the first significant deviation from a normal situation that under given circumstances can cause an accident. A ‘normal situation’ means a state where a process functions work as per the design specifications without any significant functional upset or deviation.

A barrier function is defined as a planned function that is designed to control, prevent and mitigate undesired events or accidents (S. Sklet, 2006). A barrier system is designed and implemented to perform one or more barrier functions. A barrier system may consist of various elements i.e. technical elements (hardware, software), operational activities performed by humans, or a combination of both technical and operational activities (Aven et al., 2006)

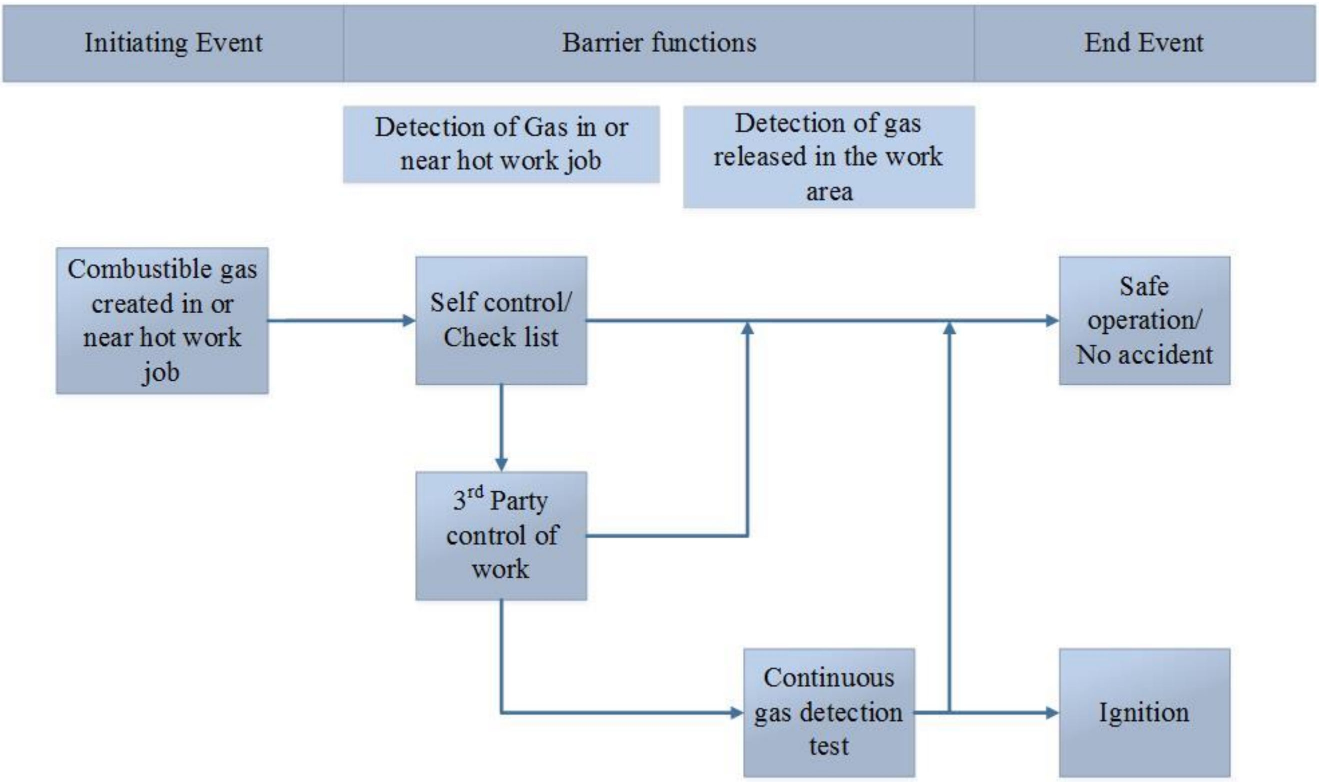


Figure 6.3: Barrier block diagram for initiating event 'combustible gas created' (Aven et al., 2006)

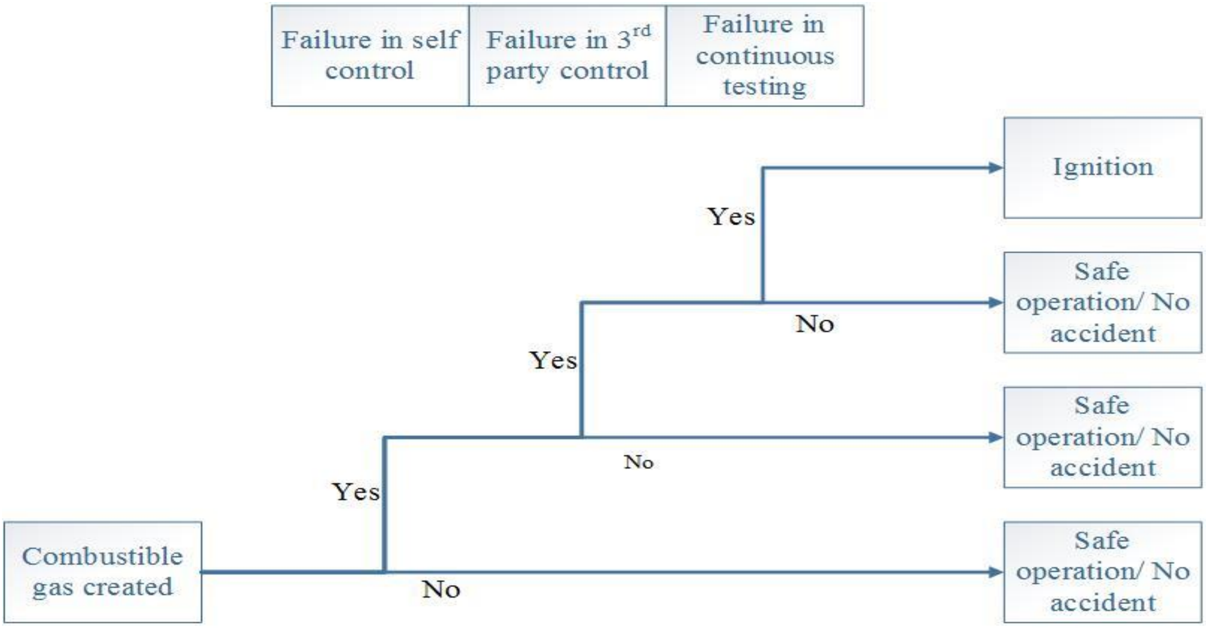


Figure 6.4: Event tree analysis for initiating event "combustible gas created"

6.2.3.2 Modeling of Safety Barriers

The next step is to model the performance of safety barriers in order to analyze the specific barrier performance considering human, organizational, operational and technical factors. Some key aspects should be focused in order to analyze the safety barrier performance: (a) reliability/availability, (b) functionality or effectiveness, (c) robustness, (d) response time and (e) the triggering event or condition (S. Sklet, 2006).

In this model, fault tree analysis is considered to analyze barrier performance. This has been used both in BORA(S. Sklet, Vinnem, & Aven, 2006) and HCL (Røed, Mosleh, Vinnem, & Aven, 2009) method. For the sake of analysis, a generic top event is adapted for a specific barrier (e.g. 'Failure to detect gas by self-control, 'failure to detect gas through continuous testing' and so on). The qualitative analysis of the fault trees results is some basic events and an overview of minimal cut sets (Rausand & Høyland, 2004). Figure 6.5,6.6 and 6.7 shows the fault tree analyses of three barrier functions' failure.

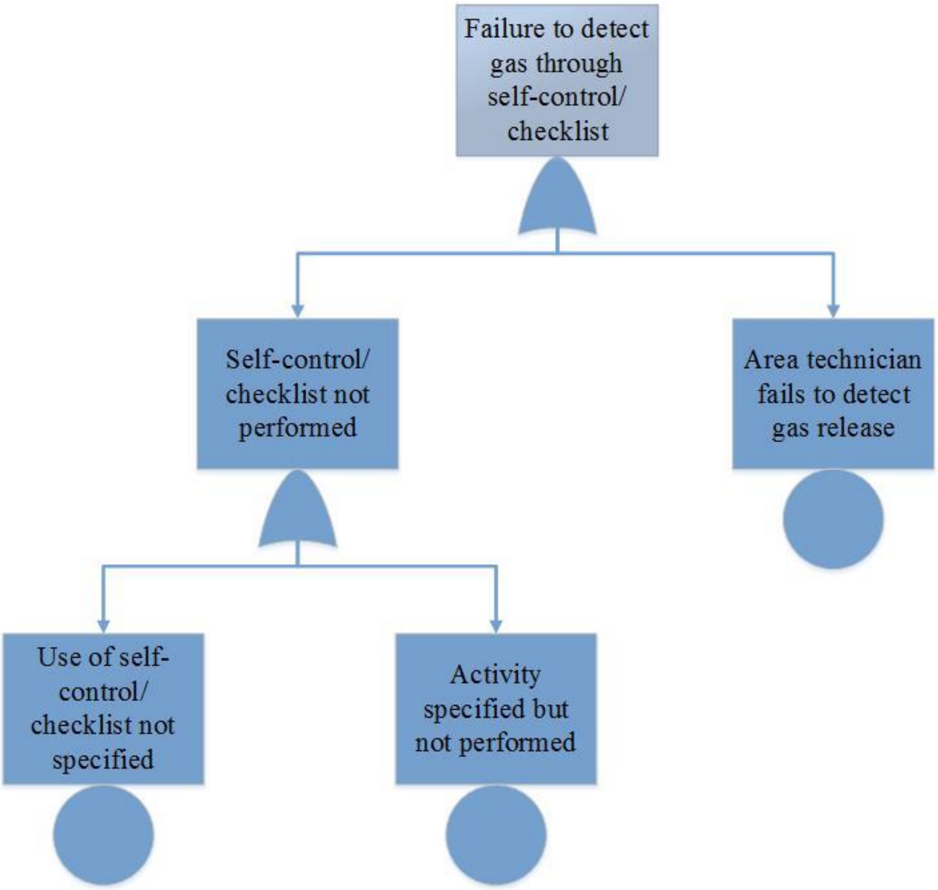


Figure 6.5 : Fault tree analysis for barrier function 'Self-control' (Røed et al., 2009)

