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BORA AND BN APPLICATIONS FOR BARRIERS SAFETY EVALUATION URGA UNIT CASE STUDY TURBOCOMPRESSOR URGA UNIT

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DEDICATION

To my parents, my sister, my pillar of strength, and to those whom I hold dear, my heartfelt gratitude flows endlessly …

Boutemedjet Hanan

With immense pleasure and infinite joy, I dedicate this modest work to:

My dearest parents who have sacrificed their lives so that I can fulfill their dreams.

My dear brothers: Houssem, Hani, Med Rami.

My dear sister: Chahinez.

My fiancé: Omar.

My entire family.

My dear friends and colleagues from the 2022/2023 class.

Manel Lahiouel

I stumble over words of joy, and my heart fills with gratitude and appreciation for everyone who stood by me and supported me throughout my educational journey. Today, I dedicate my graduation to my happiness and the light of my life, to my mother, father, and all my brothers, sisters, and friends. To my spouse, and to my aunts and uncles who were there for me in every moment.

Krim ryéne

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ACRONYMS

BN: Bayesian network

BORA: Barrier and operational risk analysis

BRD: Brides

DMR: Damrane

ESD: Emergency shut down

GEA : Gassi El adem

GEAN : Gassi El Adem Nord

GT : Gassi Touil

HAZOP: Hazard and operational

HC: Hassi –Chergui

HCN : Hassi Chergui Nord

HP : High pressure

HSE: Health, safety and environment

HTG: Hassi -Touareg

IEC: International Electrotechnical Commission

IOGP: The International Association of Oil & Gas Producers

ISO: International Organization for StandardizationInternation

LP: Low pressure

MP : Averege pressure

NZ : Nezla Sud

NZN: Nezla Nord

PFD: Probability of failure on demand

REK: Rhourde El khelf

RIF: Risk influencing factor

SBM: Safety barrier management

TOU: Toual

WT: Wadi El Theb

ABSTRACT

This thesis focuses on the conversion of results from Barrier and Operational Risk Analysis (BORA) to Bayesian networks for achieving realistic risk analysis, using the case study of Gassi Touil Sonatrach Hassi Messaoud. The research aims to demonstrate how converting BORA to a Bayesian network enhances the accuracy and reliability of risk assessments in the oil and gas industry. By comparing the outcomes of both approaches, the study provides insights into the practicality and effectiveness of utilizing Bayesian networks for realistic risk analysis, thereby assisting decision-makers in improving risk management strategies.

Cette thèse se concentre sur la conversion des résultats de l'Analyse des Risques de Barrière et Opérationnels (BORA) en réseGatesayésiens pour réaliser une analyse des risques réaliste, en utilisant l'étude de cas de Gassi Touil Sonatrach Hassi Messaoud. La recherche vise à démontrer comment la conversion de BORA en un réseau bayésien améliore la précision et la fiabilité des évaluations des risques dans l'industrie pétrolière et gazière. En comparant les résultats des deux approches, l'étude offre des insights sur la praticité et l'efficacité de l'utilisation des réseaux bayésiens pour une analyse réaliste des risques, aidant ainsi les décideurs à améliorer les stratégies de gestion des risques.

تركز هذه الأطروحة على تحويل نتائج تحليل الحاجز والمخاطر التشغيلية (BORA) إلى شبكات بايز لإجراء تحليل واقعي للمخاطر ، باستخدام دراسة الحالة الخاصة بـ Gassi Touil Sonatrach حاسي مسعود. يهدف البحث إلى توضيح كيف يؤدي تحويل BORA إلى شبكة Bayesian إلى تحسين دقة وموثوقية تقييمات المخاطر في صناعة النفط والغاز. من خلال مقارنة نتائج النهجين ، تقدم الدراسة رؤى حول التطبيق العملي وفعالية استخدام شبكات Bayesian لتحليل المخاطر الواقعي ، مما يساعد صانعي القرار على تحسين استراتيجيات إدارة المخاطر.

GENERAL INTRODUCTION

The oil and gas industry operate in a dynamic environment where risks constantly escalate due to the rapid evolution of equipment and technology. As these advancements present new challenges, it becomes crucial to identify, assess, and manage risks effectively to ensure the safety, reliability, and profitability of operations. Risk analysis methods play a pivotal role in predicting potential risks and providing valuable insights for decision-making and preventive measures.

In the field of risk analysis, various methodologies have been developed to assess and manage risks in different industries. These methods provide structured approaches to identify, analyze, and mitigate potential risks. In the context of the oil and gas industry, several commonly used risk analysis methods have proven effective in understanding and addressing the challenges faced by this sector such as: Barrier and operational risk analysis and Bayesian network.

Barrier analysis is a proactive approach that involves identifying and evaluating preventive measures and safeguards in place to prevent incidents and accidents. Operational risk analysis, on the other hand, deals with assessing the potential risks associated with day-to-day operational activities. By combining these two approaches, we can gain a comprehensive understanding of the risks prevalent in the industry

In the other hand one of the most promising methodologies for risk analysis is the application of BN. Bayesian networks provide a powerful framework for modeling and analyzing complex systems, incorporating probabilistic dependencies between various factors. By utilizing Bayesian networks, we can enhance our understanding of the relationships between barriers, operational activities, and potential risks in the oil and gas industry.

Previous studies have employed diverse methodologies to analyze risks in the oil and gas industry. (BOUTELIS, 2015) conducted a BORA study in an oil and gas industry. (Medkour, 2017) transformed a fault tree study into a Bayesian network.

The primary objective of this thesis is to investigate the feasibility and effectiveness of converting barrier and operational risk analysis into a Bayesian network. By developing such a model, we aim to improve risk assessment and decision-making processes in the industry. This research will contribute to the existing body of knowledge by bridging the gap between traditional risk analysis methods and the utilization of Bayesian networks.

To accomplish our goal, we will address the following research questions:

- What are the key elements of the application barrier and operational risk analysis in the oil and gas industry?
- How can Bayesian networks be applied to convert barrier and operational risk analysis?
- How does the converted Bayesian network model contribute to improved risk prediction and decision-making?

To explore these questions, we will conduct a thorough literature review, analyze real-world case studies, and propose a practical methodology for converting barrier and operational risk analysis to a Bayesian network model. To achieve this goal, the thesis is divided into four distinct chapters, each serving a specific purpose in the overall research endeavor.

Chapter 1 provides an introduction to safety barriers and general concepts that will face us in the next chapters.

The subsequent chapters delve into the various aspects of the research topic, building upon the foundation established in Chapter 1. Chapter 2 focuses on risk analysis methodologies and more specifically BORA and BN.

Chapter 3 provides an in-depth description of the region description in our case GASSI TOUIL region.

Chapter 4 presents the presentation of turbocompressor system and the application of BORA and BN on our system and results and analysis derived from the collected data.

Chapter01

GENERAL CONCEPTS OF SAFETY BARRIERS AND RISK ASSESSMENT

CHAPTER 01: GENERAL CONCEPTS OF SAFETY BARRIERS AND RISK ASSESSMENT

Introduction

The increasing complexity and interconnectivity of industrial processes have led to a higher risk of accidents and incidents, which can have severe consequences for human life, the environment, and the economy. One approach to mitigate these risks is to use safety barriers, which are physical or non-physical devices or measures designed to prevent or control the occurrence or consequences of unwanted events. This chapter provides an overview of the general concepts and definitions related to safety barriers, including their classification, performance criteria, and functions.

1.1. General concepts of industrial safety

1.1.1. Concept of safety

According to the Cambridge dictionary, safety can be defined as a condition or location where one is secure and not exposed to danger or risk.

As documented by the ISO/IEC 73 guide developed by ISO on the terminology of risk management, safety is defined as the state in which the absence of unacceptable risk, injury, or harm to the health of individuals, either directly or indirectly, results from damage to equipment or the environment. This definition highlights the importance of identifying and assessing risks in order to prevent harm to individuals and the environment, and to ensure a safe and healthy workplace. By adhering to this definition of safety, organizations can effectively manage risks and ensure the well-being of their employees, customers, and the wider community.

1.1.2. Concept of danger

Danger can be defined as a latent hazard capable of causing harm to individuals, property (through damage or destruction), or the environment. The impact of danger can be direct, causing physical injury or health problems to individuals, or indirect, resulting in damage to property or the environment as stated by IEC 61508.

In the OHSAS 18001 framework, danger is defined as a source or situation that can lead to injury, harm to health, damage to property, or harm to the environment in the workplace, or a combination of these factors.

It is worth noting that different standards or authors use varying terminologies to describe the concept of danger, leading to possible ambiguities. Additionally, dictionaries often conflate danger with risk, treating them as interchangeable synonyms. This lack of consistency in the use of terminology can create confusion, even in official documents and texts.

To ensure precise communication and accurate assessments when evaluating the criticality of industrial risks, it is essential to clarify and consistently employ the terminology associated with danger and risk.

1.1.3. Concept of risk

According to ISO 45001 Risk can be defined as “combination of the likelihood of occurrence of a work-related hazardous event or exposure(s) and the severity of injury and ill health that can be caused by the event or exposures”.

The combination of the likelihood of occurrence of work-related hazardous events or exposures and the severity of injury and illness that can result from them is a crucial aspect of risk management.

The likelihood of occurrence pertains to the probability that a particular hazardous event or exposure will happen. This factor must be evaluated to determine the frequency and severity of the exposure or event. On the other hand, the severity of injury and illness caused by the event or exposure refers to the potential harm or damage that could result from an incident. Health and safety professionals consider various factors such as the type of injury or illness, the extent of damage, and the long-term effects on the worker's health to evaluate this factor.

In conclusion, the combination of the likelihood of occurrence of work-related hazardous events or exposures and the severity of injury and illness that can result from them is a critical aspect of risk management. This approach aids in identifying and prioritizing risks effectively, enabling the implementation of appropriate measures to mitigate or eliminate the risks that have been identified. Health and safety professionals must consider both the likelihood of occurrence and the severity of injury and illness in evaluating and managing risks in the workplace.

1.1.4. Concept of accident

An accident refers to an unfortunate occurrence resulting from an unexpected and undesired event.

This can result in not only loss of life and injury but also other significant losses such as mission, material, financial and informational. These losses can occur due to a variety of reasons including component failures, external disturbances, interactions between system components, and individual behaviors of system components leading to hazardous system states. (Leveson, 2011)

In recent years, the oil and gas industry has witnessed several major accidents, resulting in loss of life, environmental damage, and financial losses. Some of the most notable incidents are mentioned in the table below:

Table 1.1 : A collection of the most significant oil and gas accidents that have occurred worldwide in the past 10 years, as reported by IOGP

Accident	Location	Date	Description of the accident
Deepwater Horizon Oil Spill	Gulf of Mexico	April 20, 2010	The Deepwater Horizon oil rig exploded, killing 11 people and causing a massive oil spill in the Gulf of Mexico. It is considered one of the worst environmental disasters in US history.
Lac-Mégantic Train Derailment and Explosion	Quebec, Canada	July 6, 2013	A train carrying crude oil derailed and exploded in the town of Lac-Mégantic, causing multiple fatalities and significant damage to the surrounding area.
East China Sea Oil Spill	East China Sea	January 6, 2018	An oil tanker collided with a cargo ship in the East China Sea, causing a massive oil spill and resulting in the deaths of all 32 crew members aboard the tanker

TPC Group Port Neches Explosion	Texas, USA	November 27, 2019	A massive explosion occurred at a chemical plant in Port Neches, Texas, resulting in three injuries and causing significant damage to nearby homes and buildings.

1.2. Risk assessment

1.2.1. Definition of risk assessment

Risk assessment is the process of recognizing and rating risks to determine significant risks that may impact an organization, project, or strategy. It involves risk identification, analysis, and evaluation, and serves as the starting point for the risk management process. The purpose of risk assessment is to identify significant risks that could affect corporate objectives, stakeholder expectations, core processes, and key dependencies. The assessment can be done at the inherent or current (residual) level, but it is only useful if the results are used to inform decisions and identify appropriate risk responses. (Hopkin, 2017)

1.2.2. Risk assessment process

In the realm of risk analysis or assessment, a commonly employed method comprises three integral stages: hazard identification, determination of the scale or severity of prospective damages, and, lastly, appraisal of its suitability (Kringen, 2008).

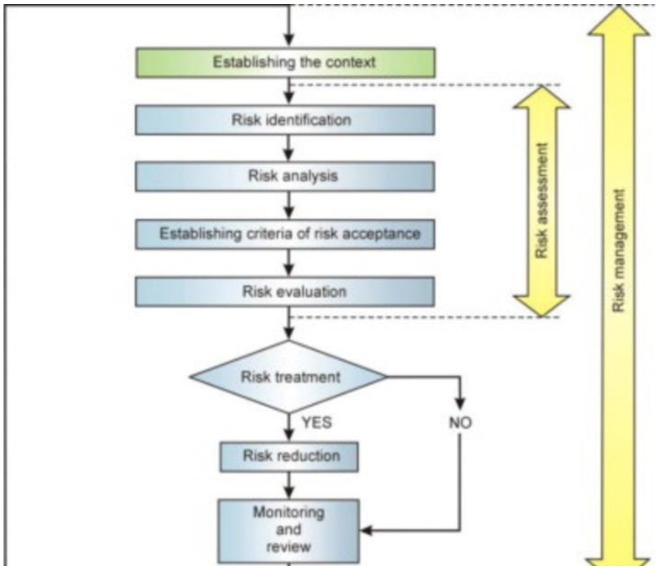


Figure 1.1: Contribution of risk assessment to the risk management process. Based on ISO/IEC 31010 (2010) and PN-N-18002 (2011)

1.3. Safety Barrier Concept

1.3.1. Safety barrier Definition

The concept of safety barriers has been the subject of extensive research and development in the field of accident prevention, with various models and definitions emerging over time. The energy-flow model, first proposed by Gibson in 1961, is one of the earliest models that focused on the exposure of vulnerable objects to harmful energy due to the absence of proper barriers between the impacted target and the source of the energy.

Another model that has gained widespread acceptance in the field of safety barriers is the Swiss cheese model, which was introduced by (Reason, 1997). This model presents a visual representation of the weak points in all barriers as Swiss cheese holes, with accidents occurring when these holes align and allow the harmful energy to reach the vulnerable object. To prevent such accidents from occurring, it is important to establish a consistent Safety Barrier Management (SBM) during the operational phase to keep the holes as small as possible.

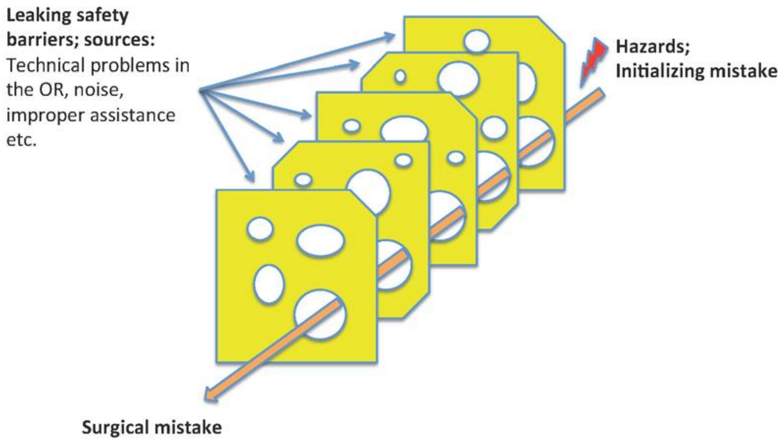


Figure 1.2: The Swiss cheese model of how defences, barriers, and safeguards may be penetrated by an accident trajectory (adapted from James Reason, 2000).