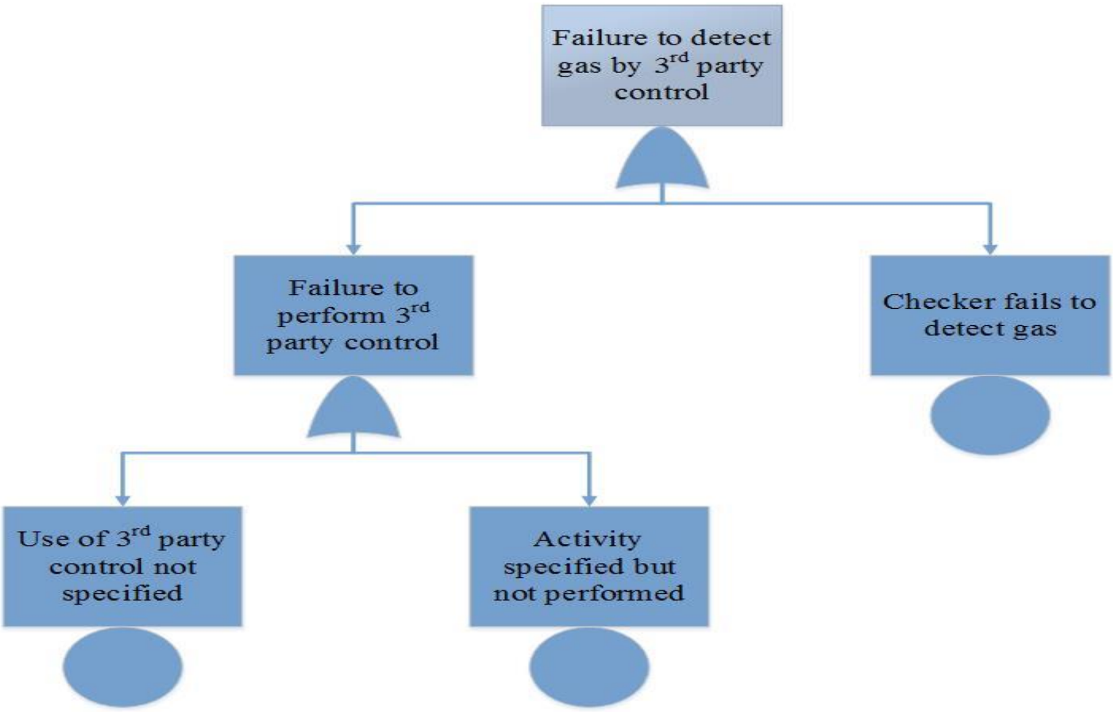


Figure 6.6 : Fault tree analysis for barrier function ‘3rd party control’ (Røed et al., 2009)

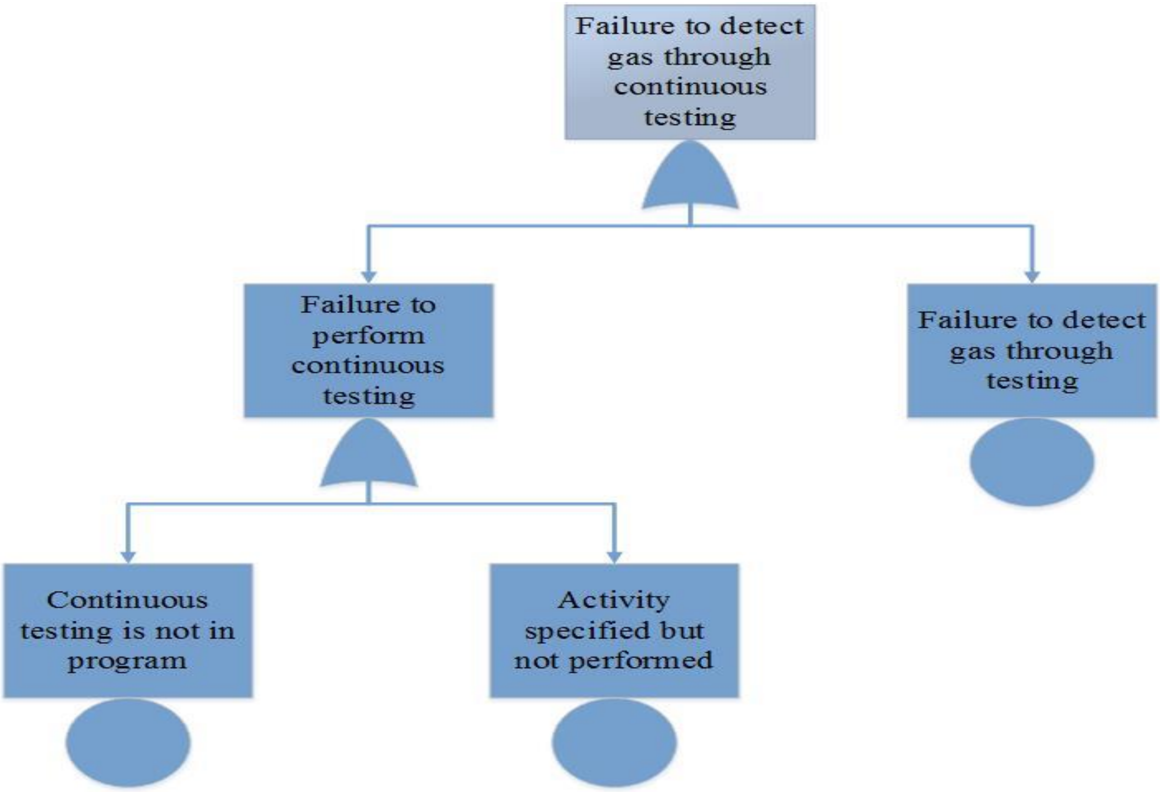


Figure 6.7 : Fault tree analysis for barrier function ‘Continuous gas testing’ (Røed et al., 2009)

6.2.3.3 Development of Bayesian belief network (BBN)

Step 3 is to develop BBNs for different basic events. In the following discussion, BBN is expressed as 'risk influence diagram' which is one form of BBN illustration. From the previous discussion, six basic events have been sorted out from fault tree analyses. These basic events are analyzed further and RIFs related to these events have been identified. The three basic events that are not considered in the BBN are the use of self-control not specified in the program, use of 3rd party control not specified in the program and continuous gas testing is not specified in the program. As they are all the results of procedural lacking hence all of them have the common RIF 'procedure'. These three basic events are not illustrated in the BBN diagram.

The purpose of BBN is to incorporate the effect of the plant specific conditions of human, organizational, operational and technical RIFs on the occurrences of the initiating events and the barrier performance. Figure 6.8, illustrates the BBNs for each basic event. Blue circles indicate the basic events and the white ones are the relative RIFs for them. This implies that specific RIFs are identified for each basic event from a generic list of RIFs (Table 5.1). The generic list may be supplemented by new RIFs when necessary.

This is the modeling technique that has been developed for the case study 'ignition' in 'hot work'. So far it is a qualitative approach but if any measurement principle can be developed for that purpose and implemented, this model can also be used for the quantitative purpose as well using BBN software like HUGIN, GeNIe etc.

After the RIF modeling, now we can go deeper and examine the individual RIFs. According to the objective, some RIFs needs to be selected and examined thoroughly. Chapter 7 describes this process.

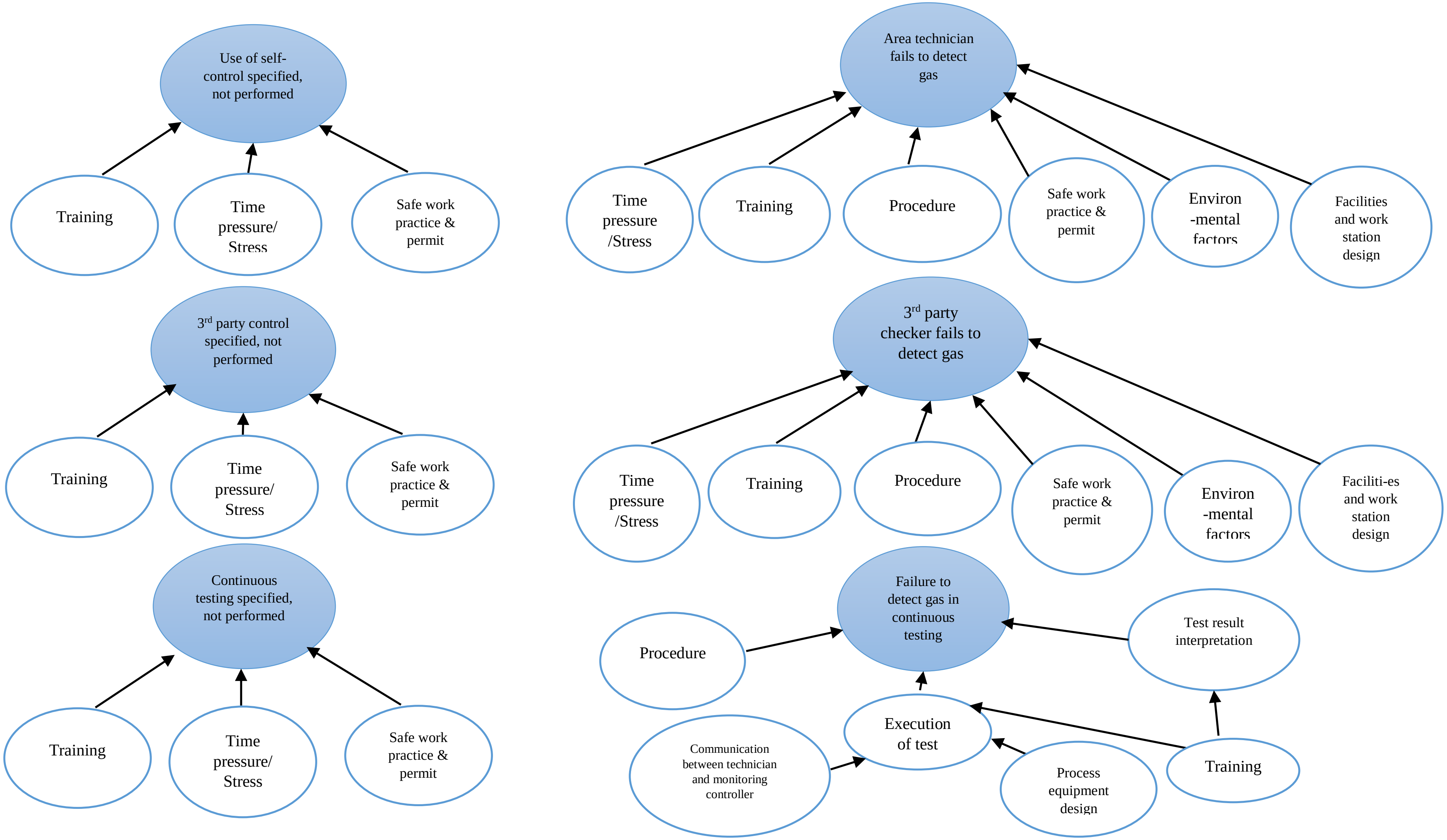


Figure 6.8: Bayesian Belief Network for each basic event (Røed et al., 2009)

Chapter 7

RIFs Evaluation

Several RIFs has been identified in the discussion of Chapter 6. These RIFs are the influencing factors of basic events of 'ignition in hot works'. This Chapter elaborates some of the selected RIFs and looks for the indicators that impact them. The selected RIFs are Time pressure/Stress, Training, and Procedure. The reason to select these three is there frequent use in the RIF model and their contribution in the basic events. Besides, if we observe Table 5.2, use of these three RIFs are also very frequent regardless of the operational steps of hot work. In the following discussion, each of the RIF is discussed separately in details.