Sklet defines it as "a physical and/or non-physical means planned to prevent, control, or mitigate undesired events or accidents." To overcome such ambiguity, the term "barrier" can be divided into three different terms, namely barrier function, barrier system, and barrier element.

The term "barrier function" refers to the planned function designed to prevent, control, or mitigate undesired or accidental events, while the term "barrier system" is a system designed and implemented to perform one or more barrier functions. In contrast, "barrier element" is a technical, operational, or organizational component in a barrier system.

Furthermore, it is important to define the term "barrier element" in terms of technical, operational, and organizational components. Technical barrier elements include engineered systems, structures, or other design features that realize one or several barrier functions. Operational barrier elements refer to tasks performed by operators or teams of operators that realize one or several barrier functions. Lastly, organizational barrier elements refer to personnel responsible for and directly involved in realizing one or several barrier functions.

In addition, the reliability of a barrier system is influenced by various factors known as performance or risk influencing factors (PIFs or RIFs), which can impact the probability of success or failure of a barrier element. Such factors include competence, work environment, supervision, and others. Although RIFs are not considered as part of the barrier element itself, they can significantly impact its performance.

In summary, safety barriers are measures or sets of measures planned to prevent, control, or mitigate undesired or accidental events. These measures can be divided into barrier function, barrier system, and barrier element, each having technical, operational, and organizational components. The reliability of a barrier system is influenced by various factors known as performance or risk influencing factors (PIFs or RIFs), which underscores the importance of identifying and understanding different terms and their definitions before conducting a barrier analysis.

1.3.2. Safety barriers classification (Sklet, 2006)

In the field of safety engineering, safety barriers play an important role in preventing and mitigating hazardous events. There are various ways to classify safety barriers, including based on their function, system, or nature.

If we consider classification based on barrier functions, safety barriers can be classified as:

- Proactive barrier functions;
- Reactive barrier functions.

Proactive barriers aim to prevent or reduce the probability of hazardous events, while mitigation barriers aim to reduce the consequences of such events. Another classification method of barrier function is according to the accident sequence, as defined in the ISO 13702 standard, which classifies barrier functions as prevention, control, and mitigation barriers.

Safety barrier systems can also be classified as:

- Physical barriers;
- Non-physical barriers.

Physical barriers refer to technical systems, while non-physical barriers involve both human and organizational factors and operational barrier elements. However, this classification may lead to confusion when it comes to barrier analyses. Therefore, it is more precise to classify safety systems as active and passive systems, as defined by (Rausand, 2014). Active systems are dependent on the actions of an operator, a control system, and/or some energy sources to perform their functions, while passive systems are integrated into the design of the workplace and do not require any human actions, energy source, or information sources to perform their function.

Furthermore, safety barriers can be classified by their level in the barrier hierarchy, which includes operational barrier elements and their associated Risk-Increasing Factors (RIFs). In this way, safety barriers can be identified and analyzed at different levels of the hierarchy.

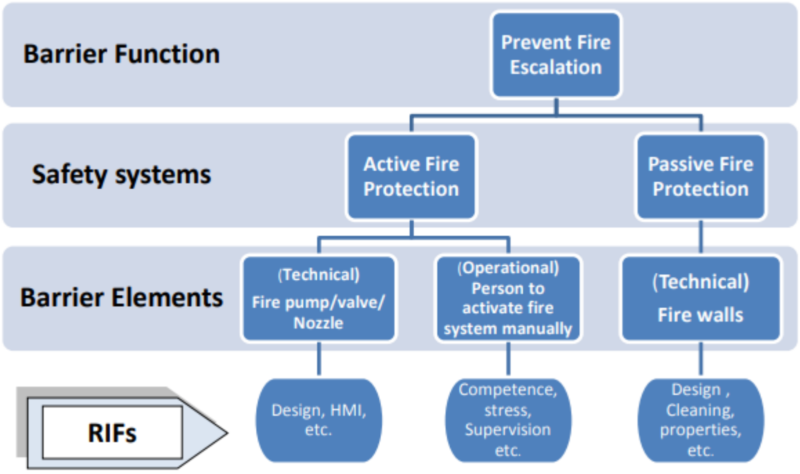


Figure1.3: Hierarchy of barrier levels including RIFs *(Sklet, 2006)*

Finally, barriers can also be classified by their nature, including material barriers, functional barriers, symbolic barriers, and incorporeal barriers, according to (Hollnagel, 2004).

1.4. Performance criteria for safety barriers

Different factors can influence the effectiveness of safety barriers. As mentioned by Sklet (2006); five characteristics that represent the performance criteria of safety barriers: functionality, reliability, response time, robustness, and triggering event or condition.

Functionality refers to the ability of a safety barrier to perform a specified function under given technical, environmental, and operational conditions. This means that safety barriers must be designed to effectively mitigate the risks associated with a specific hazard, while considering the context in which they will be used. For example, a safety barrier designed for an offshore oil platform may have different functionality requirements compared to a barrier used in a chemical plant.

Reliability, on the other hand, is the ability of a safety barrier to perform its function with an actual functionality and response time when needed, or on demand. Reliability is a crucial aspect of safety barriers, as any failure to perform their intended function could lead to catastrophic consequences. Therefore, safety barriers must be designed and maintained to a high level of reliability to ensure their effectiveness.

Response time is another important performance criterion for safety barriers, as it measures the time it takes for a safety barrier to activate and perform its intended function after a deviation occurs. The response time of a safety barrier must be fast enough to effectively mitigate the risks associated with the hazard in question. For example, in the case of a fire, the response time of a safety barrier must be fast enough to prevent the spread of flames and minimize damage.

Robustness refers to the ability of a safety barrier to resist given accident loads and function as specified during accident sequences. Safety barriers must be designed and tested to withstand extreme conditions and loads, such as those caused by explosions, fires, or natural disasters. Robustness is particularly important in high-risk industries, where the consequences of a barrier failure could be severe.

Finally, the triggering event or condition is the event or condition that triggers the activation of a safety barrier. Safety barriers must be designed to detect the triggering event or condition reliably and activate automatically to perform their intended function. For example, in the case of a gas leak, a safety barrier may be designed to automatically shut down the affected area and prevent further release of gas.

Overall, the performance criteria for safety barriers play a crucial role in ensuring the safety of people and the environment in high-risk industries. By considering factors such as functionality, reliability, response time, robustness, and triggering event or condition, safety professionals can design and maintain effective safety barriers that can withstand extreme conditions and prevent catastrophic consequences.

Other studies considered more criteria such as the case of "Assessing the Performance of Safety Barriers: A Comprehensive Methodology" by Sauni and al. (2019). In this study, the authors developed a comprehensive methodology for assessing the performance of safety barriers based on a set of performance criteria.

The authors identified 12 performance criteria for safety barriers, including functionality, reliability, response time, robustness, and triggering event or condition, as well as additional criteria such as cost-effectiveness, maintainability, and human factors.

this research highlights the importance of considering multiple performance criteria when evaluating the effectiveness of safety barriers.

Conclusion

The chapter on generalities on safety barriers introduces the concept of safety barriers and barrier systems, and provides a classification of safety barriers. It also outlines the performance criteria for safety barriers, including effectiveness, reliability, response time, robustness, and triggering event or condition. The importance of safety barriers in ensuring the safety of systems is emphasized throughout the chapter. Overall, this chapter provides a comprehensive overview of safety barriers and their critical role in preventing accidents and mitigating their consequences.

Chapter 02

RISK ANALYSIS METHODOLOGIES

CHAPTER 02: RISK ANALYSIS METHODOLOGIES

Introduction

Safety and risk management practices have become paramount in the ever-evolving oil and gas industry. With operational hazards and potential risks associated with hydrocarbon exploration, production, and transportation, innovative methodologies are needed to prevent accidents and reduce the risk of hydrocarbon releases. This chapter tackles two such methodologies that have emerged in recent years is the Barrier and Operational Risk Analysis (BORA) and Bayesian network (BN).

2.1. Barrier and operational risk analysis

2.1.1. Main elements in the risk model (Seljelid, 2007)

The BORA handbook presents a novel risk model that aims to evaluate the risk factors associated with a specific platform in a comprehensive and customized manner. Unlike traditional risk models that rely on industry-wide averages, this model considers the unique conditions and risk factors that are specific to each platform. By using risk influence diagrams, the model prioritizes and weighs each risk factor according to its relative importance. The model then adjusts the industry averages by platform-specific data to accurately reflect the probabilities of each risk factor occurring. Furthermore, the model introduces a scoring system that assigns a numerical value to the status of each risk factor, enabling the computation of the Qi values used in the risk calculation. This model provides a cutting-edge and tailored approach to risk assessment that is highly effective in identifying, prioritizing, and mitigating platform-specific risks.

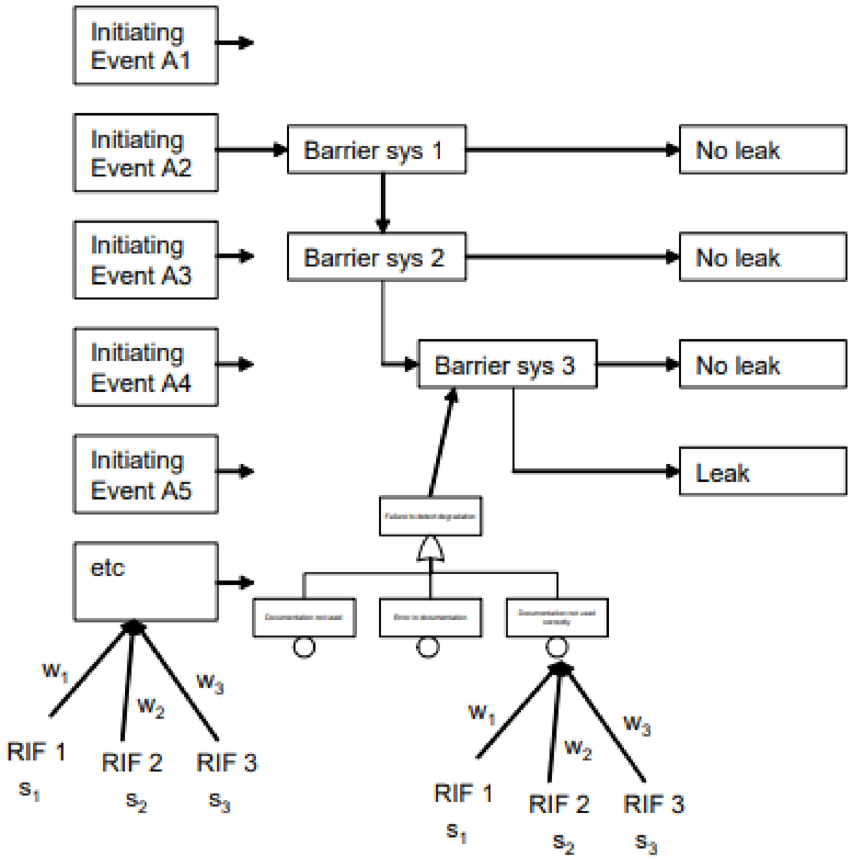


Figure 2.1: Illustration of the generic risk model *(Seljelid, 2007)*

2.1.2. Bora definition

The Barrier and Operational Risk Analysis (BORA) methodology is a comprehensive risk assessment tool designed to evaluate the safety and reliability of complex systems in various industries. Developed by Norwegian experts in the field of risk and safety engineering, the BORA methodology has become a widely used technique for assessing the safety and risk of oil and gas facilities, process industries, and other high-risk systems. (Terje Aven, 2006)

The BORA methodology is based on a combination of quantitative and qualitative risk analysis techniques, including event tree analysis, fault tree analysis, and bow-tie analysis. It emphasizes the importance of identifying and analyzing the barriers and safeguards that prevent or mitigate the consequences of hazardous events, as well as the importance of understanding the interrelationships between different parts of a complex system, it consists of several key steps, including system identification, identification of initiating events, barrier identification, modeling of barrier performance, assignment of generic event frequencies and probabilities, identification of risk influencing factors, and risk calculation. Each step is designed to systematically identify and analyze the various components of a system and their potential risks and vulnerabilities, and to develop a comprehensive understanding of the system's safety and reliability. (Seljelid, 2007)

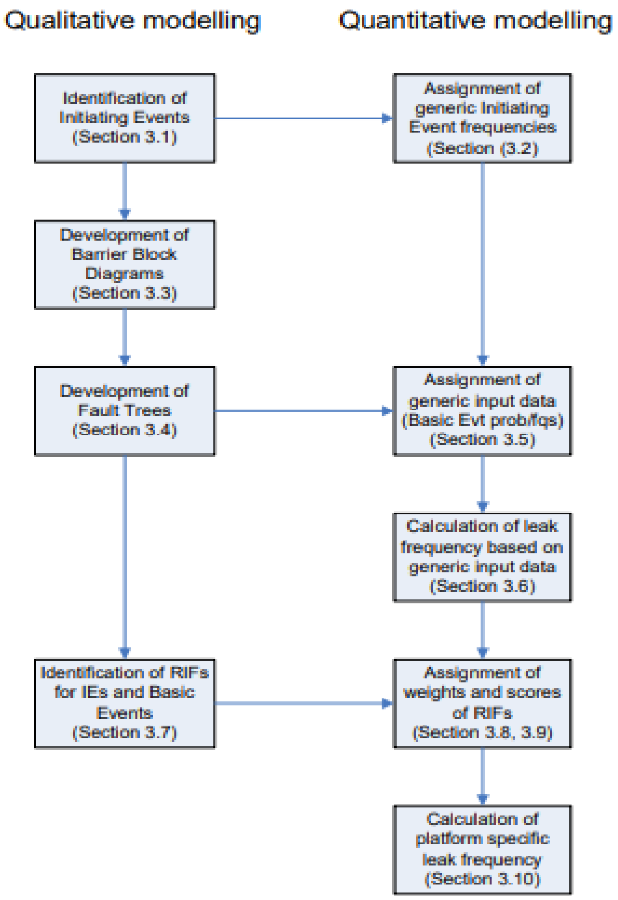


Figure 2.2: Overview on the main steps of BORA methodology *(Seljelid, 2007)*

Keeping in mind that it is based on a set of guiding principles and assumptions, including the importance of a system perspective, the need to consider both technical and organizational factors, and the need to incorporate expert judgment and experience into the risk analysis process. It is a flexible and adaptable approach that can be tailored to the specific needs and requirements of different industries and systems.

2.1.3. BORA evolution overview (Terje Aven, 2006)

BORA methodology has evolved over the years to become an important risk analysis tool in the oil and gas industry. The BORA methodology was first developed by the Norwegian oil and gas industry in the 1990s as a response to the Piper Alpha disaster, which highlighted the need for a more comprehensive risk assessment approach. The methodology was designed to be flexible, transparent, and adaptable to different types of facilities and industries.

The development of BORA can be traced back to the early 1990s when Norwegian safety experts, led by Jan Erik Vinnem, initiated a research project aimed at developing a new and improved method for risk assessment. The project focused on identifying the key elements of safety management and developing a comprehensive approach to risk assessment that considered both technical and organizational factors.