7.1 Time Pressure/Stress

Hasida and Shlomo (Zur & Breznitz, 1981) defines time pressure as the amount of information that needs to be processed and considered in one-time unit or it can be defined in terms of the time allotted for processing a fixed amount of information.

In this thesis study, the perception of Hasida and Shlomo (Zur & Breznitz, 1981) is accepted. In addition, it is considered that time pressure means to do a lot of tasks in a limited time. As a result, the employee feels the mental pressure of finishing lots of tasks and dealing with a good amount of information in a short time.

Finnish Institute of Occupational Health (Health, 2016) defines time pressure as the fast pace of work. It relates 'time pressure' with 'stress'. Stress is termed as a situation in which a person faces so many demands and challenges that he/she cannot fulfill the demand as required with the available resources. Stress manifests as restlessness or agitation, feelings of tension, or workers may have trouble sleeping. In this discussion, 'stress' and 'time pressure' are treated as two adjacent terms both indicating the same meaning.

Attwood et al. (Attwood, Deeb, & Danz-Reece, 2004) have discussed elaborately stress and relative issues about stress. The definition of stress given is as follows, "*stress* is the reaction of an organism (human or animal) to a threatening situation." To be more specific, stress can be stated as the biological reaction to any kind of adverse situation i.e. physical, mental, emotional, internal, external or chemical that disturbs human's stable or balanced state. Finnish Institute of Occupational Health (Health, 2016) describes time pressure similarly- time pressure can also be caused due to external factors e.g. urgent demands, hurry pace etc. Besides, some internal factors can be mentioned as well e.g. too few hospital staff compared to the number of patients.

Attwood et al. (Attwood et al., 2004) classify stress into two main parts:

- *Positive stress* means the desire to continue doing regular things in life and try to solve difficulties and problems. This is very important for life, as it gives the motivation to fight back against the odds, unnatural things and perhaps without this life may become boring.
- *Negative stress* generally means the stress that we don't wish for. It makes us demotivated and raises our anger, frustration, depression, tiredness and confusion. Also, it makes us less confident. Long-term negative stress can imbalance our mental state and creates physical illness e.g. cardiovascular disease and musculoskeletal disorders.

7.1.1 Sources and causes of stress

Attwood et al. (Attwood et al., 2004) have combined some sources and causes of stress from the literature review and illustrated it in a table. Table-7.1 describes these sources and causes.

Table-7.1: Sources of stress (Attwood et al., 2004)

Category	**Factors**	**Leads to**
Workplace environment	Lack of control	Job dissatisfaction Emotional and physiological strain
	Lack of management and peer support	Increased stress
	Work overload: In terms of quantity (too much to do or under a strict, short deadline) and quality (task demands exceed individual capabilities or individual feels incapable)	Increased stress and vulnerability to stomach ulcers and high blood pressure

	Work underload: Individual's knowledge and capabilities far exceed job demands	Increased stress, boredom Decreased feelings of competence and self-esteem
	Job uncertainty, task ambiguity, technology changes and job insecurity	Increased stress
	Lack of organizational commitment to employees, in term of loyalty, career development (i.e., training, skills, security)	Increased stress, health complaints, job dissatisfaction, poor performance, turnover, absence
	Job insecurity related to streamlining business, mergers, downsizing, bankruptcy and unethical corporate practices	Increased stress
Physical environment	Noise, poor lighting, vibration, heat/cold	Contribute to increased stress
Individual differences	• Personality • Lack of experience and knowledge • Lack of skills • Health of individual	Contribute to increased stress

*Increased stress refers to Negative stress.

Attwood et al. (Attwood et al., 2004) propose some ways to measure stress qualitatively and quantitatively. Questionnaires, observations, interviews etc. can be used for qualitative measurement and for quantitative purpose heart rate measurement, heart rate variability, respiratory rate, blood pressure, levels of adrenaline, noradrenaline, glucose, uric acid, cortisol, steroids in a urine sample, blood, saliva or sweat etc. can be used.

Finnish Institute of Occupational Health (Health, 2016) also points out some factors that influence time pressure at workplace such as a) Leaving tasks until the last minute, b) Many changes at work, c) Poorly organized work or unequally distribution of work, d) Client determined the fast pace of work, e) Heavy or fluctuating workload, f) Tight schedules, g) Many interruptions at work, h) Not enough workers.

7.1.2 Why Time Pressure/Stress as a RIF ?

Finnish Institute of Occupational Health (Health, 2016) reports, a significant amount of occupational accidents happens when people are in a hurry. If the time pressure increases, accidents in the workplace also increase. The feelings of this pressure may vary from person to person. Some may feel it as an obstacle, some may feel it as an unjust etc. In general, regardless of any type of industry, almost half of the employees feel that they have to rush to get their work done when they experience time pressure.

George (George, 1974) argued that a stressful condition is a reason for decision hesitation problem as it refers to a conflict and a threat of negative consequences. Furthermore, lack of knowledge while taking a decision about alternatives or failure to process all available information can cause cognitive strain as well as emotional stress. Time pressure can contribute to the increase of this psychological stress because of unavoidability and a stronger sense of failure emanating from incompetence in processing and weighting information. In addition, because of inadequacy, some information may need to be ignored that are considered important to the decision makers which, in the end, may result in helplessness. This also increases the mental pressure of the worker.

Miller (Miller, 1960) proposes three ways to overcome a time-pressed situation. The first one is Acceleration that means processing all information at a faster speed. This kind of activity under pressure can result in some error because of a temporary overload of memory or some limitation in the capacity. The second one is Avoidance of the decision. But avoiding the decision may cause a selection of random choice in the case of unavoidable decision making. The third one is Filtration i.e. a compromise strategy, choosing only subjectively important data for consideration. But again, it squeezes the decision arena and left only a few choices to select. The reason behind including Miller’s discussion is that during time pressure an employee may choose to overcome it in this ways which ultimately may cause an accident.

The above discussion clearly shows how important the time pressure as a risk influencing factor (RIF) and how it can affect the operations while decision taking. In addition, it also indicates to some accidents caused because of time pressure ensuring how hazardous it could be if not properly analyzed.

7.1.3 Time pressure /Stress in Hot work

In this case, study, where ‘Hot work’ is taken for further investigation, time pressure plays a vital role as it is very much possible to create any kind of incident to trigger any hazardous source which ultimately can cause a severe accident.

Øien (Knut Øien, 2001b) states that each RIF can be denoted by some ‘risk indicator’. A RIF is a factor that influences the risk level of a system/ facility, whereas, a ‘risk indicator’ is a measurable representation that is introduced to solve the measuring problem of theoretical RIFs. In other words, with the help of risk indicator the state of each RIF can be understood and measured. Øien (Knut Øien, 2001b) presented it for quantification purpose instead of performing the only qualitative analysis. But the main challenge is to measure the ‘risk indicators’ as they are difficult to measure in all situations. In addition, the indicators must be some selected aspects that influence the RIFs most and it is possible that the selected indicators might not be the critical aspects of the RIF.

In this study, the procedure of Øien (Knut Øien, 2001b) is followed. So for each RIF, some indicators are pointed out which could be related to ‘Hot works’. In the later discussion, the indicators related to ‘Time Pressure/Stress’ are discussed.

7.1.4 Indicators of Time Pressure/Stress

The following indicators are sorted out for the RIF ‘Time pressure/Stress’: a) workload, b) work schedule, c) supervision, d) changes at work.

Indicators (a), (b) are adapted from Attwood et al. (Attwood et al., 2004), Table 7.1 and indicators (c), (d) are adapted from the discussion of Finnish Institute of Occupational Health (Health, 2016) on time pressure.

a) Workload

Crowl (Crowl, 2007) analyzed and described the effect of the workload in the workplace. He states, “An individual’s physical and mental workload directly affects his/her stress level”. Crowl (Crowl, 2007) further continues that excessive workload leads to human error, because of the over engagement with the activity. At high-stress situation, the personnel may avoid any new information (e.g. alarm) and primarily focus on the known factors. Furthermore, the personnel can skip the tasks that he/she thinks as less critical and rely on only the skills he gather from previous experience and ignore knowledge-based behaviors.

The excessive workload for a longer time can lead to manifold human errors. This may result in inattention during work operation. Also, shortcuts could become the trend in the workplace. Cross-checks between workers and work groups are eliminated. Various minor incidents are ignored, there is no enough time to do that.

On the contrary, less workload can lead to human error as well. Crowl (Crowl, 2007) reports an example of a computer-based process where the operator just has to follow the procedure and respond to upsets if there any. In such cases, the operator could get bored and reluctant to respond to urgency. Besides, the operator may deliberately push the process beyond the limit to challenge himself/herself. Not only that, the management may reward the personnel for setting up new production record (the record which has happened accidentally) regardless how it has achieved.

In the nutshell, it can be concluded, the workload should not be such that it raises the stress level of the worker neither it should not be such that it makes the worker bored and less attentive.

b) Work Schedule

Work schedule refers here to the work duration in the workplace. It influences personnel’s physical and mental condition which at the end can also affect one’s stress level. If the work schedule is not designed regarding human body nature then in some certain period of day or night the employee may feel tired and fatigue for which he/she cannot concentrate on the appointed operation. This may rise employee’s stress level.

In this context, fatigue is regarded as extreme tiredness that may be a result of work schedule mismanagement. And because of fatigue and tiredness the employee cannot concentrate on the work task and may become frustrated with his own performance. As a result, the employee can feel stressed about the work task to do.That is how it may be a cause of increased stress.

Night work and long working hours can proceed to fatigue that can cause demotivation, inattentiveness, poor communication, forgetfulness and so on. Fatigue may cause operational errors and often it happens to be the root cause of several incidents. It can effect to a number of key physical and mental abilities that make it impossible to do some simple tasks Crowl (Crowl, 2007).

The human body functions with a biological rhythm with a periodic change in physical measurements such as heart rate, body temperature, blood pressure, chemical response etc. This biological rhythm works and functions in a 24-hour cycle that is termed as ‘Circadian cycle’. Our body responses to this cycle and behave differently in different hours of daytime (Attwood et al., 2004). The following Figure 7.1 is illustrated to show how our body behaves in different hours of day and night time.