2.1.4. BORA main steps (Seljelid, 2007)

a. System Identification:

The first step in the BORA methodology involves identifying the system being analyzed. This includes all equipment, processes, and procedures that are involved in the operation of the system. This step is critical to ensure that all aspects of the system are considered when conducting the risk assessment.

b. Identification of Initiator Events Related to Tasks

In this step, the focus is on identifying all possible events that could initiate a hazardous scenario in the system. This involves looking at the tasks involved in operating the system, and considering all potential failures that could occur during these tasks. This step is crucial in ensuring that all potential hazards are identified and evaluated.

c. Assignment of Generic Frequencies for Each Initiator Event

Once all potential initiator events have been identified, the next step is to assign generic frequencies to each event. This involves using historical data and industry standards to estimate the likelihood of each event occurring. These frequencies are used to calculate the overall risk associated with the system.

d. Identification of Barriers and Development of Barrier Block Diagram

In this step, the focus is on identifying all barriers that exist in the system that could prevent or mitigate the consequences of a hazardous scenario. This involves developing a barrier block diagram that visually represents the barriers and their relationship to each other. This step is crucial in understanding the effectiveness of the barriers in place and identifying any gaps that need to be addressed.

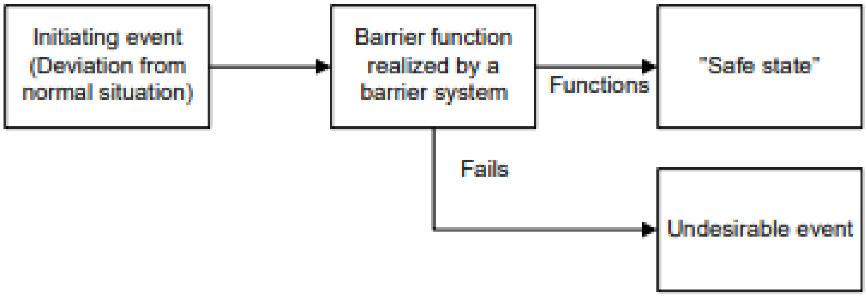


Figure 2.3: Illustration of block diagram

e. Modeling of Safety Barrier Performance

After the barriers have been identified, the next step is to model their performance. This involves assessing the effectiveness of each barrier in preventing or mitigating the consequences of a hazardous scenario. This step is critical in understanding the overall risk reduction provided by the barriers and identifying any areas that require improvement.

f. Assignment of Generic Base Event Probabilities

In this step, the focus is on assigning generic probabilities to the base events that could occur within the system. These probabilities are used to calculate the overall risk associated with the system.

g. Calculation of the Frequency of the Undesirable Consequence Based on Generic Base Event Probabilities

Once the generic base event probabilities have been assigned, the next step is to calculate the frequency of the undesirable consequence. This involves using industry standards and historical data to estimate the likelihood of the consequence occurring.

$$F_{GL\,IEi} = F_{IEi} . P_{f.BS1} . P_{f.BS2} . P_{f.BS1} \qquad (I)$$

Where:

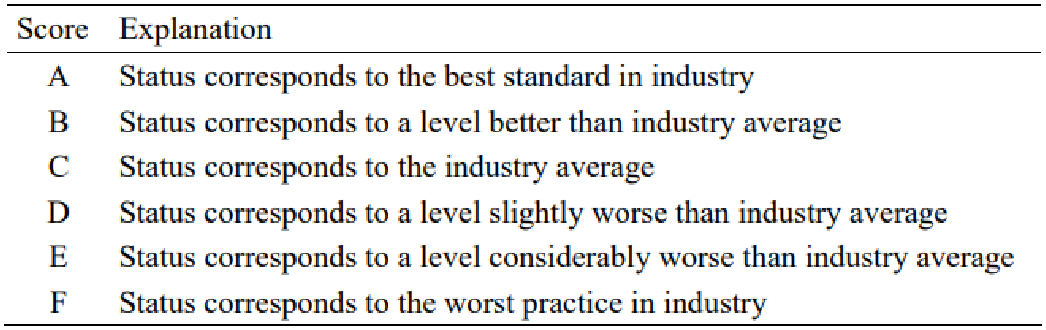
F_{IEi} : $frequency\ of\ initiating\ event\ i$

$P_{f.BS1} = Probability\ of\ failure\ of\ barrier\ system\ i$

h. Identification of Risk Influencing Factors (RIF)

In this step, the focus is on identifying any risk influencing factors that could impact the frequency of the undesirable consequence. This involves looking at factors such as human error, environmental conditions, and equipment reliability. This step is critical in understanding the overall risk associated with the system.

Table 2.1: Generic scheme for scoring of RIFs



Score	Explanation
A	Status corresponds to the best standard in industry
B	Status corresponds to a level better than industry average
C	Status corresponds to the industry average
D	Status corresponds to a level slightly worse than industry average
E	Status corresponds to a level considerably worse than industry average
F	Status corresponds to the worst practice in industry

i. Assignment of RIF Weights and Scores

Once the risk influencing factors have been identified, the next step is to assign weights and scores to each factor. This involves using industry standards and expert judgment to determine the relative importance of each factor. These weights and scores are used to calculate the overall risk associated with the system.

j. Re-adjustment (Correction) of Probabilities and Average Frequencies

After the weights and scores have been assigned, the next step is to re-adjust the probabilities and average frequencies based on the risk influencing factors. This involves using mathematical models to adjust the probabilities and frequencies and to calculate the overall risk associated with the system.

The probabilities or frequencies that are typically used in quantitative analysis within the industry are modified to assign values that are specific to the platform being analyzed.

This is done to account for the unique conditions and risk factors that are specific to the platform. The original probabilities or frequencies are adjusted based on the weights and scores assigned to the platform's risk influence diagrams.

The adjustment process follows the principle that the probability or frequency of an event occurring on a specific platform, denoted as $P_{rev}(A)$, should be based on installation-specific factors. The value of $P_{rev}(A)$ is determined through a specific procedure:

$$\boldsymbol{Prev(A) = Pave(A).Ki} \qquad \text{(II)}$$

Where:

$$\boldsymbol{Ki = \sum_{i=1}^{n} Wi.Qi} \qquad \text{(III)}$$

The probability of an event A occurring within the industry, represented as $P_{ave}(A)$, is assigned a specific value. This value is determined based on the weight or importance of each risk influence factor (RIF) associated with event A, denoted as wi, and a measure of the status of each RIF, represented as Qi. The total number of RIFs considered in this analysis is denoted as n.

$$\boldsymbol{\sum_{i=1}^{n} Wi = 1} \qquad \text{(IV)}$$

The values for Wi are obtained through the process of assigning weights. To determine the Qi values, each status score (A-F) is associated with a numerical value.

The Qi values are calculated according to the following steps:

- An expert judgement is used to determine the lower limit ($P_{low}(A)$) and the upper limit ($P_{high}(A)$) for the probability or frequency of event A occurring on the platform being analyzed.
- For each RIF (i=1,2,...n), the following calculation is performed:

$$Qi\ (s) = \begin{cases} Plow/Pave\ \ if\ s = A \\ 1\ ifs = C \\ Phigh/Pave\ if\ s = F \end{cases}$$

where **s** indicated the score or status of RIF no i.

To determine the Qi values for RIFs with a score of B, we use a linear relationship between the Qi values for RIFs with scores A and C. We assign numerical values to each status score (A-F) as follows SA = 1, SB = 2, SC= 3, SD = 4, SE = 5, et SF = 6.

Based on these values, we can calculate the Qi value for RIFs with a score of B's using the following formula:

$$\boldsymbol{Qi = \frac{Plow}{Pave} + \frac{(SB - SA).(1 - \frac{Plow}{Pave})}{SC - SA}} \qquad \text{(V)}$$

To determine the Qi values for RIFs with a score of D and E, we use a comparable linear relationship between the Qi values for RIFs with scores C and F. We apply suitable coefficients and scores for each RIF in the calculation.

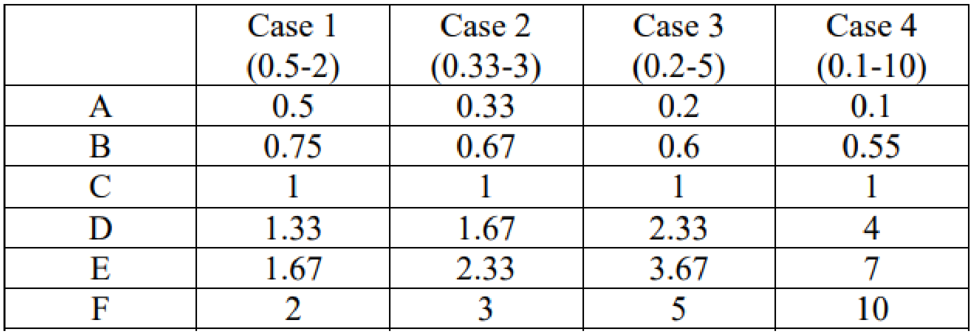
$$\boldsymbol{Qi = 1 + \frac{(SD - SC).(\frac{Phigh}{Pave} - 1)}{SF - SC}} \qquad \text{(VI)}$$

To calculate the Qi values for RIFs with a score of E, we utilize a comparable linear relationship between the Qi values for RIFs with scores C and F. We apply the relevant coefficients and scores for each RIF in the computation.

$$\boldsymbol{Qi = 1 + \frac{(SE - SC).(\frac{Phigh}{Pave} - 1)}{SF - SC}} \qquad \text{(VII)}$$

- **Case 1**: $P_{low}(A)/P_{ave}(A) = 0,5$ and $P_{high}(A)/P_{ave}(A) = 2$;
- **Case 2**: $P_{low}(A)/P_{ave}(A) = 0,33$ and $P_{high}(A)/P_{ave}(A) = 3$;
- **Case 3**: $P_{low}(A)/P_{ave}(A) = 0,2$ and $P_{high}(A)/P_{ave}(A) = 5$;
- **Case 4**: $P_{low}(A)/P_{ave}(A) = 0,1$ and $P_{high}(A)/P_{ave}(A) = 10$.
-

Table 2.2: Qi combination of selected P_{low} and P_{high}



	Case 1 (0.5-2)	Case 2 (0.33-3)	Case 3 (0.2-5)	Case 4 (0.1-10)
A	0.5	0.33	0.2	0.1
B	0.75	0.67	0.6	0.55
C	1	1	1	1
D	1.33	1.67	2.33	4
E	1.67	2.33	3.67	7
F	2	3	5	10

g. Recalculation of Risk

Once all of the above steps have been completed, the final step is to recalculate the overall risk associated with the system. This involves combining all of the data and calculations from the previous steps to obtain a comprehensive understanding of the risk associated with the system.

In conclusion, the BORA methodology is a comprehensive risk analysis tool used to identify and evaluate the risks associated with complex systems. Each step in the methodology is critical in ensuring that all potential hazards are identified.

2.2. Bayesian network

2.2.1. Definition of Bayesian networks

Bayesian networks are graphical models that represent the probabilistic relationships among a set of variables. They have become a popular tool for representing and manipulating knowledge in an expert system. They are often used due to their advantages. Bayesian networks also allow the incorporation of prior knowledge, as they are versatile, meaning the same model can be used for evaluation, prediction, diagnosis, or decision optimization. This helps to make the effort of constructing the Bayesian network cost-effective. (NAOUAR, 2007).

2.2.2. Bayes' Theorem

Thomas Bayes (1702-1761), born in London, England, developed a theorem that is based on the propagation of information within a network, specifically the calculation of posterior probabilities of certain variables based on a number of observations on other variables.

$$P(B\backslash A)=\frac{P(A\backslash B).P(B)}{P(A)} \qquad \text{(VI)}$$

By its symmetry, it allows for reasoning in both directions, calculating the probability of B given A, but also of A given B. In one direction, we seek to explain a cause, while in the other, we quantify a consequence .(Embarki, 2012)

Bayes' theorem is based on conditional probabilities, which state the probability of event B occurring given that event A has already occurred. It is denoted as P(B|A) or PA(B), and read as "the probability of B happening given that A has occurred."

Conditional probability is therefore about finding the probability of a second event when we already know that a first event has occurred.

The formula for calculating conditional probability is:

$$P(B\backslash A) = \frac{P(B\cap A)}{P(A)} \qquad \text{(VII)}$$

Where P(B∩A) represents the probability of the intersection of the two events. Additionally, it is necessary for P(A) to be between 0 and (P. Naim, 2004)

2.2.3. Formal Definition

Bayesian networks are among the models of probabilistic analysis. They provide a mathematical formalism and solid theoretical foundations for modeling complex systems. (MRAD, 2015)

A Bayesian network B = (G, P) is defined by:

1. a directed acyclic graph G = (X, E) where X is the set of nodes and E is the set of arcs,

2. a probability space (**Ω**, P),

3. a set of random variables X = {X1,...,Xn} associated with the nodes of the graph and defined on (**Ω**, P).

It consists of two essential components:

1. A graphical component consisting of a directed acyclic graph: The nodes represent relevant variables in the domain, and the arcs represent the dependency relationships between the variables.

2. A numerical component consisting of a set of conditional probability distributions for each node in the context of its parents. (MRAD, 2015)

Bayesian networks describe the distribution of probabilities associated with a set of variables, some of which are directly dependent on others, while others are conditionally independent.

In summary, a Bayesian network is a directed acyclic graph where the nodes represent variables associated with conditional probability tables (CPT). (Embarki, 2012)

2.2.4. Causality Graph (Patrick Naïm, 2008)

The most intuitive graphical representation of the influence of an event, a fact, or a variable on another is probably to connect the cause to the effect with a directed arrow.

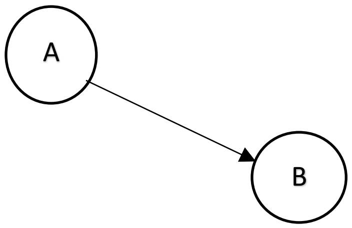


Figure 2.4: Causality Graph

Assuming that A and B are events that can be observed or not, true or false. From a common-sense perspective, the graph above can be interpreted as follows: "The knowledge I have of A determines the knowledge I have of B".

The causal relationship is represented by the logical implication A→B. This relationship means that if A is true, B is also true. If A is false, B can be true or false.

Table 4 represents the possible configurations of A and B in the case where the causal relationship A→B is true. From a logical standpoint, it simply represents the contrapositive of A→B. From a causal perspective, it demonstrates that a relationship exists.

The causal relationship, being directed, is reversible from the effect to the cause, even if it is only partially reversible.

Table 2.3: Logical implication

A	B
True	True
False	True
False	False

If there exists a causal relationship from A to B, any information about A can modify my knowledge of B, and conversely, any information about B can modify my knowledge of A.

With the graphical representation of causality, we can determine the direction of knowledge flow in the graph, but we cannot determine the quantity of this knowledge flow. Therefore, a probabilistic representation associated with the graph is necessary.

With a causal relationship A→B, we can represent the quantity of this relationship by the conditional probability: p(B|A). (Patrick Naïm, 2008)

2.2.5. Structure of a Bayesian Network

The structure of a Bayesian network is a graph in which the nodes represent random variables, and the edges connect these nodes, which are associated with conditional probabilities.

The graph is acyclic, meaning it does not contain loops. The edges represent relationships between variables that are either deterministic or probabilistic. Thus, observing one or more causes does not necessarily lead to the effect or effects that depend on them, but only changes the probability of observing them.

The structure is defined by experts, and the probability tables are calculated from experimental data. It is possible to use algorithms, such as simulated annealing or certain genetic algorithms, to construct the network. (EUSTACHE, 2007)

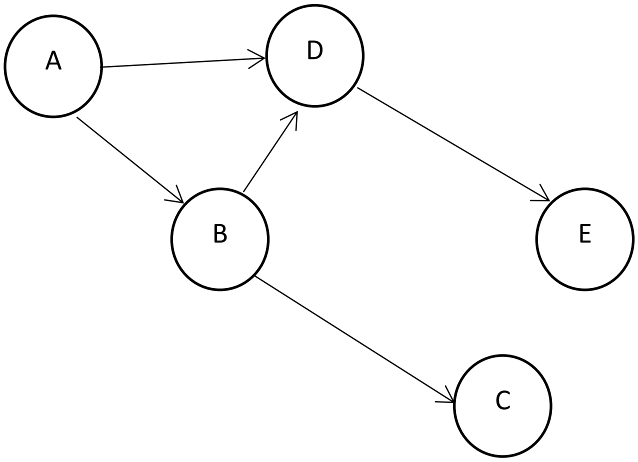


Figure 2.5: Structure of a Bayesian network with five variables

2.2.6. Construction of Bayesian Networks

The construction of a Bayesian network involves three essential steps, which are presented in the following figure (Figure 08). Each of the three steps may involve gathering expertise through written questionnaires, individual interviews, or brainstorming sessions. Advocating for either of these approaches in a general context would be at least risky. (Naim P., 2004)

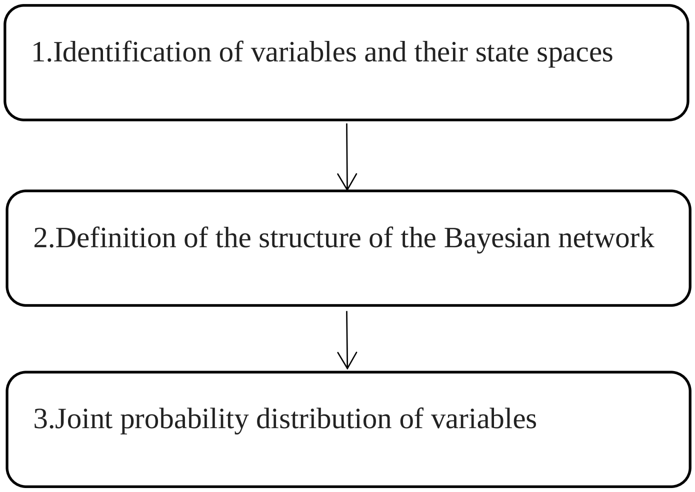


Figure2.6: Steps of constructing a Bayesian network

The first qualitative step consists of defining all the variables of the system, with a precise specification of the state space for each variable.

The second step is the probabilistic step, where the idea of a joint distribution is introduced, defined on the variables to generate the observation database and to choose a graph structure that is compatible with the variables.

The third step is the quantitative step: it involves the numerical evaluation of conditional probability distributions. (Embarki, 2012)

2.2.7. Use of a Bayesian Network

A Bayesian network is a causal graph that is associated with an underlying probabilistic representation. This representation allows for quantitative reasoning about the causal relationships within the graph.

The essential use of Bayesian networks is to calculate conditional probabilities of events that are related to each other through cause-and-effect relationships. This use is called inference. (Embarki, 2012)

A fundamental difficulty of Bayesian networks lies precisely in the operation of transposing the causal graph into a probabilistic representation. Even though the only probability tables necessary to fully define the probability distribution are those of a node conditioned on its parents, it remains that defining these tables is not always easy for an expert. (NAOUAR, 2007)

Conclusion

In conclusion, the BORA methodology is a well-established risk assessment tool that has undergone significant improvements and refinements over the years to become one of the most comprehensive and reliable approaches available in the oil and gas industry. Its flexibility and adaptability allow it to be applied to various types of facilities and industries, making it an invaluable tool for risk management.

The methodology consists of a series of steps, including system identification, identification of initiator events related to tasks, assignment of generic frequencies for each initiator event, identification of barriers and development of a barrier block diagram, modeling of safety barrier performance, assignment of generic base event probabilities, calculation of the frequency of the undesirable consequence based on generic base event probabilities, identification of Risk Influencing Factors (RIF), assignment of RIF weights and scores, re-adjustment (correction) of probabilities and average frequencies, and recalculation of risk.

Additionally, the chapter has explored the application of Bayesian networks as a probabilistic modeling tool for risk analysis. By capturing complex dependencies and uncertainties, Bayesian networks offer a robust framework for decision-making. The inclusion of practical examples has showcased the versatility and applicability of this method in diverse contexts.

Chapter 03

GASSI TOUIL REGION DESCRIPTION

CHAPTER 03 : GASSI TOUIL REGION DESCRIPTION

Introduction

This chapter provides an overview of the internship company that we completed our internship with during our HSE Master's degree program. The internship took place at Sonatrach Prodution Devison in Gassi Touil.

This chapter presents a comprehensive examination of the background and history of the internship company, together with its products or services, mission and vision, organizational structure, culture, competitive advantages and challenges. Additionally, it provides a personal account of our experience working at the company.

3.1. Introduction of Gassi Touil Region (SONATRACH)

The Gassi Touil region is one of the ten regions that currently make up the Production Division of the upstream sector. It has various basic facilities to ensure the production, storage, and shipment of hydrocarbons, including:

- A crude oil shipping unit.
- Separation chains.
- Crude oil storage units.
- A gas treatment unit.
- A gas injection unit for maintaining pressure in the reservoir.
- An oil desalting unit for environmental protection.

3.2. Geographic location

The Gassi Touil region is part of the Wilaya of Ouargla. It is located about 1000 km from Algiers and 150 km southeast of Hassi-Messaoud, located near the Hassi-Touarg site, next to National Road No. 03 linking Ouargla-Ain Aminas. It covers an area of approximately 170 km long and 105 km wide. The rainfall is low in winter and zero the rest of the year. Temperatures vary between -5°C and +50°C. The landscape is made up of sand plateaus and dune ridges.

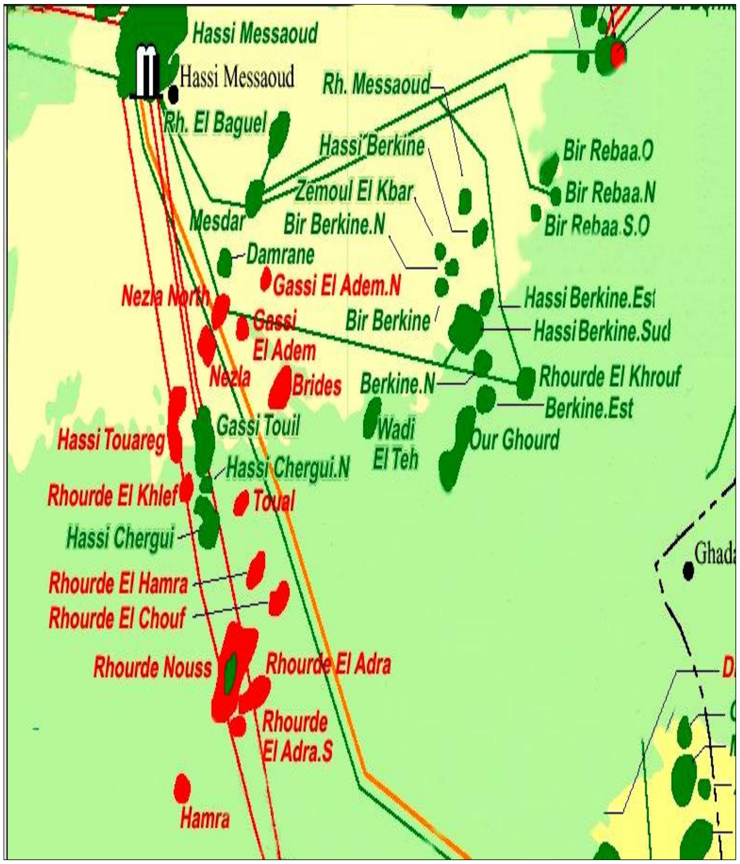


Figure3.1: Geographic location of Gassi Toui Region

3.3. History of discoveries in the GT region

The Gassi Touil region is an oil and gas region, consisting of several fields, including:

- NEZLA Nord discovered in 1958, 10 wells drilled for oil and gas.
- NEZLA Sud discovered in 1958, 21 wells drilled for gas.

- Hassi Touareg Nord discovered in 1959, 08 wells drilled for gas.
- Hassi Touareg Sud discovered in 1959, 06 wells drilled for gas.
- Gassi Touil discovered in 1961, 80 wells drilled for oil and gas.
- Hassi Chergui Nord discovered in 1962, 01 well drilled for oil.
- Hassi Chergui Sud discovered in 1962, 09 wells drilled for oil.

Fields under development:

- Brides discovered in 1958, 06 wells drilled for dry gas.
- Toual discovered in 1958, 09 wells drilled for gas and condensate.

3.4. The fields of Gassi Touil

3.4.1. The production facilities

They include a crude oil treatment unit, a gas treatment unit, a gas reinjection unit, and an energy production unit.

a. Installation for treatment and storage of crude oil

Figure 3.2: Installation for treatment and storage of crude oil

1963: Installation of 02 storage tanks on the field near the GT1 well, with a unit capacity of 310m3.

1965: Installation by the REPAL company of:

- 1 separation battery (battery1)
- 1 storage tank of 3390m3 (R1)
- 1 gravity shipping line of 20" in length, 800m long, connecting tank R1 to the 30" Ohanet-Haoud-El-Hamra pipeline.

1968: Realization of the crude oil separation unit, consisting of:

- 3 separation batteries (battery2, 3, 4)
- 2 test batteries (test1, test2)

Expansion of the storage area through the construction of:

- 1 new storage tank of 3390m3 (R2)
- 2 floating roof storage tanks of 20,000 m3 each (R21, R22)

Construction of a crude oil shipping pump station consisting of:

- 3 centrifugal electric pumps (P1, P2, P3), with a unit flow rate of 1250m3/h under a water head of 40m.
- 1 transfer pump from tank to tank (P4), with a unit flow rate of 250m3/h under a water head of Flow rate: 250m3/h at a head of 40 meters of water.
- 1 line of 20" to connect the pump room to the shipping line.

1975: extension of the storage park with a third tank of 20,000 m3 (R23).

1976: extension of the crude treatment unit with a new separation battery (battery 5).

1980: installation of a separation battery (battery 6) reserved for condensate stabilization.

1985: installation of a second transfer pump in parallel with the existing one (P4bis).

1991: installation of the test battery (test 3). Installation of the first two tanks of 310m3 (R3 R4), recovered from the field to be used as test tanks.

1992: installation of separator HP7, with a processing capacity of 850m3/day of crude oil and 2MMm3/day of associated gas, for the recovery of flared gas. This separator receives production from wells with high GOR. The oil-gas separation is done at 65 bars without flash to allow the gas to be sent to the gas treatment unit inlet, which operates at 60 bars. The crude oil treatment unit consists of:

- A separation section;
- A storage and shipping section. The separation section includes a series of 9 batteries. Each battery consists of a pair of separators. The storage and shipping section include 7 storage tanks and a shipping pump room. Installed processing capacity: 21850 m3/day. Installed storage capacity: 67400 m3. Pump room: 1250 m3/h at a head of 40 meters.

b. Natural Gas Processing Installations:

Figure 3.3: Natural Gas Processing Installations

1976: Realization of the gas processing unit by the French company SOFREGAZ. This unit was installed to process the gas from Gassi Touil for two years initially, then the gas from the fields of Nezla and Hassi-Touareg after their connection and commissioning in 1980 and 1984, respectively.

1988: Depletion of gas reserves resulted in a pressure drop that was felt crucially from 1988 onwards. The cooling process based on the potential energy of gas reached its thermodynamic and technical limits (inlet pressure limited to 95 bars by design).

1992: To overcome this situation, a low-pressure processing plant was planned for 1994. In the meantime, a quick and temporary solution was adopted in 1994. It involved the renovation of the existing installations by adding turboexpanders (revamping) to exploit the maximum inlet gas pressure and ensure adequate cooling that would enable the current plant to operate until 1995 or 1996.

The installed initial processing capacity is 20 million Nm3/day of gas for a production of 2,900 tons of recovered condensates.

The unit mainly consists of:

- 4 identical treatment trains called chains: with a unit capacity of 5 million std m3/day.
- 1 input manifold where the effluent arrivals from the 4 gas fields (GT, NZ, HTG) are connected.
- 2 diethylene glycol (DEG) regeneration units.
- 2 condensate-DEG mixture heaters.

Each chain includes:

- 1 inlet separator called FWKO (Free Water Knock Out Drum) to recover the liquids.
- 1 cold insulated separator, called LTS (Low Temperature Separator).
- 1 heat exchanger, single-pass shell-tube type.
- Each pair of chains shares in common:
- 1 common separator to receive the recovered condensates in the FWKO and LTS of the chains.
- 1 heater for the condensate-DEG mixture to facilitate their separation by reducing their viscosities.

c. Gas Injection Unit:

The gas injection unit was carried out in two phases:

The first phase consisted of the construction of a station with 3 motor compressors, and the second of an extension identical to the first station. The total installed capacity is 4.2 million m3/day.

1974: Construction of the gas injection unit associated with the American company Dresser Rand.

It consists of 3 reciprocating motor compressors with a unit capacity of 744,000 Nm3/day.

1980: Extension of the injection unit by installing 3 other compressors identical to the first:

Unit capacity: 744,000 Nm3/day

Power: 3200 HP

- 1st stage suction pressure: 380 psig
- 1st stage discharge pressure: 1000 psig
- 2nd stage suction pressure: 1000 psig

- 2nd stage discharge pressure: 2500 psig
- Speed: 360 rpm

3.4.2. Associated Gas Recovery Unit:

Figure 3.4: Associated Gas Recovery Unit

The new centrifugal station replaces the old alternative unit and collects 4.9 MM std m3/day of flared gas from various points in the gas injection unit and gas processing unit. The compressed gas is reinjected at a pressure of 152 bars (abs) into injection wells to maintain the reservoir pressure.

3.4.3. Fuel Gas Unit:

The function of this unit is to condition the fuel gas required for various consumers (turbine, BP compression seals, and HP-BP torch sweeps).

This conditioning is carried out in three stages:

- Separation of the liquid phase
- Heating
- Filtration
- The total fuel.

s from various points in the gas injection unit and gas processing unit. The compressed gas is reinjected at a pressure of 152 bars (abs) into injection wells to maintain the reservoir pressure.

3. The fields

The Gassi Touil region is responsible for exploitation and development of the following fields.

4.1.Fields in operation

Table 3.1: Fields in operation

Field	Acronym	Nature of fluids
Gassi Touil	GT	Oil + condensate gas
Hassi –Chergui	HC	Oil
Nezla Sud	NZ	Condensate gas
Hassi -Touareg	HTG	Condensate gas
Nezla Nord	NZN	Oil
Hassi Chergui Nord	HCN	Oil

4.2. Fields under development

Table 3.2: Fields under development

Field	Acronym	Nature of fluids
Brides	BRD	Dry gas
Toual	TOU	Condensate gas
Gassi El adem	GEA	Condensate gas

4.3. Fields in semi-operation

Table 3.3: Fields in semi-operation

Field	Acronym	Nature of fluids
Wadi El Theb	WT	Oil

Rhourde El khelf	REK	Condensate gas
Gassi El Adem Nord	GEAN	Condensate gas
Damrane	DMR	Oil

Conclusion

The principal objective of this chapter is to facilitate a more profound comprehension of the internship company and its activities, thus aiding contextualization of the specific projects and tasks executed during the internship. Furthermore, this chapter may also prove useful to individuals with an interest in the industry or company in question.

Chapter 04

APPLICATION OF BORA AND BN ON THE TURBO COMPRESSOR SYSTEM

CHAPTER 04: APPLICATION OF BORA AND BN ON THE TURBO COMPRESSOR SYSTEM

Introduction

In order to identify and evaluate the risks related to the chosen turbo-compressor system in the most comprehensive way possible, and consequently to establish adequate security measures through the BORA and BN method, we have adopted the following process for our work starting with the application of the HAZOP method to **the separator S- 05 and the centrifugal compressor thermodyn C03** of MP-HP section of the URGA unit to identify the causes, consequences, and, existing safety barriers accompanying each deviation then passing to the application of the Event tree method to the MP-HP section of the URGA unit in order to determine the safety barriers and accident scenarios, and evaluate their occurrence frequencies and finally the application of the Fault tree method to the safety barriers. These are the main steps to start with to perform a BORA method on our operational system, followed by converting it to Bayesian network in order to get a comparative analysis and enhanced modeling capabilities.