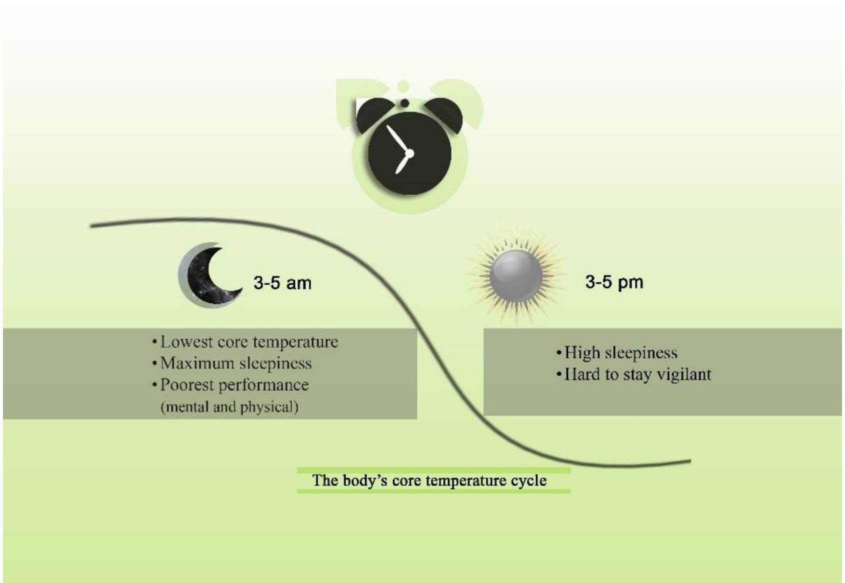


Figure 7.1: Time of day and effects on fatigue and performance (Crowl, 2007)

In the light of Attwood et al. (Attwood et al., 2004) work some further discussion on fatigue that is related to work schedule is presented.

The productivity, error and accident rates are influenced a lot by fatigue. For instance, alertness and performance of a personnel change in various hours of day and night time. In addition, insufficient quantity of sleep time increases fatigue during work hours. Extended working hours (generally beyond 8 hours) in such type of work where constant concentration and attention is needed, may decrease performance and increase error rates and accident rates. Statistics shows that there is an increase of 80-180% in error rate because of the extension of working hours from 8 to 12 hours. ((Kelly & Schneider, 1982);(Tepas, 1985))

Some major accidents investigation shows fatigue played a vital role in human error. For example, Bhopal chemical plant and Chernobyl nuclear plant accidents data report that these accidents happen in between midnight to 4 AM. The human error rate is twice the average in this time range compared to day time. It can be related to Figure 1 too as it clearly presents the poorest performance in this time range.

Hence, work schedule can be related to time pressure as personnel finds it difficult to become vigilant in several working hours that can result increased stress/time pressure.

c) Supervision

In an organization, proper supervision is counted as an important factor. According to Thau et al.(Thau, Bennett, Mitchell, & Marrs, 2009), there has been enough research which proves that supervisor's mistreatment persuades employees to act in such a way that can be harmful both for the organization and individuals. Goulder (Gouldner, 1960) comments that employees who are mistreated or abused by their supervisor respond back with mistreatment to the organization and to the supervisor.

On the contrast, a study of Bono et al. (Bono, Foldes, Vinson, & Muros, 2007) depicts the positive effect of good supervision and leadership. A study was organized in a health care center for 2 weeks and the result presents that supervisors were engaged with the employees emotion in 3 ways: "(a) Employees experienced fewer positive emotions when interacting with their supervisors as compared with interactions with coworkers and customers; (b) employees with supervisors high on transformational leadership experienced more positive emotions throughout the workday, including interactions with coworkers and customers; and (c) employees who regulated their emotions experienced decreased job satisfaction and increased stress, but those with supervisors high on transformational leadership were less likely to experience decreased job satisfaction". The study also says that stress created in the workplace is long lasting (up to 2 hours) and not easily reduced.

This kind of studies gives a fine argument and proof about the influence of supervision in employees behavior and this may result in time pressure.

d) Changes at work

Changes at workplace suggest to the situation when there are frequent changes in the work tasks. Frequent changes can confuse the personnel and may cause lack of confidence. As a result, the employees fill an extra pressure which hinders him to perform even a simple task.

Figure 7.2 illustrates the RIF 'Time pressure/Stress' and the relative indicators with it.

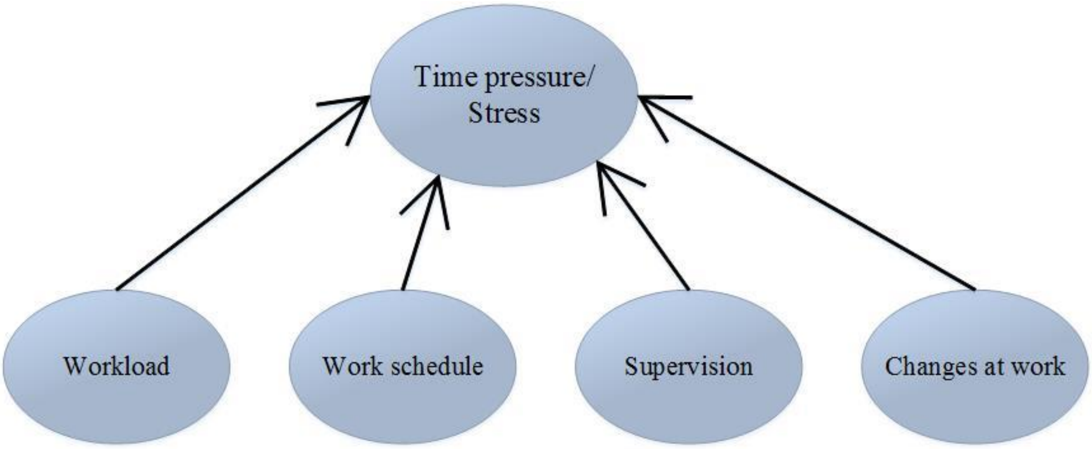


Figure 7.2: Indicators of Time pressure/Stress

7.1.5 State and Scoring

The state is assumed to depict the present condition of a RIF or an indicator and scoring used to give a measurement procedure and understand in what state the RIF or indicator is in.

Table 7.2: States and scores of indicators (Time pressure/Stress)

Designation	**State value**
Too high	5
High	4
Optimal	3
Low	2
Too low	1

Table 7.3: Weights of the indicators (Time pressure/Stress)

Indicator	**Weight**
Workload	0.3
Work Schedule	0.3
Supervision	0.2
Changes at work	0.2

In this discussion, the indicators are assumed to be in a state and corresponding state value is given to each of them. From the indicator value, a value of each RIF (here 'time pressure/Stress') is measured. Each indicator is assumed to be in five states: 'too high', 'high', 'optimal', 'low' and 'too low'. In addition, each state is given a score. For instance, if the indicator 'work schedule' is in 'optimal' state, this means that work schedule is designed in a suitable manner following proper physical and mental concerns and this state is in the favor of employees. Table 7.2 illustrates the state and score of each indicator for 'time pressure/stress'.

The weights of the corresponding indicator are also mentioned in Table 7.3. The variety of weights for each indicator shows the relative importance of each indicator for the RIF. It is assumed that the indicators 'Workload' and 'Work Schedule' is the most influential from the literature review as these are main concern in the workplace, especially in 'hot works' if there is not proper distribution of workload and no proper schedule maintaining then the worker may feel stressed that could cause any occupational error. 'Supervision' and 'Changes at work' are given least weight because these are also important enough to have an impact on time pressure/stress but not as influential than the previous two indicators.

With the help of these indicators the value of 'Time pressure/Stress' is measured. In this purpose, the methodology introduced by Øien (Knut Øien, 2001a) is followed. The equation is as follows:

$$r_k = \sum_{j=1}^{n_k} v_{kj} r_{kj} \qquad (1)$$

r_k = the measured value of the relative RIF (here 'Time pressure/Stress'),

v_{kj}= weight of each indicator

n_k= number of indicators (in this topic n_k =5)

So, to measure the value of r_k with the help of Equation (1), there will 5^p combinations where '5' is the number of states of each indicator and 'p' is the number of indicators. So in this case $5^p = 5^4 = 625$ combinations.

As the indicators values are between 1 to 5, so it is obvious that the value of RIF will also remain in this range. It is assumed that the RIF has three states- 'High', 'Optimal' and 'Low' that varies from 1 to 4. Table 7.4 shows the value and state of the RIF.

Hence, the state of the RIF is easily conceivable from the value of Table 7.4. For example, if the value is 3.5, then it means the state of 'Time Pressure/Stress' is high, it needs improvement so that it comes down at least in the optimal range.

Table 7.4: States and scores of 'Time pressure/Stress'

State	Score (State value)
High	3~5
Optimal	2~3
Low	1~2

7.2 Training

Attwood et al. (Attwood et al., 2004) define training as the main source of information for personnel to improve his/her skills. In other words, training means to learn the activities that help an organization's employees to develop their own knowledge, skills and abilities which are needed for particular job/ operation. As Crowl (Crowl, 2007) states, "Training provide skills and/or knowledge for the current job".

7.2.1 Objectives

Attwood et al. (Attwood et al., 2004) summarize some prime objectives of training:

- Maximize skill and knowledge
- Achieve consistency in procedural activities
- Minimize the time that trainees require for skills and knowledge.

An efficient training system would be that considers and implements human factors principles and design the program according to the task to perform. Not only it provides employees effective training but also it measures its own effectiveness. Without enough knowledge and practice of skills to perform, the employee cannot transform from amateur to expert.

7.2.2 Why Training as a RIF?

Training is the method to transfer the knowledge of skill and experience of performing a job as perfectly as possible following all the safety precautions. Therefore, it ensures not only the successful completion of work but also the safety of employees.

Attwood et al. (Attwood et al., 2004) commented, “The effectiveness of the training, along with practice, can help reduce errors by building the employee's expertise on how to execute procedures”. In 90’s a survey in the UK from five local authorities reported that almost 80 percent both managers and social worker stated that they received limited training which as a result increased their work pressure and error rates (Connelly, 1996).

Lingard (Lingard, 2002) has conducted an experiment in a business construction industry employees to assess the effect of first aid training in their occupational health and safety behavior and to find whether the training motivates them to avoid injuries and illness or not. The experiment continued for 24 weeks and an evaluation of training is performed after the training. For the evaluation, participants were interviewed in-depth to find out about their motivation changes or not, in order to control occupational safety and health risks, before and after the training. A researcher was appointed to find out objective changes in the workplace by directly observing the workplace before and after the first aid training. The result is that first aid training makes a positive effect on occupational health and safety in participants’ mind. They started to believe that they themselves can contribute to the behavior of controlling risk both for themselves and the organization. The training also reduced participants’ willingness to take occupational risks and increase perceived probability that they will suffer a work-related injury or illness. Therefore, Lingard (Lingard, 2002) summarizes the impact of this experiments by commenting that the first aid training triggers up the sense of risk control behavior of the participants. Hence, it is suggested to arrange training for all the employees rather than training only some few number of people- ‘first aiders’.

From the year 1979 to 1984, a study has been conducted in British Columbia to investigate how effective the motorcycle safety training program is to prevent accidents. Henceforth, two groups were formed to compare each other - one group had a formal training motorcycle riding and other group had no such formal training. But both of the group had Class 6 license which was used for the general purpose for all kinds of vehicles. After the comparison, it was noticed that the group who had formal motorcycle training had fewer accidents for all type of accidents (including motorcycle accidents) and faced less severe accidents. This study gives the evidence in support of training to reduce human and material cost due to accidents (McDavid, Lohrmann, & Lohrmann, 1989).