4.1. Criteria for choosing the Turbo-compressor system

Turbo-compressor represents a very important (strategic) system in the oil industry for the following reasons:

- It is a complex system with various risks;
- Any failure in the system causes production shutdown;
- The Turbo-compressor system is subject to significant thermal constraints, making it susceptible to deviations and, consequently, an increase in the risk of fire and explosion.

To properly analyze the MP-HP section of the URGA unit through HAZOP, we have chosen the following parameters: Pressure, Temperature, Flow.

Part01: Application of BORA method on the the separator S- 05 and the centrifugal compressor thermodyn C03 MP-HP section

4.2. Application of HAZOP method to the separator S- 05 and the centrifugal compressor thermodyn C03 MP-HP section

4.2.1. Functional analysis of the MP-HP section

A- Description:

The function of this section is to compress 4,900,000 Sm3/J of gas into two stages (MP-HP) at 153 bars (abs) before injecting it into wells.

B- Gas supply circuit:

Gas supply associated to S-03 separator (MP compression) comes from two sources. These are the output of the reciprocating type Duplex down stroke charge compressor BPC enough to140kgycl type A1 TP-HSO1-M64 stage_221mlp12 inlet.

C- MP/HP Turbo compressor:

The HP compression line is composed of two MP/HP compressors driven by the same gas turbine operating at variable speed (FRAME 5 type, manufacturer GE ENERGY, category B).

The first MP compressor compresses gas from 19.5 absolute bars to 65.2 absolute bars., The HP compressor compresses from 64 bar absolute up to 153 bars absolute.

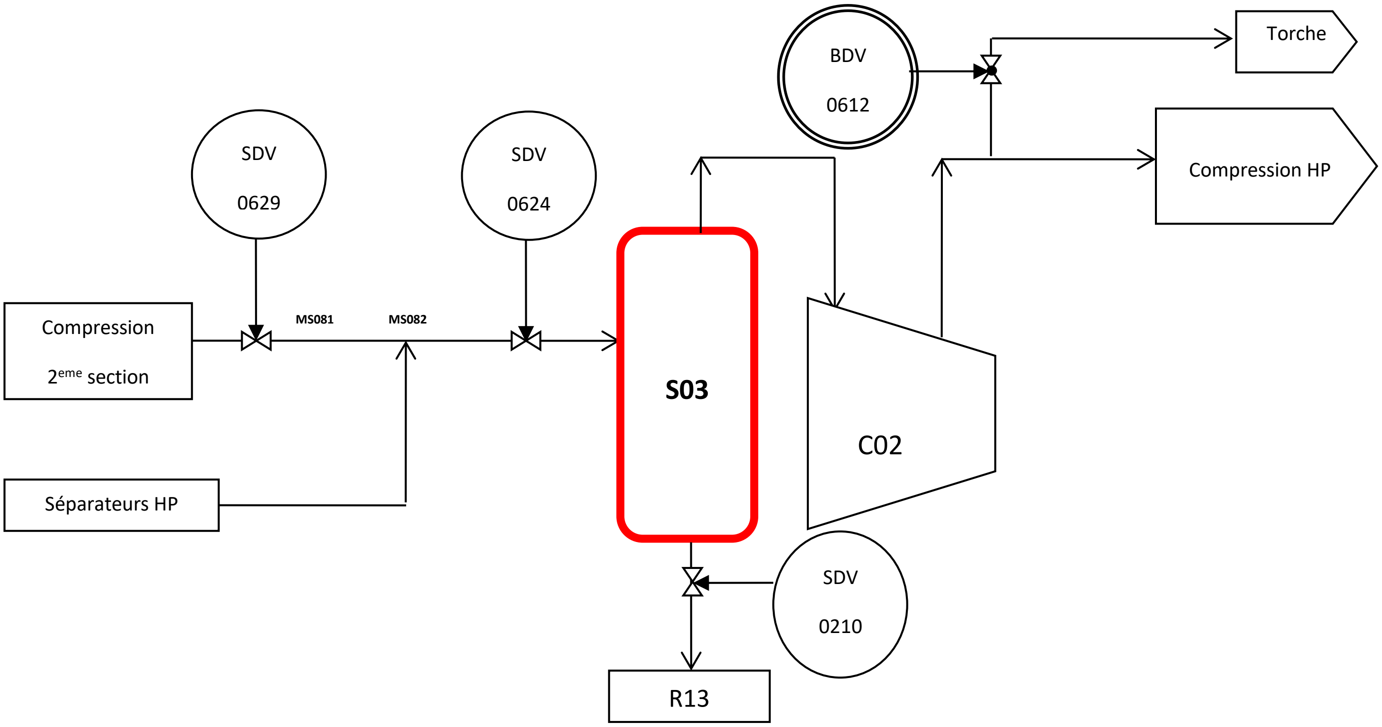


Figure 4.1: compression MP section: Locating separator S- 05

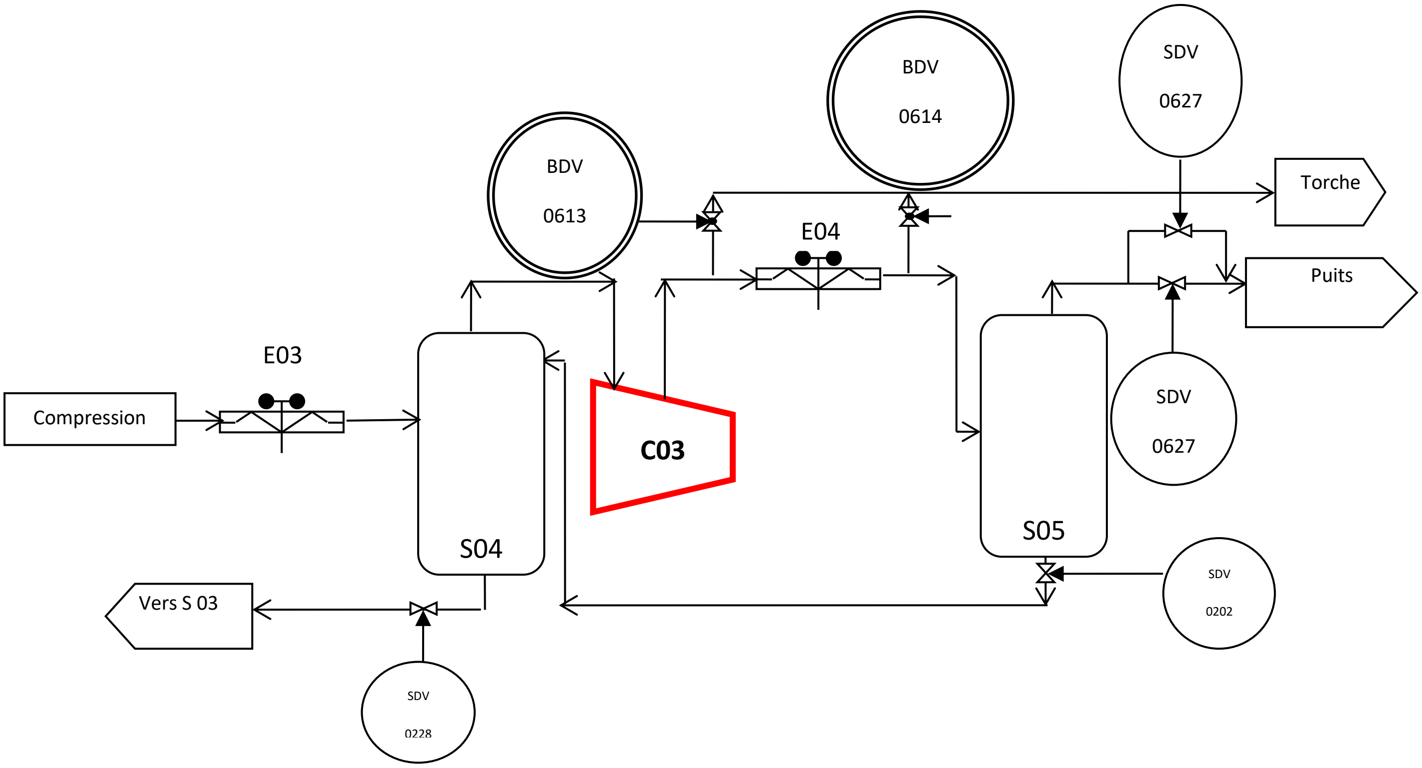


Figure 4.2: compression HP section: Locating centrifugal compressor thermodyn C03

Table 4.1: HAZOP -HAZARD AND OPERATIONAL STUDY- of Seperator S05 and compressor C03

Parameter : Temperature		**HAZOP -HAZARD AND OPERATIONAL STUDY-**		**Page**: **01**/05
System: HP URGA-CP turbo compressor				**Subsystem 1:** Separator **S- 05**
Keyword	**Deviation**	**Causes**	**Consequences**	**Existing safety**
More than	High temperature	- Failure of E – 03 A/B air coolers - Electrical cut-off	- Damage to air cooler bundles and exchangers - Gas leakage, fire -thermal burn	- Anti-surge valve - Temperature alarm tshh 0447 (>58°) + operator - BDV 0613 - ESD

Parameter : Pressure		**HAZOP -HAZARD AND OPERATIONAL STUDY-**		**Page**: **02**/05
System: HP URGA-CP turbo compressor				**Subsystem 1:** Separator **S- 05**
Keyword	**Deviation**	**Causes**	**Consequences**	**Existing safety**
More than	High Pressure	- SDV022 and SDV0627 A/B closed position blockage	- Damage to air cooler bundles and exchangers - Explosion	- Opening of pressure relief valves BDV0612, BDV0613 and BDV0614 - Pressure alarm PT + operator - ESD

Parameter : flow rate		**HAZOP -HAZARD AND OPERATIONAL STUDY-**		**Page**: **03**/05
System: HP URGA-CP turbo compressor			**subsystem 2:** thermodyn C03 centrifugal compressor	
Keyword	**Deviation**	**Causes**	**Consequences**	**Existing safety**
More than	High air flow rate	- HP overspeed - IGV mis adjustment - Bleed valves remain closed	- Vibration - Poor combustion - Mark V alarm - Turbine trip .	- Vibration detector - Mark 5 (visual and audible alarm)
Less Than	Low air flow rate	- Compressor installation failure - Blade wear - Filter clogging - IGV mis adjustment - Failure in the lubrication oil circuit (oil passing to compressor following bearing failure)	- Poor combustion - Poor cooling (combustion chamber + turbine + axial compressor) - Axial compressor surging - Mark V alarm - Turbine trip	- Mark 5 (visual and audible alarm)

Parameter : Pressure.		**HAZOP -HAZARD AND OPERATIONAL STUDY-**	**Page : 4/5**
System: Turbo compressor		**subsystem 6:** centrifugal Compressor thermodyn C03	
Deviation	**Causes**	**Consequences**	**Existing safety**
Low section pressure	- Improperly studied compressor rotation speed - Upstream compressor leakage - Defect the BP (Low speed) level	- Insufficient discharge flow - Vibration - Mark 5 alarm - Turbo compressor shutdown - Fire - Explosion	- Temperature sensor - Mark 5 (visual and audible alarm) - Signal Verification (control room) - Pressure sensor - Mark 5 (visual and audible alarm)
High section pressure	- Improperly studied compressor rotation speed - BP overspeed - FV 03 VALVE remains open	- High compressor discharge pressure - Noise - High gas temperature - Mark 5 alarm - Turbo compressor shutdown	- Signal Verification (control room) - All aerosols function - Compressor shutdown

Parameter : Pressure		**HAZOP -HAZARD AND OPERATIONAL STUDY**	**Page: 5**/5
System: Turbo compressor		**subsystem 6:** centrifugal Compressor thermodyn C03	
Deviation	**Causes**	**Consequences**	**Existing safety**
Low discharge pressure	- Improperly studied speed - Low section pressure (leakage of gas in the C02, C03 section circuit (corrosion/erosion)) - non-return valve stuck closed	- Alarm on Mark V - Compressor trip due to low discharge flow rate - System shutdown - Ignition /explosion	- Pressure sensor - Mark 5 (visual and audible alarm)
High discharge pressure	- Improperly studied speed - High suction flow rate - Closed non- return valve of the discharge line	- Compressor damage - Pressure rise up to the maximum pressure - Safety valve popping - Alarm on Mark 5 - Compressor trip - System shutdown	- Pressure sensor - Mark 5 (visual and audible alarm)

4.3. Scenario A: Explosion at Separator S-05

4.3.1. Scenario A description

Table 4.2: Description of scenario A

Scenario Name	Explosion at Separator S-05
General Description	Explosion at the separator due to containment loss
Initiating Event	Containment loss
Existing Safety Barriers	The explosion can be prevented if the following safety functions are carried out: • Surveillance system • ESD • Relief valve

4.3.2. Step 01: Assignment of generic data to initiating and basic events

The occurrence frequencies of the chosen initiator events are presented in the following table, all initiating and basic events are estimated by assigning industry average frequencies and probabilities. Average data are established from (OREDA, 2002) and (ICSI, 2009):

Table 4.3: The occurrence frequency of initiator event

Initiator event	Frequencies (/year)
Loss of containment	10^{-2} /year

Table 4.4: Failure rate of base events components

Components	Failure rate λ /h
Pressure transmitter (PT)	3×10^{-7}
Distributed control system (DCS)	5×10^{-4}
Emergency shutdown valve (SDV)	2.1×10^{-6}
Analogue input failure	1.6×10^{-7}
CPU failure	4.8×10^{-7}
Digital output failure	1.6×10^{-7}
DCS failure	5×10^{-4}
Relief valve Fail to open	1.4×10^{-6}
Structural deterioration	6.5×10^{-7}

4.3.3. Step 02: Elaboration of event tree

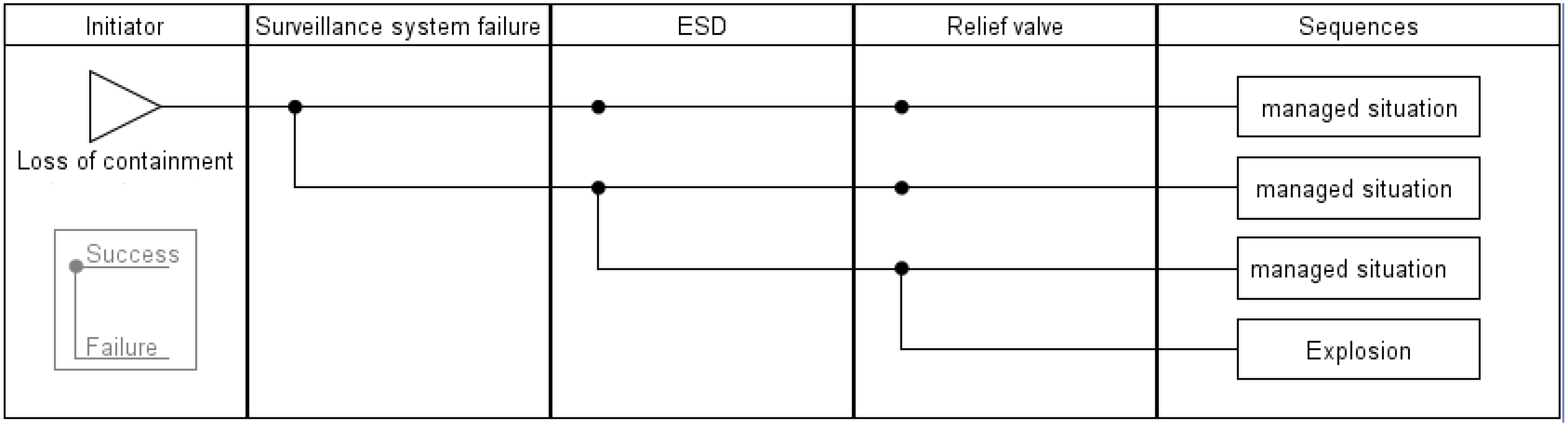


Figure4.3: Event tree of scenario A

4.3.4. Step 03: Elaboration of safety barrier failure trees and basic events probabilities

The figures below are obtained by the GRIF software and the table 11:

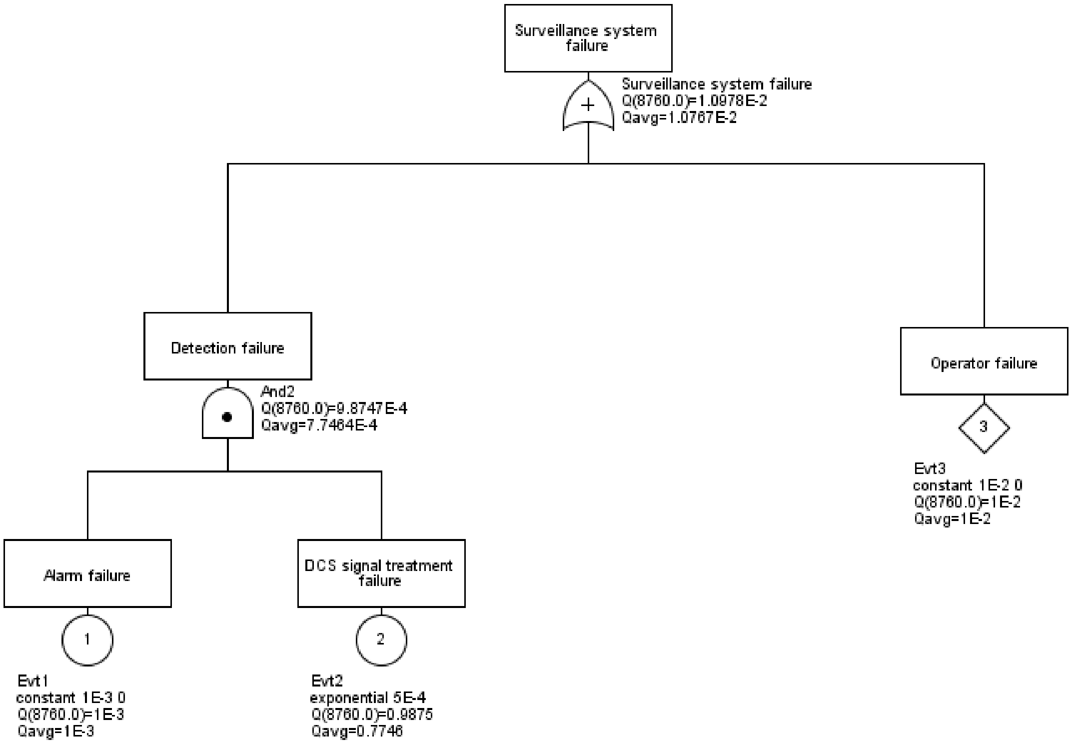


Figure 4.4: Failure tree of barrier A1

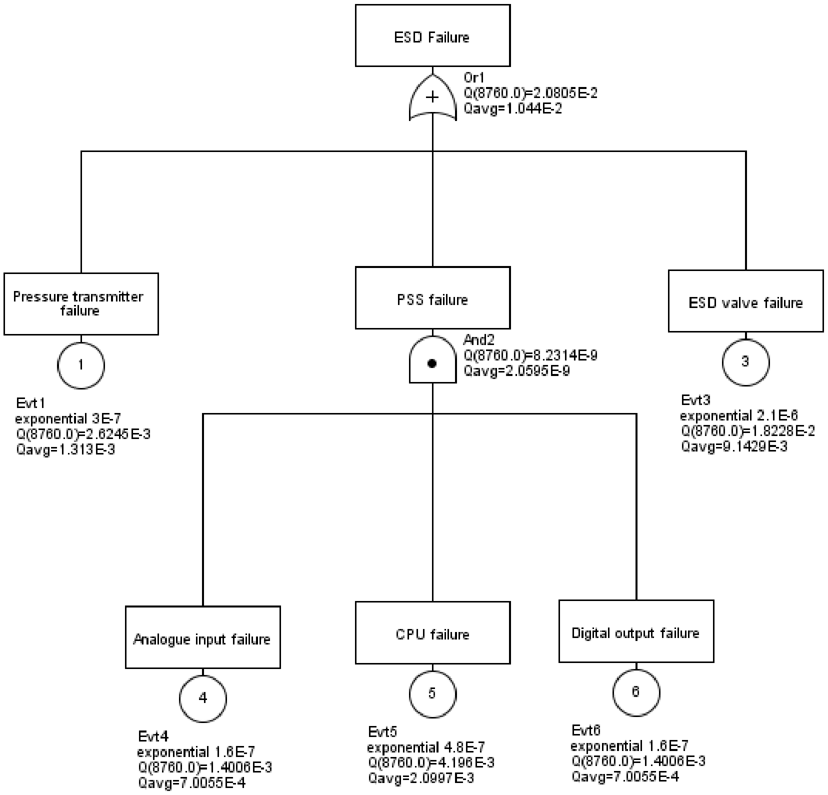


Figure 4.5: Failure tree of barrier A2

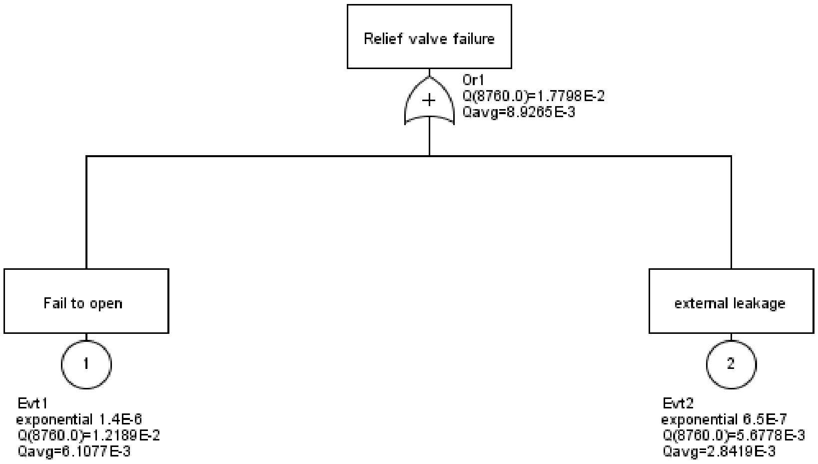


Figure 4.6: Failure tree of barrier A3

- **Basic events probabilities**

the results are obtained by the GRIF software and the table:

- **For barrier 01:**

Generally human factor is treated case by case, it is hard to get a constant failure rate therefore the following calculation are estimated based on the PFD established from the historical data and information of the process:

$$\boldsymbol{PFD}\ operator\ failure = 10^{-2}$$

$$\boldsymbol{PFD}\ alarm\ failure = 10^{-3}$$

$$\boldsymbol{PFD}\ DCS\ signal\ treatment\ failure = 5 \times 10^{-4}$$

Based on the previous data:

$$\boldsymbol{PFD}\ surveillance\ system = 10^{-2}$$

Table 4.5: Basic events probabilities of barrier 01

System	Min	Max	Average
Surveillance system failure	1 E-2	1.0978 E-2	1.0767 E-2
Detection failure	4.9988 E-7	9.8747 E- 4	7.7464 E-4
Alarm failure	1 E-3	1 E-3	1 E-3
DSC signal treatment failure	4.9988 E-4	0.9875	0.7746
Operator failure	1 E-2	1 E-2	1 E-2

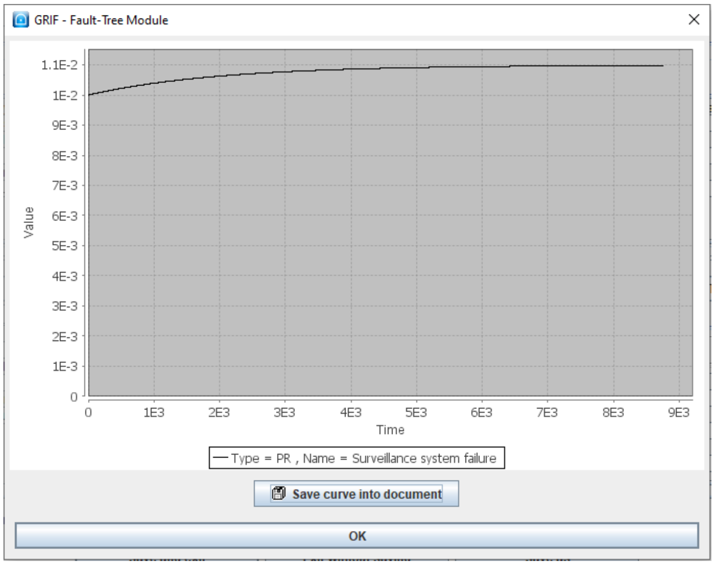


Figure 4.7: Graphical illustration of basic events probabilities of barrier 01

- **For barrier 02:**

Table 4.6: Basic events probabilities of barrier 02

System	Min	Max	Average
PSS Failure	0	8.2314×10^{-9}	2.0595×10^{-9}
Pressure transmitter failure	3×10^{-7}	2.6245×10^{-3}	1.313×10^{-3}
ESD valve failure	2.1×10^{-6}	1.8228×10^{-2}	9.1429×10^{-3}
Analogue input failure	1.6×10^{-7}	1.4006×10^{-3}	7.0055×10^{-4}
CPU failure	4.8×10^{-7}	4.196×10^{-3}	2.0997×10^{-3}
Digital output failure	1.6×10^{-7}	1.4006×10^{-3}	7.0055×10^{-4}
ESD failure	2.4×10^{-6}	2.0805×10^{-2}	1.044×10^{-2}

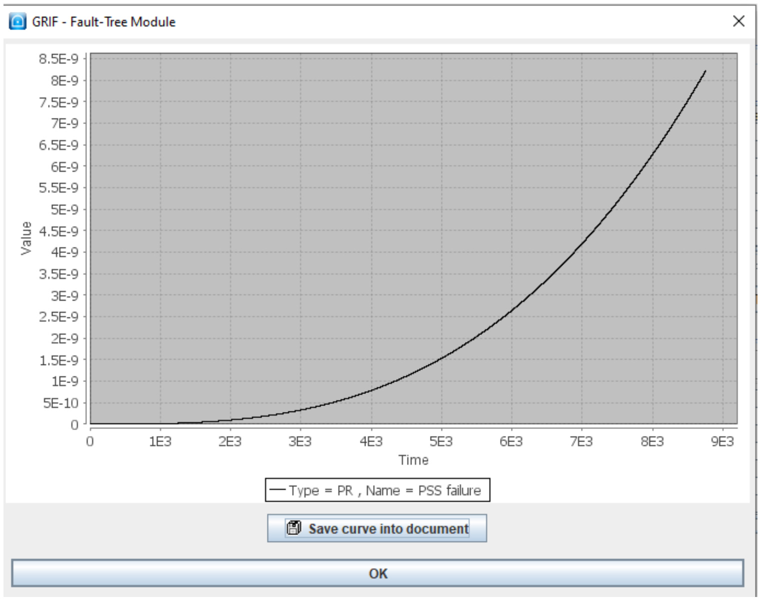


Figure 3: Graphical illustration of basic events probabilities of barrier 02

- **For barrier 03:**

Table 4.7: Basic events probabilities of barrier 03

System	Min	Max	Average
Fail to open	6.5×10^{-7}	5.6778×10^{-3}	2.8419×10^{-3}
Structural deterioration	2.05×10^{-6}	1.7798×10^{-2}	8.9265×10^{-3}
Relief valve failure	2.7×10^{-6}	2.3374×10^{-2}	1.735×10^{-2}

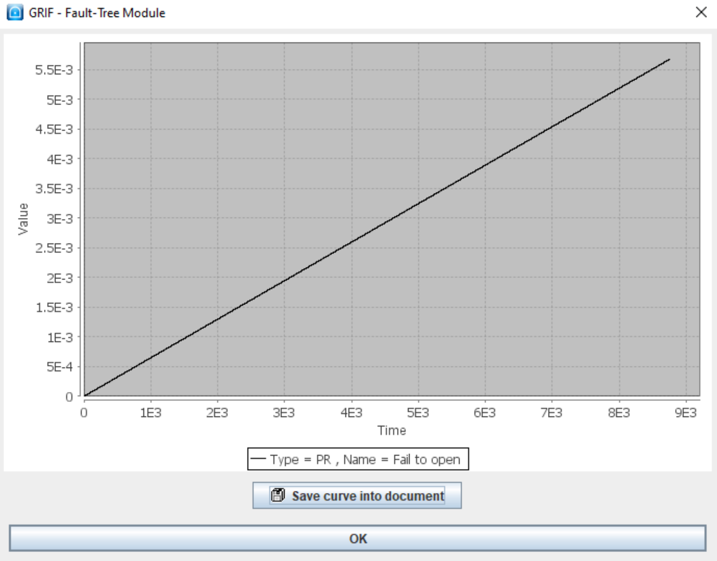


Figure 4.9: Graphical illustration of basic events probabilities of barrier 03

4.3.5. Step 04: Calculation of the average leak frequency F_{ave} (A) of the consequence of scenario A

The quantification of the frequency of the generic undesirable consequence arising from accident scenario A is accomplished through the multiplication of the initiating event frequency and the probability of barrier failure (PFD). The precise formulation of the equation is predicated upon the architecture of the barrier database (DBB), and thus:

$$\mathbf{F_{ave}\,(A) = F_{avg}\,(A0).\ PFD_{avg}\,(A1).\ PFD_{avg}\,(A2).\ PFD_{ave}\,(A3)\ \ldots\ldots}\ \text{(VII)}$$

$$\mathbf{Fave\ (A) =}\ 9.31 \times 10^{-9}\ \ \mathbf{(/year)}$$

4.3.6. Step 05: Identification of risk influencing factor for IE and BE and implementing influence diagrams

a. RIF Classification

Upon identifying the Risk Influencing Factors (RIFs) for both the initiating and basic events, a classification of these factors is carried out according to their inherent characteristics into distinct categories. The table provides an overview of these factors and their respective categories.