These discussions show the significance of ‘training’ in an organization and how it can affect both the individual and organization. With proper training risk reducing measures could be taken and thus controls any hazardous source.

7.2.3 Training in ‘Hot Work’

In this thesis work where ‘Hot work’ is the main case study, ‘training’ could mean several of skills such as ‘training to do hot work’, ‘training to take proper safety arrangement before starting hot work’ etc. In this context training is considered as ‘training to detect gas’. The reason behind choosing this particular training is that in the discussion of chapter 6, we have seen that ignition happened mainly because of failure to detect gas. Hence, to emphasize on this particular incident the risk influencing factor ‘Training’ is considered as ‘training to detect gas’.

7.2.4 Indicators

The indicators identified for ‘training’ are as follows: (a) Content, (b) competence of trainer, (c) vocational training experience, (d) experience in gas testing, (e) experience in hot work, (f) transfer of training.

Indicator (a) is adapted from Crowl (Crowl, 2007), (b) is adapted from Attwood et al. (Attwood et al., 2004), (c), (d), (e) are adapted from Øien (Knut Øien, 2001a) and (f) is adapted from Punia (Punia & Kant, 2013)

a) Content

The content analysis identifies the knowledge needed to perform the actions in an operation. It is the trainees who are the main target of training, to whom appropriate knowledge should be provided as a prerequisite (Crowl, 2007). The content can be consists of two types of tools to facilitate the learning process. One, tools that support the trainer in teaching the trainees such as, manuals, courses, lectures, presentations, videos, relative tables etc. Second, tools that give hands-on experience such as, group discussions for problem-solving, paper-pencil exercises, using mock-up instruments, simulations etc. (Chapanis, 1996) Trainees need to have proper opportunities to implement their knowledge practically in actual operations. Training not only trains the trainee for the operations but also builds up the mind of trainee's to make a decision in time emergency where only rules and instruction knowledge is not enough (Kletz, Kletz, Kletz, & Chemist, 1991).

Gordon (S. E. Gordon, 1994)suggests that specific indications should be included in contents and it should be cross-referenced with the current rules and regulations to use it as a basis for teaching methods. Besides, training pace should be such that it does not overload the trainees and gives them enough time to assimilate and imply their learnings. To identify whether the training is helping the trainees or not, assessments e.g. spot tests, solving some imaginary problems etc. could be arranged and feedback of trainees could be checked through. Attwood et al. (Attwood et al., 2004) proposed some ways for preliminary testing of the contents such as computerized self-paced instruction versus classroom lecture versus progressive workbook exercises etc. The best way to get feedback is to test the prototype program on the users because then the developer can observe the learner's perspective directly and organize the training as so.

b) *Competence of Trainer*

Trainers need to be efficient in teaching. They must have experience in the relevant field they are teaching. In addition, they need to be aware of the cultural differences such as variation in the approach of asking questions and deliver their message keeping it in mind. While hands-on training they need to have sufficient practical experience on that particular job/operation. Besides, the trainer should watch the trainee during practice to check the proficiency of him/her (Attwood et al., 2004).

c) *Vocational training*

Vocational training means to teach a personnel practically about a specific work/job. It is generally a non-academic training with the intention to teach an employee how to work in the workplace. Normally employees who work in a craft or as a technician who work in support of an engineer, a nurse etc. are vocationally trained.

It is very important that the trainee should be vocationally trained. Before starting in the real workplace he/she should have a minimum knowledge of the job so that he/she can manage his/her own safety. For example, in hot works the welders, the gas tester etc. are the people who are vocationally trained.

d) Experience in Gas testing

The experience of direct job does really count much. Because the more an employee performs the job the more he/she knows about the pros and cons. Sometimes there are some deviations in the fieldwork that were probably missed out in the training. Sometimes the equipment functions a little strange. The result may vary from time to time. These are all the situations that only a field worker can experience.

e) Experience in Hot work

The overall hot work experience is also a must besides vocational training and gas testing experience. The personnel who has experience on performing hot work job in several kinds of workplace such as, any process plant or oil facility or another kind of industrial plant he/she must have an extra knowledge of welding circumference. In addition, he/she can also presume any kind of environmental factor if there any. Hence, the previous work experience of a well-known contractor needs to consider whether this experience is transferring to other personnel or not through training.

f) Transfer of Training

Transfer of training indicates the effectiveness of training. Training transfer means the successful use of trained knowledge and skills in the job. Baldwin & Magjuka (Baldwin & Ford, 1988) mentioned that for transfer to occur, "learned behavior must be generalized to the job context and maintained over a period of time on the job". Saks and Haccoun (Saks, Haccoun, & Belcourt, 2010) express a similar opinion- it is the generalization of achieved skill and knowledge in the training and maintaining it over time. Saks and Haccoun (Saks et al., 2010) suggest a method to improve and facilitate training transfer i.e. the training can be given in three phases that are before, during and after of a specific operation. Moreover, follow-up session could be useful too (Punia & Kant, 2013)**.**

Figure 7.3 illustrates the RIF 'Training' and the relative indicators with it.

7.2.5 State and Scoring

Not all the indicators are measurable directly with numbers e.g., indicator (a) and (f) are not measurable. A possible suggestion is that to organize an interview session with the field employees. The interview could be consists of questionnaires, some test for employees etc. An expert then can suggest the possible states of these indicators from the observation of interview.

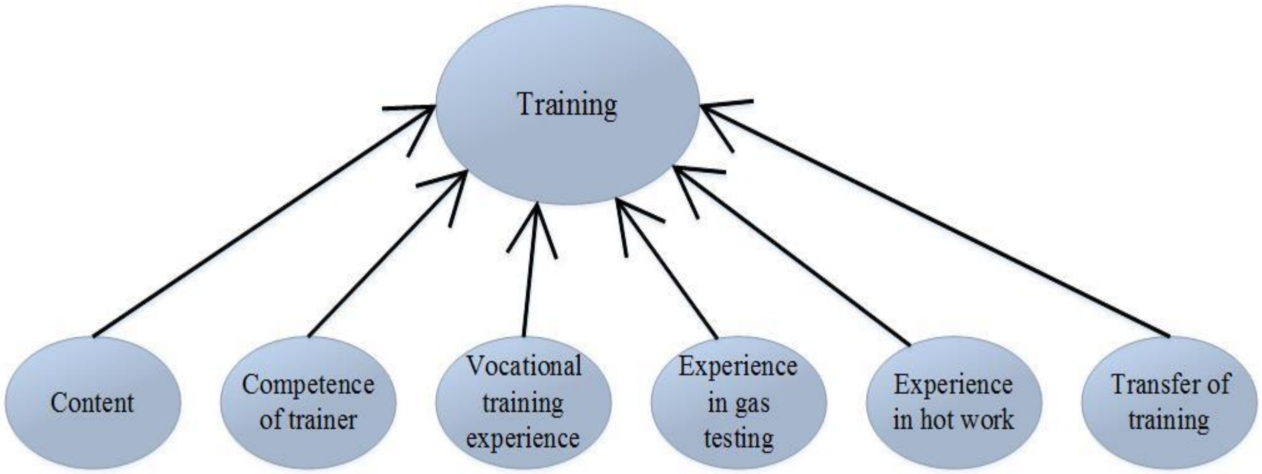


Figure 7.3: Indicators of Training

On the other hand, indicator (b), (c), (d), (e) can be measured. For example, indicator (b) can be judged with the no. of the year the trainer has been training, indicator (c), (d), (e) are also measured in that way. The proposal is that for indicator (b) if the no. of the year of experience is equal to or greater than 7 years then the state is 'good' and the score is 5. If it's between 3 to 7 years then the state is 'average' and the score is 3. If less than that, the state is 'poor' and the score is 1. Indicator (c), (d), (e) are also proposed in a similar way. Table 7.5, 7.6, 7.7, 7.8 shows the states and scores for the respective indicators.

Table 7.5: Indicator 'Competence of Trainer'

No. of years of experience	State	Score
≥7 years	Good	5
3~7 years	Average	3
< 3 years	Poor	1

Table 7.6: Indicator 'Vocational training'

No. of years of training	State	Score
≥2 years	Good	5
1~ years	Average	3
< 1 years	Poor	1

Table 7.7: Indicator 'Experience in Gas testing'

No. of years of experience	State	Score
≥7 years	Good	5
3~7 years	Average	3
< 3 years	Poor	1

Table 7.8: Indicator 'Experience in hot work

No. of years of experience	State	Score
≥8 years	Good	5
3~8 years	Average	3
< 3 years	Poor	1

Table 7.9: Weight of the indicators.

Indicator	Weight
Content	0.2
Competence of trainer	0.1
Vocational training experience	0.2
Experience in Gas testing	0.2
Experience in hot work	0.2
Transfer of training	0.1

Table 7.10: States and state value of 'Training'

Designation	State value
Good	3.5~5
Average	2.5~3.5
Poor	1~2.5

The weights of the indicators are shown in Table 7.9. Indicator (a), (c), (d), (e) has equal weight of 0.2 unit as they assumed to be the major indicator for the RIF. Because without an updated and well-organized content the training could be not useful. And practical training about the job is very much important as well. Indicators (b) and (f) considered as significant but given a lower weight than others.

The RIF calculation is done with Øien's (Knut Øien, 2001a) procedure. The values and weights of indicators are used for the measurement of RIF. The proposal for the RIF value is given in Table 7.10. The principle that is followed for RIF state selection is that the more the value is closer to 5 the state is 'Good' and vice versa. Although there a range for all states is proposed.

7.3 Procedures

In a process plant procedure is a core part of daily operations management. As Attwood et al. (Attwood et al., 2004) states, "Procedures are important because they provide rules to be followed and standardized records of safe and approved operations and maintenance practices". In general, procedure means an organized form (mostly written) to manage several operations in a plant . In one sentence, procedure functions as an internal law for the organization. Different operations may have the different procedures but it is must to integrate all the procedures in order to make sure that all the operations in a plant are functioning simultaneously. Attwood et al. (Attwood et al., 2004) mention some key advantages that procedure provides:

- Gives consistent information across the plant.
- Minimize guesswork.
- Improve overall efficiency in a facility
- Ensures safe operations.

When a Procedure is needed

Attwood et al. (Attwood et al., 2004) give an overview how to determine when a procedure is needed or not. It is suggested that according to task description, there might be three possible ways to determine it : (1) complexity of the tasks, (2) frequency of the tasks required to execute, (3) consequences of the possible error made during the tasks. Tasks with moderate complexity that needs several steps, mostly infrequent which are executed less than once per month and has at least moderate consequence of error need procedures. For the rest cases, the procedure is suggested for review or persuaded .

With the idea from Table 7.11, we can compare our case study hot work and its tasks to determine whether it needs a procedure or not. Clearly hot works fall the 'Procedure needed' category. Hence, a suitable and proper procedure is needed for a safe hot work operation.

Types of Procedures

Attwood et al.(Attwood et al., 2004) categorize procedures into three types: (a) operating (b) emergency and (c) maintenance. Whereas, Crowl (Crowl, 2007) adds one more category in it, ‘start-up and shutdown procedure. Following the discussion of Crowl (Crowl, 2007), a detail description of these types is discussed.

Table 7.11: Guidelines for when a Procedure is Needed (Attwood et al., 2004)

Task Characteristic	**Procedure, Checklist or Sign-off Steps Needed**	**Procedure Available for Reference or Review**	**Procedure, not Needed, Learned in Training**
Severity of consequences is error is made	Moderate to high (e.g., injury, process delay, equipment damage)	Moderate (some impact on process or safety)	Low (no impact on process or safety)
Complexity	Moderate to high (more than 9 procedure steps, quick decisions)	Moderate (5 to 9 procedural steps)	Simple (less than 5 steps)
Frequency	Infrequent (less than once per month) to frequent (weekly)	Infrequent to frequent	Very frequent (multiple times per week)

- *Start-up and shut-down procedures* are the written instructions to bring up a process to operating conditions and to bring down the process to non-operating conditions. This is applied both to the planned and not emergency situations.

- *Operating procedures* are the step by step instructions, also includes safety instruments e.g., warning, notes etc., for safely performing the tasks.

- *Emergency procedures* mean the written instruction to bring a system into safe and stable position given that there is a system upset.

- *Maintenance procedures* are written instructions to ensure all the equipment are available for production so that there is always an integrity between different parts of the facility.

7.3.1 Why Procedure as a RIF

The procedure is the instruction that needs to be followed as correctly as possible to avoid any kind accident. An emerge of a hazardous source is very likely to happen due to any deviation from the written instruction. Some research has been discussed on this behalf.

Alireza et al. (Noroozi, Khakzad, Khan, MacKinnon, & Abbassi, 2013) have researched on the impact of human error in pre- and post- maintenance procedures. Although the main research was on human error and its effect in process industry, but their final result was, "ignoring human error in quantitative risk analysis of pre- and post- maintenance procedures can result in noticeable difference in the amount of envisaged risk" So, it is quite visible there is an effect of human error in the maintenance procedure which at last affects the overall risks. Therefore, this study concludes that 'procedures' also need to be considered with concern to manage the risk scenario.

One of the most remarkable accidents can be included in this discussion is Piper Alpha in 1988. It was a combination of several safety failures ultimately killing 167 employees. Elisabeth (Pate-Cornell, 1993) has studied this incident and finds out several reasons for this hazardous event. The accident source was a leak of hydrocarbon from one of the condensate pump. This condensate pump had only one redundancy which was open for repair work by the workers from day shift. So the pump was out of order and the only available pump was the redundant one. But unfortunate the night crew that was supposed to operate that night was not informed about this repair work. And while in the operation during the night the redundant pump failed and the night worker initiated the pump which was open for repair. This was the starting event of this accident which later on combined with other failures and caused this deadly accident. Elisabeth (Pate-Cornell, 1993) marked this information gap as a failure of the permit to work systems, which indicates the procedure failure.

7.3.2 'Procedure' in Hot work

Pettersen and Nygaard (Petterson & Nygaard) have analyzed the Statfjord Field and did a thorough risk analysis related to the field. In this report under the section 'Fire and Explosion', it is mentioned that 'hot work' is identified as one of the major contributors to the ignition probability. Therefore, to prevent the field from ignition more restrictive hot work permit procedures have been introduced. As a result, hot work is permitted in such area of the platform where the resulting consequences of an accident would be intolerable unless the process is shut down and process system depressurized. So, in this case study, it is evident that how much importance is given to procedural improvements to prevent the hot work accident in a platform.

The Partridge-Raleigh Oilfield Explosion can be mentioned as well. Although the accident's cause was an undetected gas which ultimately ignited and exploded. But the report from U.S. Chemical Safety Board (CSB, 2007) says that before the hot work there was an inspection for fuel presence in the production tank (in which the hot work intended to perform) with an oxy-acetylene torch under the tank. And this is a dangerous and unsafe procedure of fuel checking which clearly shows a procedural fault in the hot work process.

7.3.3 Indicators

The indicators that have been pointed out for 'Procedure' are: (a) proportion of relevant personnel having received SJA training, (b) no. of SJA carried out last quarter of the year, (c) detail information, (d) conciseness, (e) consistency.

Indicators (a), (b) are adapted from Øien's (Knut Øien, 2001a) and indicators (c), (d), (e) are adapted from Crowl (Crowl, 2007).

In the book of Marvin (Rausand, 2013) a detail description about SJA/JSA (Safe Job analysis/Job Safety Analysis) is given. SJA is a simple risk assessment method that is used to review the procedures and practices in an organization to identify any possible potential hazards and generate risk reducing measures. Each job is segmented into several tasks and for each task observations, experience and checklists are used to identify hazards and associated controls with it. This is done and documented in SJA/JSA worksheets.

a) Proportion of relevant personnel having received SJA training

The proportion of relevant personnel received SJA training or not needs to be measured in order to make the procedure more viable and safe. Although it might be confusing to include this indicator in 'procedure' rather than including it in 'training'. The reason behind including it under' procedure' is that if the organization procedure does not emphasize on the SJA training it may be overlooked or may be done with less importance. If the organization permits only a few personnel with SJA training to work then rest of the employees will work without knowing the key facts of SJA training. And without SJA training, the employees may not be aware of risk taking and cause some error. That is how procedure influences on SJA training of employees in the organization.

b) No. of SJA carried out last quarter of the year

With this indicator, the safety practice of an organization is understood. The more an organization organizes SJA checks the more it is concerned about safety. But again, SJA takes resources and time. Hence, during SJA scheduling resources and time needs to be considered.

c) Detail information

The procedure (written instructions) should be sufficiently informative and accurate. It describes all the tasks of a job considering the safe performance and safety of the personnel. The level of details of a procedure is measured according to the experience and capabilities of the users, their training, and responsibilities.

d) Conciseness

It is very important that the procedure is concise and to the point. It gives a clear idea about the task steps and precautions if needed. The language should be easy and perceivable. In short, conciseness means to include only ‘need-to-know’ and discarding ‘nice-to-know’.

e) Consistency

While formatting the procedure, each term related to the operation must be used with a standard and fixed term. Otherwise, with different terms of the same component the employee may get confused and make any mistake. Furthermore, selection of vocabulary should be as simple as possible so that anyone can easily identify and remember it.

Figure 7.4 illustrates the RIF ‘Procedure’ and the relative indicators with it.

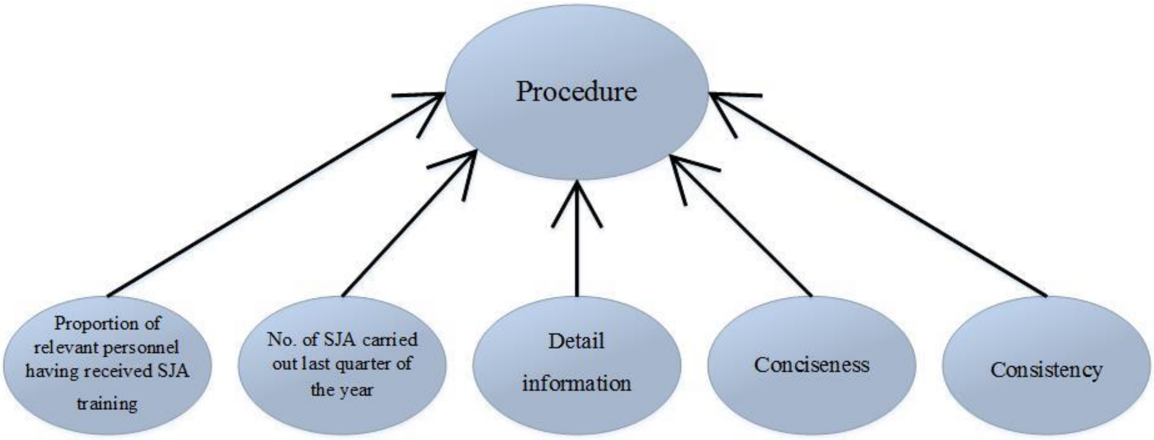


Figure 7.4: Indicators of Procedure

7.3.4 State and Scoring

The state and scoring of the indicators could be a little bit difficult as all the indicators cannot be measured in numbers. Indicators (a), (b), (c) can be measured in numbers of personnel proportion, the number of SJA check in the organization and number of experience of the users respectively. But indicator (d) and (e) cannot be measured in numbers. One proposal is that to interview the field worker with several questions e.g., do you find it easy to understand the procedure, can you follow as it is written now etc. With the result of the interview, an expert can comment on the conciseness and consistency of the procedure.

Three states are proposed for all the indicators- Good, Average and Bad and each state is assigned a value. For indicator (a), it is supposed that if all of the relevant personnel got the SJA training then it's in ‘good’ state, if 70% or above personnel got training then its ‘average’ state, otherwise, it's in ‘bad’ state. For indicator (b), the state depends on the total tasks going on the organization. If the organization or industry requires many separate tasks then the more tasks have SJA check the more it's safer to work in the organization. Hence, the proposal is if more than 80% tasks of the organization have a SJA check in each quarter then the state is ‘good’, between 50-70% the state is ‘average’, less than 50% it’s ‘bad’ state. Considering indicator (c) the number of year of training a personnel gets is counted. If a personnel is trained for 2 years with full details side by side with his regular job in the organization then indicator (c) is in ‘good’ state, if it is 1 year then ‘average’ state, if no experience then it's recommended as ‘bad’ mode. The states of indicator (d) and (e) are decided by an expert. Table 7.12 shows the state and score of the all the indicators.

Table 7.12: State and scores of indicators for ‘Procedure’

Designation	State value
Good	5
Average	3
Bad	1

Table 7.13: States and state value of ‘Procedure’

Designation	State value
Good	3.5~5
Average	2.5~3.5
Bad	1~2.5

Each of the indicators has given equal weights they are all equally important in the case of the RIF ‘Procedure’. As there are 5 indicators and they are equally weighted so each of the indicators gets 0.2 unit weight.

With state value and weights of indicators, the value of the RIF is measured according to Øien’s (Knut Øien, 2001a) approach. From the value of indicators, it is easily conceivable the value of RIF will remain in between these number. So, a state and state value are also proposed for the RIF. It is shown in Table 7.13.

The proposal of the scoring of states of RIF is given considering the scores of indicators’ states. The more the RIF value is closer to ‘good’ value of the indicators it is assumed to be in good state. Same goes for the rest two states.

Chapter 7, assesses some RIFs and does a deep analysis. The chapter describes the origin of RIFs, when its needed, process how to measure the RIFs.