Table 4.8 : RIF classification *(BOUTELIS, 2015)*

RIFs category	RIFs
Human characteristics	Competence
	Fatigue
Technical system characteristics	Design
	Power supply
	Maintenance
	Corrosion
	System complexity
Organizational/operational factors:	Absence of human operator
	Communication

b. Developing influence diagrams of the initiating events and basic scenario A

In order to identify RIFs for IE and BE, a set of influence diagrams are implemented:

- **For the initiating event A0**

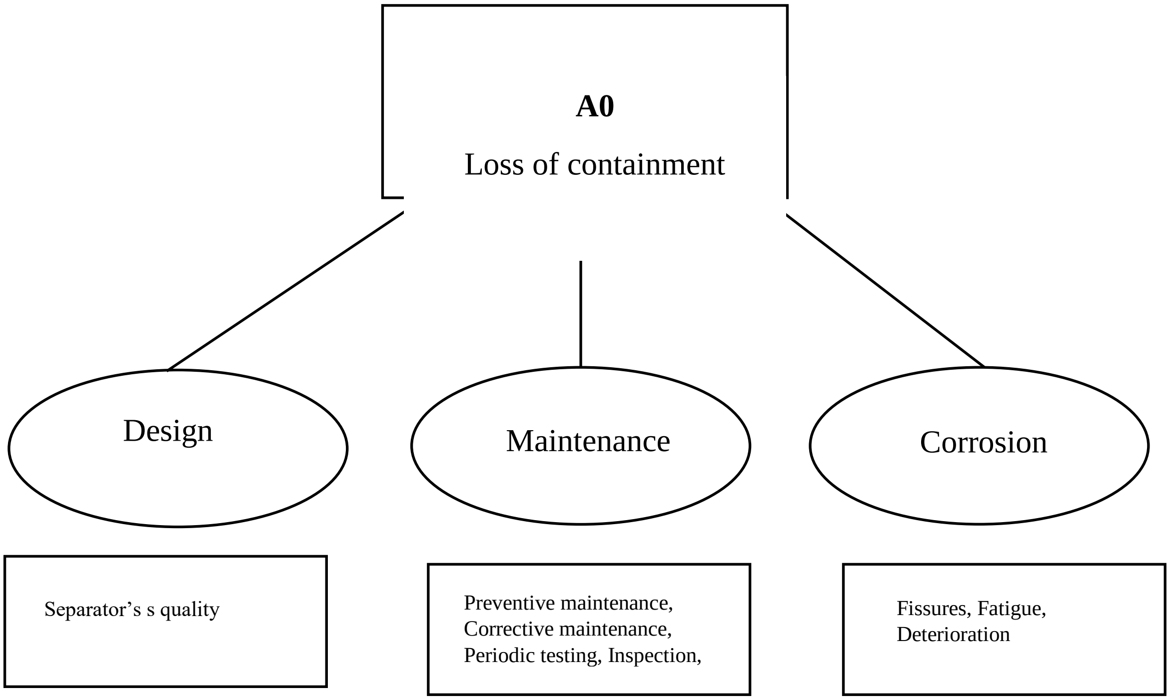


Figure 4.10: Influence diagram A0

- **For barrier A1**

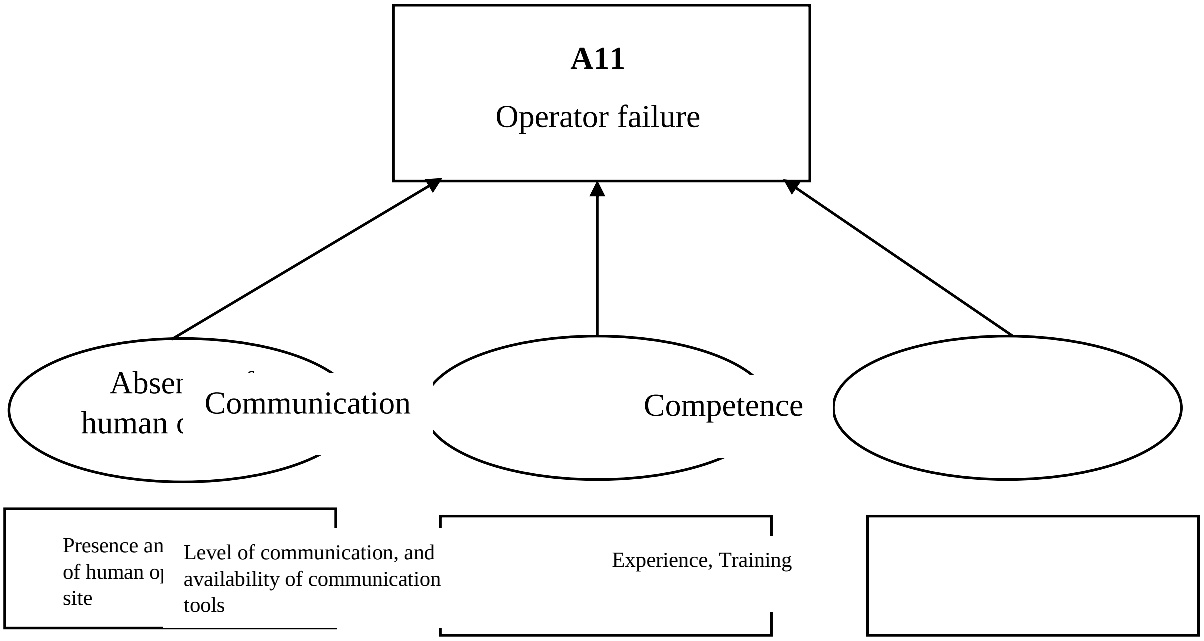


Figure4.11: Influence diagram A11

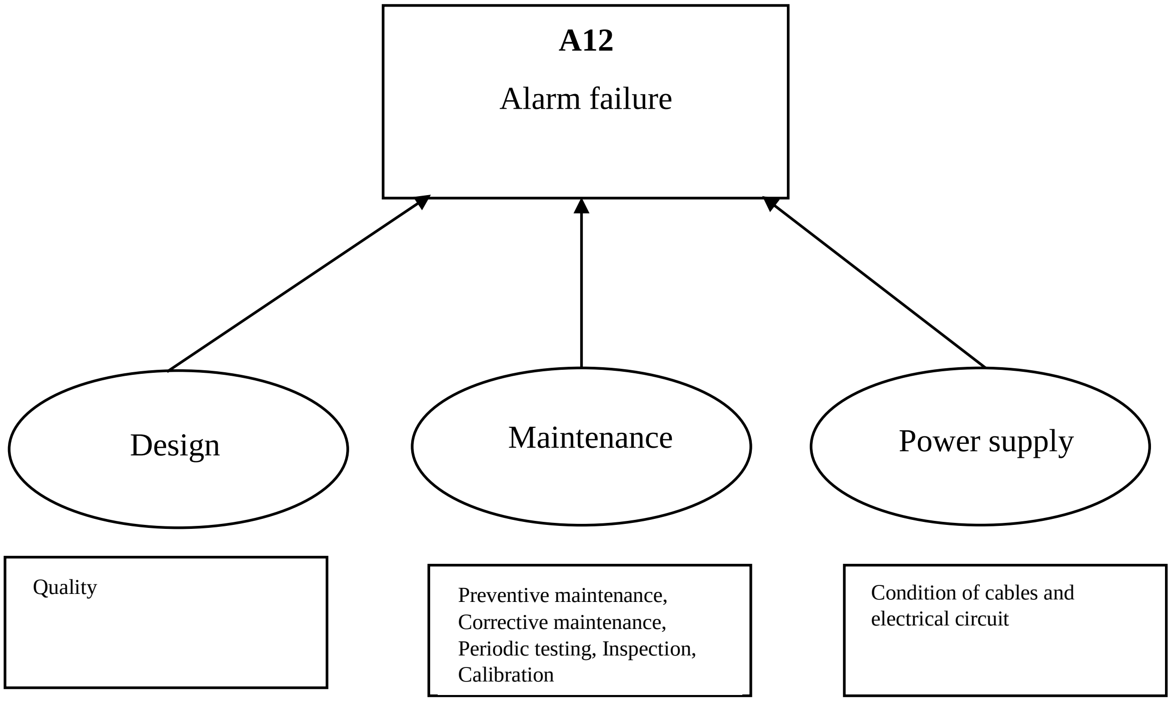


Figure4.12: Influence diagram A12

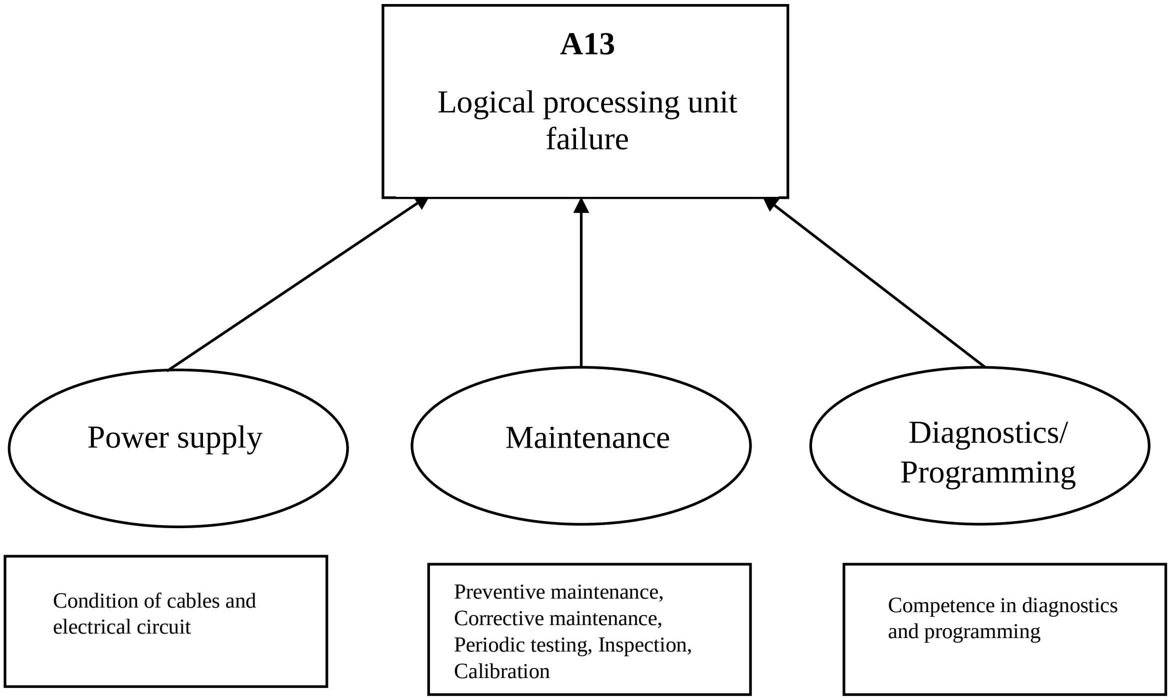


Figure 4.13: Influence diagram A13

- **For barrier A2**

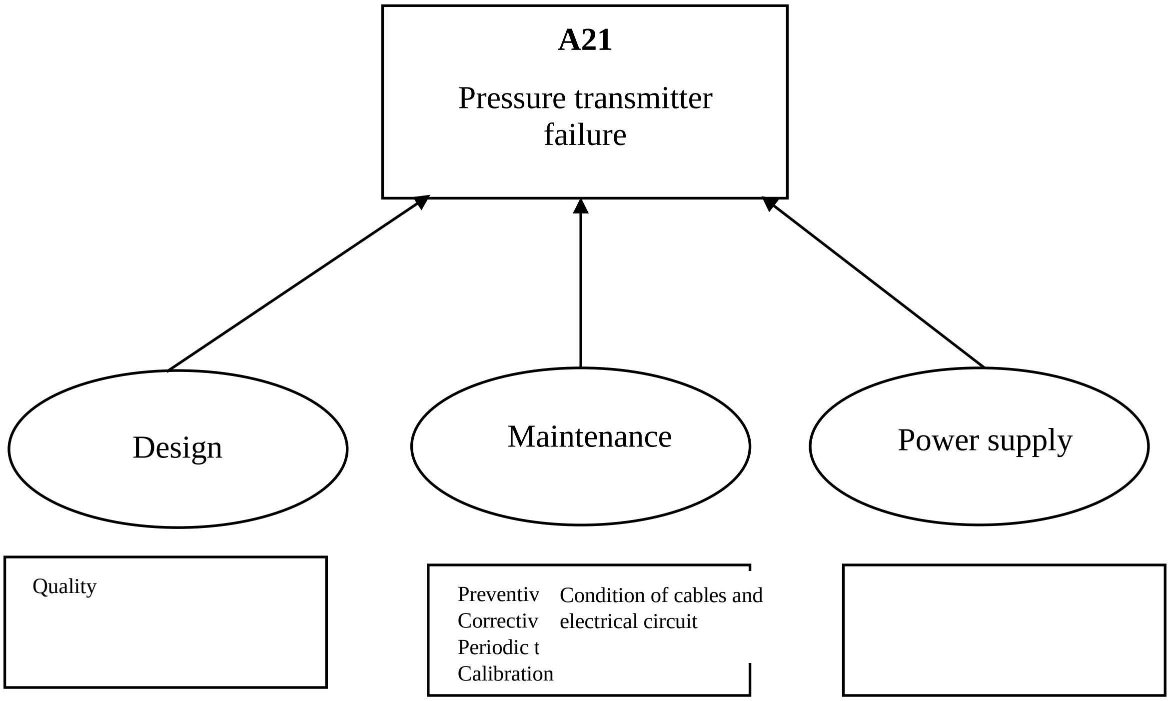


Figure 4.14: Influence diagram A21

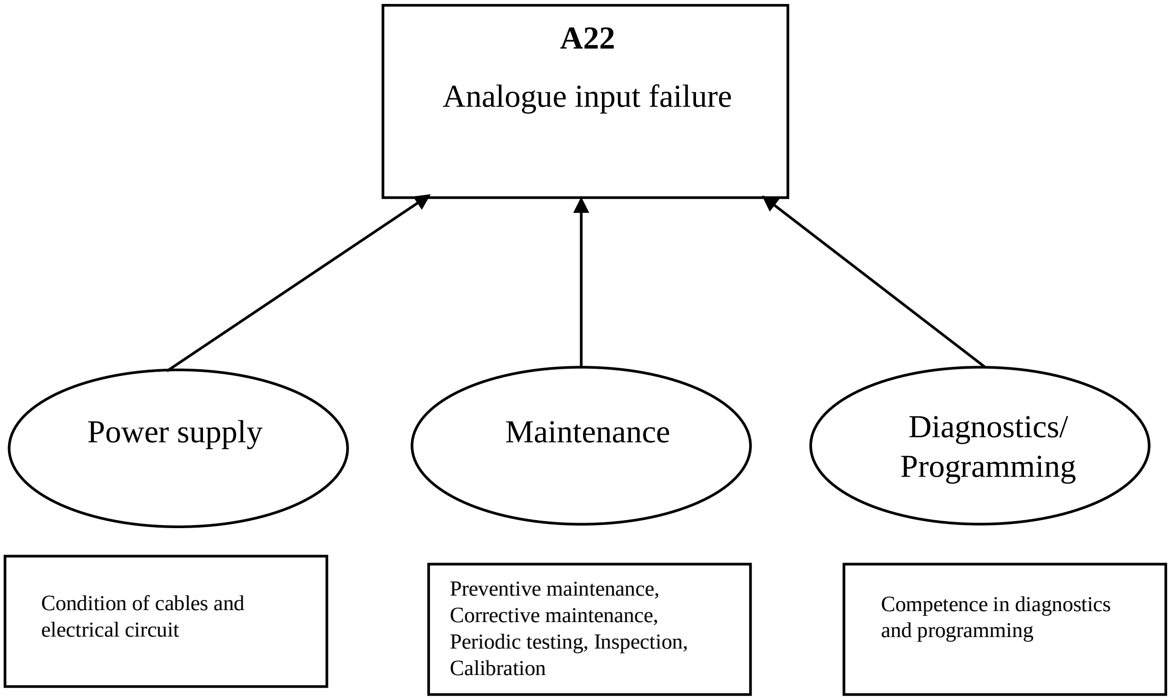


Figure 4.15: Influence diagram A22

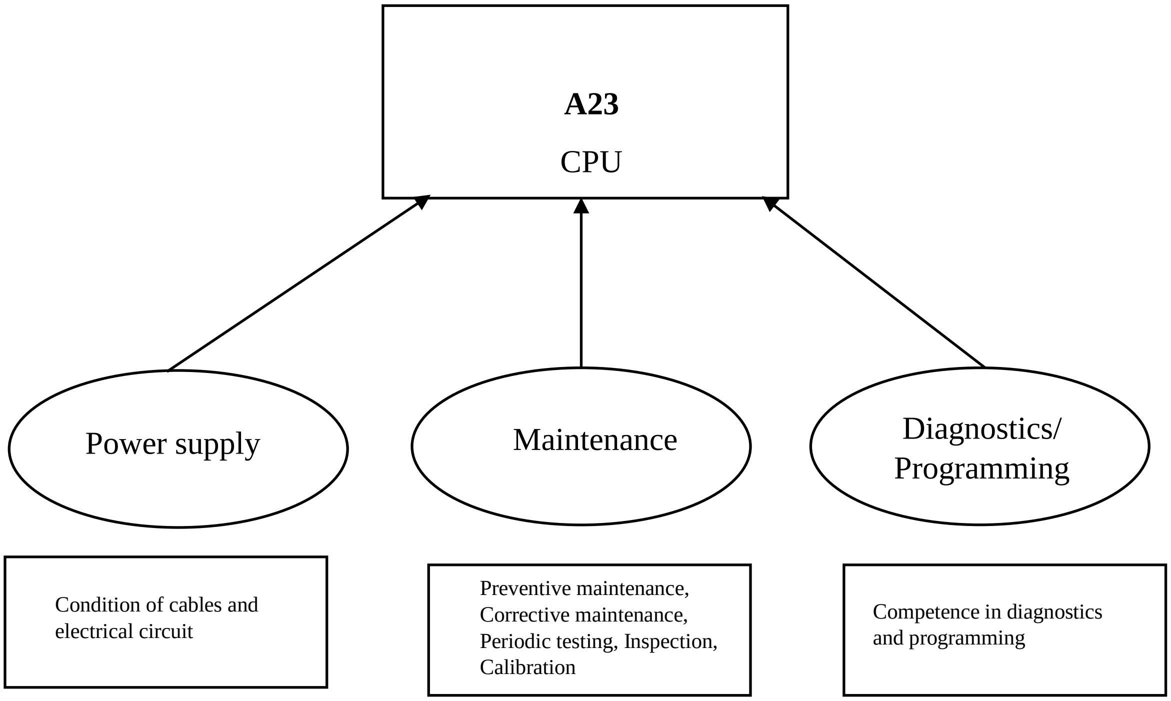


Figure 4.16: Influence diagram A23

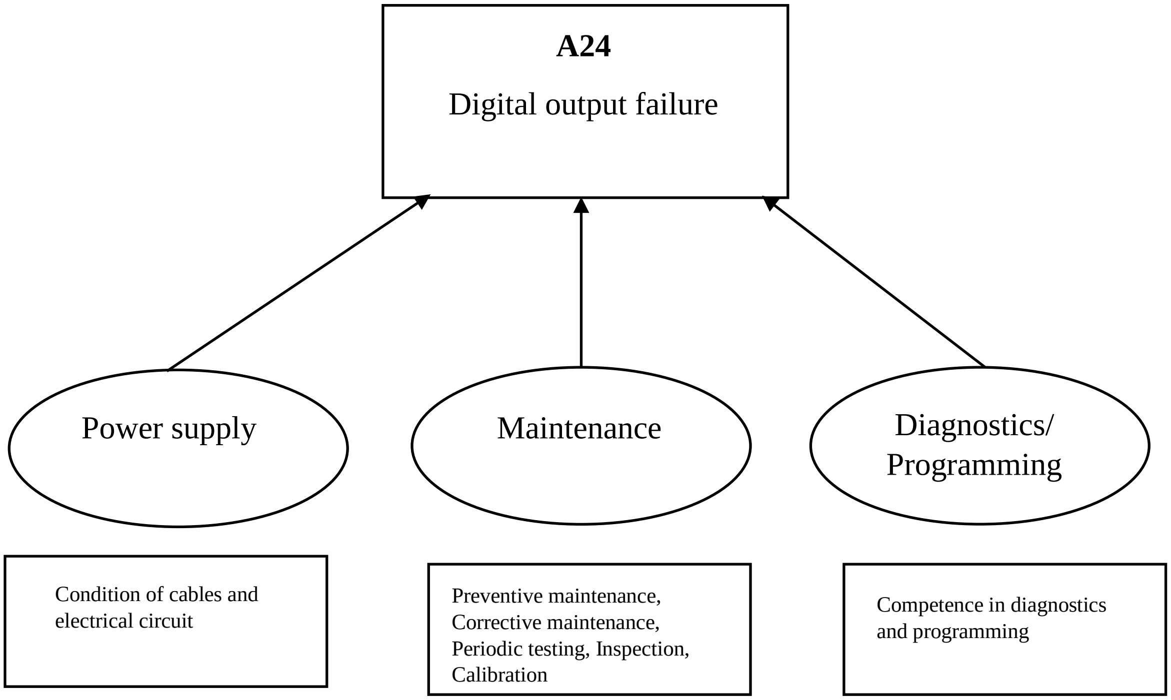


Figure 4.17 :Inflence diagram A24

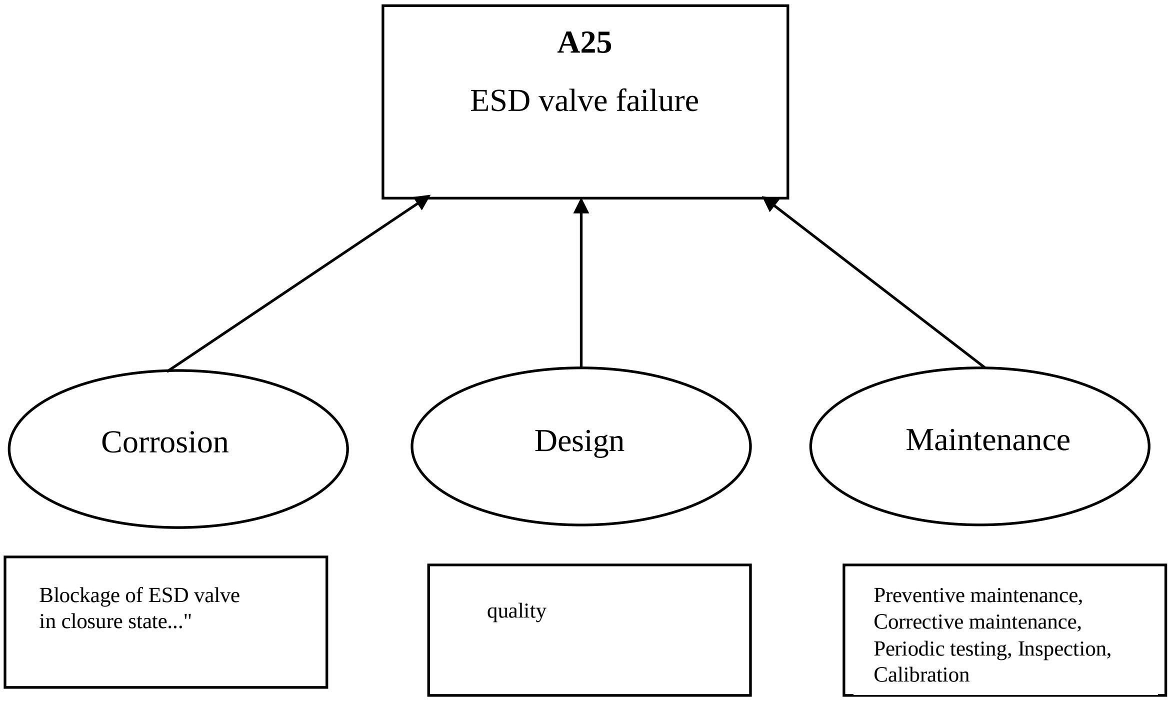


Figure 4.18: Influence diagram A25

- **For barrier A3**

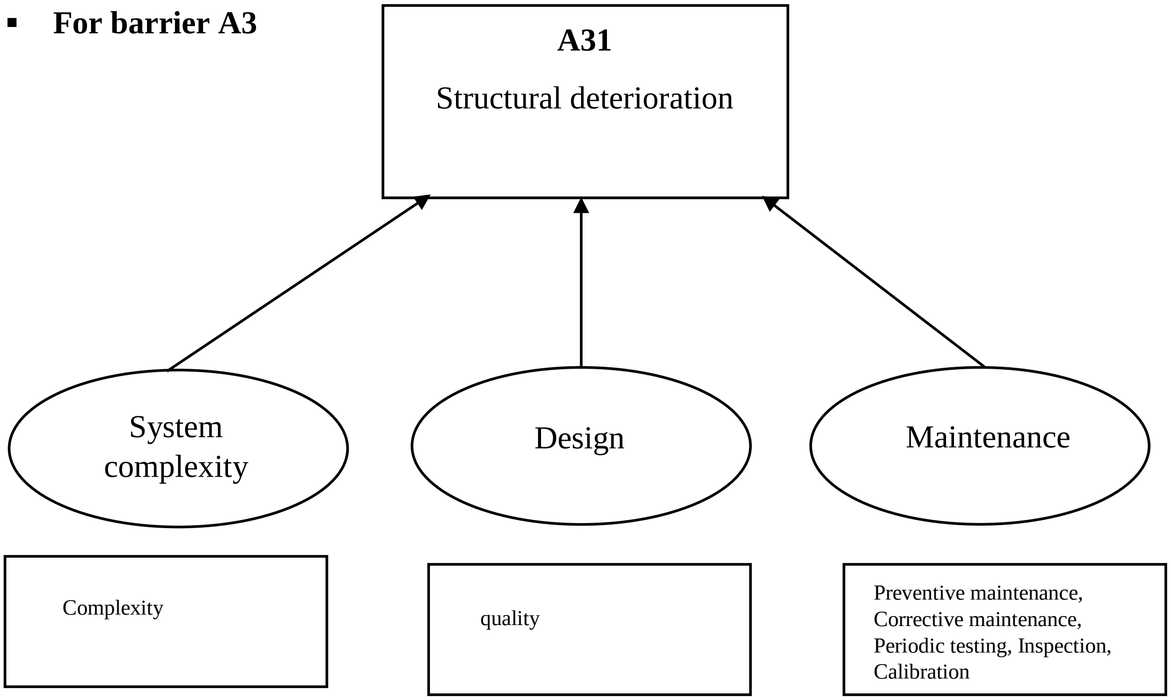


Figure 4.19: Influence diagram A3

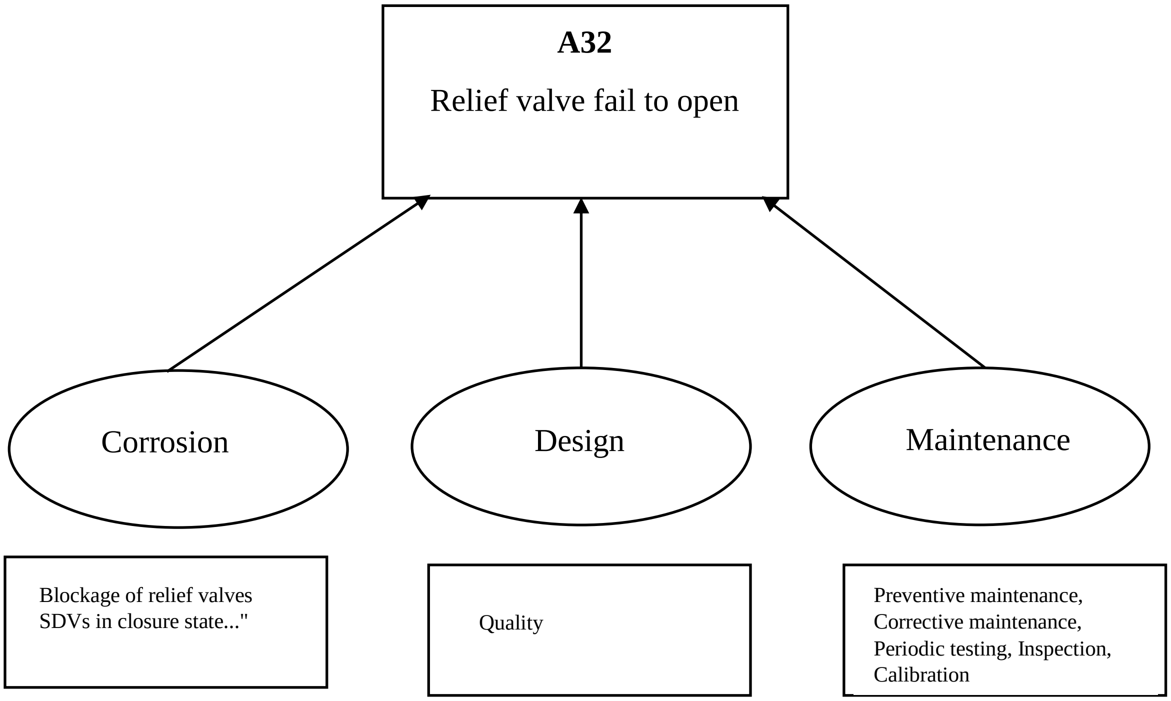


Figure4.20: Inflence diagram A23

4.3.7. Preliminary results

The coming table includes the initial data and results we got from GRIF and table 11:

Table 4.9: Preliminary results

Barrier	Initiating/basic event	Pave
A0	**A0** Loss of containment	1×10^{-2}
A1	**A1** Surveillance system failure	1×10^{-2}
	A11 Operator failure	1×10^{-2}
	A12 Alarm failure	1×10^{-3}
	A13 DCS signal treatment failure	5×10^{-4}
A2	**A2** ESD Failure	1.044×10^{-2}
	A21 Pressure transmitter failure	1.31×10^{-3}