Chapter 8

Non-linearity in Models

This chapter discusses non-linearity and its difference with linearity. In the discussion of Chapter 7, it is evident that the relationship of RIFs with performance is non-linear. For this purpose, some selected methods are discussed regarding their handling of RIFs' non-linear behavior and how they can be utilized to solve this non-linearity.

8.1 What is non- linearity?

Non-linearity is a relationship that cannot be described in linear combination. It is a common issue to examine cause-effect relations. To overcome these kinds of cases, complex modeling and hypothesis are required. Non-linearity without explicit definition can lead towards random and variable outcomes.

Some examples might be more convenient to understand this concept. In section 7.1, positive and negative stress is discussed. Positive stress has been described as a factor that can influence a personnel to give more effort with enthusiasm and alacrity. Therefore, it is beneficial for the workplace in a certain limit. But the moment stress has crossed the limit then the same stress has become negative stress and starts deteriorating employee's performance. Hence, there is a relation between stress and performance. This relation can be illustrated in a graph look like diagram to visualize the relation more clearly. Figure 1 shows the relation between stress and performance.

A linear illustration is also drawn in Figure 2 to represent the relation between motivation and performance. This relation is linear because when the motivation is high, performance also increases and it goes like that way.

In the present models, non-linearity is not considered with proper attention. Therefore, these methods are not properly applicable to solve the non-linearity issue of RIFs. Some methods like HCL, ORIM, BORA, Risk_OMT are assessed regarding the issue of non-linearity and some points of these methods are discussed as limitations that may contribute to the non-linear results of RIFs (limitations are meant only the issues that may give non-linear results). Some suggestions are also mentioned in this regard.

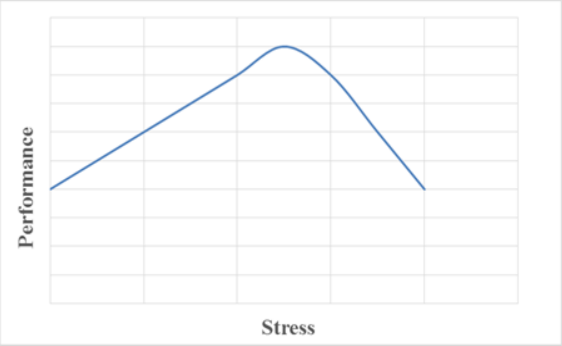


Figure 8.1: Non-linear relation between Stress and Performance

Figure 8.2: Linear relation between Motivation and Performance

8.2 ORIM (Organizational Risk Influence Model)

Øien (Knut Øien, 2001a) has proposed the ORIM method for quantification of risks in HC leak. This method consists of three frameworks - (1) Organizational model, (2) Organizational risk indicators, (3) A quantification methodology.

The organizational model discusses the causes of the leak and links them together. RIFs are identified in this discussion. Afterward, organizational risk indicators are identified related to selected RIFs.Then a quantification method is applied to quantify the risk. The quantification method that Øien (Knut Øien, 2001a) applied is introduced in section 7.1.5 for the quantification of RIFs with the selected indicators.

8.2.1 Non-linearity in ORIM

The quantification approach that Øien (Knut Øien, 2001a) proposed, needs the weights and scores (meaning the state of each indicator) of indicators. But there are some limitations of this approach-

(i) The fixed weight of each indicator.

(ii) All the indicators of each RIF must have an equal number of states for calculation. The second limitation can easily be understood by looking the equation (1) in section 7.1. Øien (Knut Øien, 2001a) used in his research. These limitations contribute in the non-linearity of RIFs and it makes difficult to understand the behavior of RIFs.

8.2.2 Suggestions for non-linearity improvement of RIFs in ORIM

Some suggestions can be reflected upon to improve this non-linearity problem. Firstly, If the weights of the indicators could change according to the state of the indicators then it might have some influence in RIF's behavior. For that purpose, a fixed weight indicating a fixed state of the indicator can be used. For example, if the state of the indicator is good, the weight will be 0.5 and if the state is poor the weight will be 0.7. In that way, the non-linearity behavior may reduce to some extent. Secondly, if a new equation or quantification approach is developed that can handle different states of indicators for RIF value calculation it might also influence the non-linearity.

8.3 Barrier and Operational Risk Analysis (BORA)

Aven (Aven et al., 2006) have developed this method for the qualitative and quantitative analysis of hydrocarbon release focusing on the organizational factors. The approach of BORA is to combine fault trees, barrier block diagram or event trees and risk influence diagram to analyze the risk associated with hydrocarbon release. The main steps of BORA release are: (1) a risk model development, (2) analysing and modelling the safety barriers, (3) assigning industry average probabilities and calculating risk based on this probabilities, (4) developing risk influence diagrams, (5) scoring of risk influencing factors, (6) weighting of risk influencing factors, (7) changing and adjusting of industry average probabilities/frequencies, and (8) recalculation of the risk related to hydrocarbon release.

In Chapter 6, BORA method has been adopted widely for RIF modeling of hot works specifically for 'ignition'. For this purpose, a barrier block diagram, an event tree, a fault tree and has been used. In addition, 'risk influence diagram' is used in the RIF modeling. Although it has been mentioned as a 'Bayesian network' considering that 'risk influence diagram' is one of the ways to bayesian network representation.

8.3.1 Non-linearity in BORA

In BORA the RIFs related to the basic event of an accident is considered. Further, the RIFs are rated from RIF audit, TTS (Technical condition safety) result and RNNP (Risk level in the Norwegian Petroleum Activity) result. And weigting process is performed according to expert judgment. Some limitations of this method regarding non-linearity are - (i) rating process of RIFs, (ii) Relative weighting of RIF, (iii) ignoring interaction between RIFs.

(i) Rating process of RIFs

Rating process has been done very carefully collecting data from different sources. But there should be some expert judgments too. Experts opinion could give much more knowledge about the behavior of RIFs in the field work and their impact in accidents. This might be a reason of non-linear behavior of RIFs in this method.

(ii) Relative weighting of RIF

In BORA during giving weights to the RIFs, relative weighting is followed. That means to identify the most important RIF in the plant and giving it highest weight (in that case 10). Then the rest RIFs are compared and given weights compared to the most important RIF's weight. This relative weighting can also influence non-linearity as there is a possibility of having more than one RIF of the same importance. For example, if RIF_a and RIF_b has the same importance in the same plant, even then an expert has to assume one as most important and weight the RIFs. This may vary the assessment and give non-linear aspects. Furthermore, it may be the case that, changing the state of one RIF may change the state and weight of other RIF(s). This is also significant in non-linearity.

(iii) Ignoring interaction between RIFs

In BORA, the impact of one RIF on another RIF is ignored. This might hinder the availability of information about RIF(s) and result in non-linear outcomes.

8.3.2 Suggestions for non-linearity improvement of RIFs in BORA

At first, including expert judgments in RIF rating could be a measure for non-linearity in the result. In addition, the sources that have been already used from before, should be included. This may give better rating result. Secondly, relative weighting can be ignored by developing a model for RIF weighting. Each RIF will be scrutinized according to the respective case study and given a weight. This will remove the confusion of selecting the most important RIF. Thirdly, the interaction between RIFs can be examined thoroughly whether there is any impact of one RIF's state change to another.This will give a knowledge of RIFs characteristics.

8.4 Hybrid Causal Logic (HCL)

Røed et al. (Røed et al., 2009) have emphasized on risk analysis methods of operational phase and uses human and organizational factors for analyses. They developed a method termed as ‘hybrid causal logic (HCL)’ which is combined with Bayesian belief networks. This work is basically an extension of BORA method and explaining HC more explicitly. The steps performed in this method are as follows: (1) defining RIFs and causal relationships between the basic event of fault trees, (2) identifying RIFs and distinguish the concurrent ones (3) building a BBN (4) building the conditional probability table (5) assigning one state for each RIF (6) calculating the risk results.

The advantage of this method over BORA is that it included BBN in the analysis and it considers the dependencies between basic events with the help of common causal roots in BBN. During the scoring of RIFs, it took expert evaluation and TTS (Technical condition safety). The weighting of this method is quite improved compared to other methods. It considered the effects of all the parent nodes on the child node. The process is to lock other parent nodes in an average state when one selected parent node has changed its state from best standard to worst standard and then analyze this specific node. For instance, if there are three parent nodes X,Y,Z, and the child node is P, so if the parent node X changes its state from A to F then parent node Y and Z are locked in average state C. Afterward, normalization is used to calculate the final weight.

8.4.1 Non-linearity in HCL

Some key points to mention those may contribute to the non-linearity of RIFS in HCL are:

(i) While scoring the RIFs it disregards other data sources like RNNP, RIF audit those are used in BORA analysis. Only TTS result data and expert opinion are granted. Because of that, it is possible not to get proper information on RIF and its behavior. Thus assessing the RIFs without explicit knowledge and ultimately resulting non-linearity.

(ii) Weighting procedure seems very well explained, but again there is the same problem as in ORIM that it disregards the influence of changing one node’s weights to another nodes’ weights. Rather it just makes constant the weights of other nodes. Locking other nodes’ weight on an average value may not give proper assessment value and cause non-linearity in RIFs.

(iii) Using BBN opens the opportunity to interconnect different RIFs with each other and also it can connect a single RIF to various basic events. But BBN can be varied according to experts while RIF modeling and different opinion can give different results. This may also provide non-linear results.

8.4.2 Suggestions for non-linearity improvement of RIFs in HCL

Firstly, HCL can also include other data sources while scoring RIFs, rather than stick to only TTS and expert evaluation. Secondly, to find out the effect of parent node on the child node, a model can be developed to understand the diversity of parent nodes' states. The model should be able to measure the effects of each parent node independently but not fixing other parent nodes' states. Thirdly, to generate an idea to make a generally standardized structure of BBN that can be used as a model for BBN analyses. Through this way, it might be possible to remove the variation in results from different experts or sources about RIF characteristics.

8.5 Risk modeling- Integration of Organizational, Human and Technical factors (Risk_OMT)

Vinnem et al. (J. Vinnem et al., 2012) tailored a new method to analyze the impact on leak frequencies of manual operations and interventions. Like HCL, this method also includes BBN but only to analyze human error such as slip, mistake, a violation. The human errors are modeled as the basic events of each of the failure. Later on, these human errors are analyzed further and RIFs related to these errors are identified into two levels. Level 1 RIFs represents direct influence on the basic events and level 2 represents the aspects of management that have an influence on level 1 RIFs.

According to Reason (J. Reason, 1990a), *the violation* is defined as "deliberate - but not necessarily reprehensible -deviation from those practices deemed necessary (by designers, managers, and regulatory agencies) to maintain the safe operation of a potentially hazardous system" [Reason, 1990:195]. "*Mistakes* involve actions that are based on the failure of interpretation of procedures, and/or failures of judgmental/inferential processes involved in the prescribed activity"(J. Vinnem et al., 2012)It does not consider whether it happens according to actor's plan or not. Examples of mistakes could intrinsic type such as competence, fatigue etc. and extrinsic type such as communication, information, workload, time pressure etc. Vinnem et al. (2012) also defined slips and lapse as, "*slips and lapses* involve actions that represent unintended deviation from those practiced represented in the formal procedures" In this discussion, slips and lapses mean error execution, unintended violations, failure to interpret prescribed procedures.

In Risk_OMT, interviews and surveys are used for scoring the states of the RIFs. And for weighting of the RIFs only expert opinion is considered. Common cause for the basic events is also considered.

8.5.1 Non-linearity in Risk_OMT

There are a few key notes to mention those might influencing in the non-linearity of RIFs in Risk_OMT model. Those are:

(i) Scoring of the RIFs is done only with the help of interviews and surveys. No other relevant sources, such as those used in BORA or HCL, are used in this method. Of course, the opinion of field workers are very essential, but only interview and survey result may not fulfill proper criteria of RIFs while scoring. This can be a reason of non-linearity criteria of RIFs in this method.

(ii) While giving weights to the RIFs only expert opinion is used whereas in HCL effects of parent nodes are also considered for weight derivation. And it is possible to vary the opinion of several experts. As a result, RIF behavior is not comprehended correctly and assessment may give non-linear outcomes.

8.5.2 Suggestions for non-linearity improvement of RIFs in Risk_OMT

Firstly, the scoring method could be more precise with some quantification analysis like the method used in ORIM can be applied with proper consideration according to the case study. In addition, some data sources as it is used in the BORA method can be added to make the scoring more suitable. Secondly, weighting process could be more generalized and effects of previous nodes should be considered in order to get more reliable data.

In a nutshell, chapter 8 explains non-linearity briefly. Furthermore, it describes how the existing methods deal with it.

Chapter 9

Discussion and Further Work

This chapter summarizes the main objectives of the thesis work and how these objectives are emphasized in different chapters. In addition, the description of analyses, working procedures in different chapters are included.

The *first objective* is to select a work task and go through in details of this work task using task analysis or equivalent method. And look for any relevant failure or risks possibility in the work task.

In the beginning, a comprehensive literature review is presented in chapter 2 mostly related to risk, risk indicators, and human factors. The chapter illustrates past works on major accidental risks, instantaneous risk, the influence of risk indicators in risk assessment of major accidents and a short description of the human factor and human error. Following that, a detail description about Bayesian networks and its function is discussed in chapter 3. Bayesian network is used very widely in this thesis work and some basic notes about this model are summarized in chapter 3.

Hot work has been selected for analysis in this thesis work and details about hot work activities and its steps is discussed in chapter 4. Including that, standards related to hot work activities, how to do that according to HSE Guideline is described explicitly. Afterward, procedures of hot work is discussed. Hot works activities are segmented and step by step description of this operation is documented. Figure 4.1 shows all the steps related to hot works including all key tasks of each step is illustrated. Failure or risk related to this task is discussed simultaneously with the next objective discussion.

The *second objective* is to identify relevant RIFs based on the breakdown of selected work task. And mention possible failure in the steps of work task. Also to specify why the RIFs are selected and why they influence the task performance and probability of error.

Chapter 5 is documented for the discussion of the second objective. At first, this chapter gives a short introduction about RIF and RIF classification. Different authors classified RIFs in a different way. Some classified it in technical, operational and organizational factors, some proposed to categorize it in facilities and equipment, people and management factors. Both classifications mean the RIFs in risk analysis in a similar way. In this thesis work, the second classification is accepted. Then the present procedures to measure RIFs are also included in the description. After that, two approaches of RIFs selection i.e. process-based approach and system-based approach are described. The process-based approach is to break down a task operation step by step and analyze each step. The system-based approach is to analyze an accident scenario in a chosen activity. As our main aim is to analyze the hot work task step by step and identify the RIFs for each step, hence processed-based approach is selected for RIFs identification. Table 5.2 shows the operational steps in hot work and identifies the RIFs relevant to each step. A column in this table shows the error that is assumed to happen in each step which could ultimately lead to the hazardous event (ignition). Following this table of RIFs identification, an explanation of why these RIFs are selected is given for a specific operational step.

The *third objective* is to build a model for work task (in this case hot work).

Chapter 6 is designed to meet this objective. In section 6.1, Two accidents related to hot work is discussed first. One accident was related to welding and another one was related to cutting. Both of them ended up to ignition in the plant and the result was fatalities and environmental loss. From the accident description, it is evident that why ignition is the main interest of analysis in hot works. Afterward, section 6.2 gives some description of RIF modeling i.e. the objectives of RIF modeling, qualitative and quantitative aspects of a few present models from the literature search. In addition, the qualitative and quantitative aspects of the proposed model relevant to hot work accident is attached. Following that, Section 6.2.3 describes the proposed model for ‘ignition in hot work’. The proposed model consists of barrier block diagram (a barrier block diagram can be converted into an event tree and the event tree can be used for quantification process), fault tree analysis of safety barriers failure and BBN diagrams for each of the basic event of barrier failures. Although the BBNs are similar to risk influence diagram from BORA method, but as risk influence diagram is one of the presenting ways of BBN, hence here the term BBN is used instead of risk influence diagram.

The *fourth objective* is to describe potential indicators for measuring the RIFs and the influence of these indicators on the work task.

Several RIFs are identified in chapter 5. But due to time limitation, only a few of them are analyzed thoroughly. Three RIFs are selected for detail analysis. These are Time pressure/ Stress, Training, and Procedure. Because of their frequent presence in the RIF identification

Table 5.2, these three RIFs are selected. Chapter 7 gives a broad idea about each of the RIFs, their indicators and how to score the indicators and RIFs.

A detailed review of each RIF is presented in Chapter 7 from the literature search. What could be their sources, some real life incidents related to each RIF, why they could be regarded as a RIF, why they are regarded in hot work, indicators for RIFs, measuring the score and state of the indicators and RIFs are discussed. For measuring the scores of RIFs, Øien's (Knut Øien, 2001a) approach, using the scores of indicators, is utilized.

The *fifth objective* is to discuss non-linearity and how non-linearity can be modeled. Chapter 8, is utilized for this purpose. This chapter explains what is non-linearity and discusses some existing methods seeking the reason why the existing methods are unable to remove non-linearity. Some suggestions also are given in this regard.

Non-linearity is a common scenario in cause-effect relations. Without clear explanations, non-linearity can direct towards random results. An example of the non-linear relation between performance and stress is discussed with the figure is given in Chapter 8. A linear example is also included to justify the difference between them. The compared method for non-linearity is ORIM, BORA, HCL, and Risk_OMT. Only these methods are selected because they have been included in the previous discussion of Section 6.2.1 and Section 6.2.2.

Strengths

Some key strong points of this thesis work are:

- The proposed model elaborates the barriers and barrier failures for the incident ignition in hot work as it is done in BORA model for HC leak frequency. This represents the barrier deficiencies and the weak areas of the barriers.
- The barrier failures are analyzed further and the basic events for each of the barrier failures are sorted out.
- BBN gives a more detail insight by indicating RIFs for each of the basic events of fault trees found for barrier failures.
- A few selected RIFs are elaborated more thoroughly and indicators of each RIF are marked out and discussed with scoring. This gives the analysis a quantification platform and increases the reliability of the analysis.

- Non-linearity is discussed with examples. Some existing methods which give the non-linear results are suggested for some modifications. With modification, the existing methods are supposed to be used regardless of the non-linearity problem.

Limitations

Some of the limitations of this thesis work are:

- In chapter 6, no interaction between RIFs and basic events is considered. This may limit the analysis scope.
- In chapter 7, in the RIF measurement, the indicators that are used are not always measurable. Some indicators show subjective properties. In this case, only experience expert can give some score to the indicators for the sake of RIF measuring.
- Data unavailability has been very acutely observed throughout the thesis work. As a result, in many cases assumption is the only solution.
- The outcome of this report i.e. the impact of human factors of operational activities is not presented in a standard structured way. It is very important to present it to the users in a way that they can easily perceive the prime point.

Further work

This report discusses the effect of human factors on operational activities. If discusses further some of the RIFs and indicators related to them. However, there are some areas where some further work can be emphasized are:

- In chapter 5, RIFs are identified for the several operational steps in hot work. Table 5.2 shows the RIFs for different errors that can happen and result in the hazardous event (ignition). In this discussion, the focus is on ignition. And all possible errors that can cause ignition are pointed out. Therefore, some future work like assessing some other hazardous event can be considered. This may extract some new errors in hot work.
- In chapter 5, only operational step 8 is emphasized for detail analysis. Other steps should be analyzed to find out some more information.
- In chapter 6, the proposed model has been used only for a qualitative purpose. With proper data, it can be utilized as a quantitative analysis also.

- In chapter 6, in the BBN network of basic events, some separate basic events are utilized. This gives an explicit idea about the RIFs related to each basic event. But the BBN can be much more improvised using the interaction between basic events, interaction between basic events and RIFs, interaction between RIFs. This can be another future work proposal.
- In chapter 7, while measuring the indicators of RIFs there are some indicators which are hard to measure directly with numbers. Expert opinion, interviews, surveys etc. are the possible solutions mentioned in the report. A further work on these subjective RIFs may be arranged to develop a standard method in order to measure them.
- Chapter 8 describes non-linearity in a very limited way. With more knowledge on non-linearity of RIFs, some future work such as how to model the non-linearity of RIFs is another future proposal.

Chapter 10

Conclusion

The prime intentions of this thesis work is to analyze a specific work task, find out the basic steps of the work task and associated failure with each step with the focus of human errors, identify the RIFs relevant with the failures and then develop a risk model, describe some selected RIFs in depth, in the end, examine the term ‘non-linearity’ associated with RIF behavior. With the selection of hot work as the work task and the basic steps of hot work, the report represents a proposed model for hot work accidents, specifically focusing on ‘ignition in hot work’. The proposed model uses barrier block diagram/ event tree, fault tree and BBN for analyses. Barrier failures have been identified in barrier block diagram, barrier failures are analyzed by fault tree tool resulting in some basic events for failure, each of the basic event is analyzed through BBN and some RIFs are spotted out for the basic events. Among these RIFs only three RIFs i.e. ‘time pressure/stress’, ‘training’, ‘procedure’ are selected and further described in details. Four indicators for ‘time pressure/stress’, six indicators for ‘training’ and five indicators for ‘procedure’ are selected and described. With the scoring measurement of indicators, all the RIFs are also measured. The score of the RIFs’ indicates the state of RIFs’. The non-linear behavior of RIFs is explained shortly. Several existing methods such as ORIM, BORA, HCL, Risk_OMT are analyzed under the light of non-linearity and some limitations are sorted out that can cause non-linearity. Among the limitations, weighting procedure of RIFs in different methods is a common one and this contributes significantly in non-linearity of RIFs. The end outcome is the details analysis of RIFs that are very influential in the failure of the selected work task and the non-linear behavior of RIFs not only shows the limitations of models but also gives an urge of improving the existing model in order to cope with this non-linearity model.

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