	A22 Analogue input failure	7×10^{-4}
	A23 CPU failure	2×10^{-3}
	A24 Digital output failure	7×10^{-4}
	A25 ESD valve failure	9.14×10^{-3}
A3	**A3** Relief valve failure	8.92×10^{-3}
	A31	2.84×10^{-3}

	Structural deterioration failure	
	A32 Relief valve fail to open	6.1×10^{-3}

4.3.8. Step 06: Calculation of RIFs (Risk Influencing Factors) Weights (Importance)

In this stage, a five-point scale is employed, ranging from high to low importance, to assess the quantitative significance of Risk Influencing Factors (RIFs). The weights assigned to RIFs are determined based on a scale of 10 - 8 - 6 - 4 - 2. These weighting coefficients are then normalized to ensure that the sum of weights for RIFs influencing a base event is equal to 1. To illustrate, let us consider the calculation of weights for RIFs associated with the initiating event A0. Similar evaluations are conducted for all other factors in a comparable manner. (Seljelid, 2007)

Note that the importance of RIFs has been determined through our judgment based on the experts' opinion. It is an evaluation based on experience feedback on the separator.

Table 4.10: Example of calculating the weight of RIFs (initiator event A0)

A0 Containment loss

RIF	**Importance (weights)**					**Normalized weighting**
RIF	**High (10)**	**(8)**	**(6)**	**(4)**	**Low (2)**	
WA01 Conception					■	0.125
WA02 Maintenance	■					0.375
WA03 System complexity				■		0.5
Weight	10	0	0	4	2	1
Total weight			16			1

4.3.9. Step 07: Evaluation of the Q score of RIFs

According to (Haugen, 2005) Risk influencing factors refer to the variables that have the potential to affect the frequency or probability of an event transpiring. It is noteworthy that these factors do not serve as impediments but rather as elements that influence the efficacy of existing barrier.

This stage involves determining the status of RIFs by relying on expert judgments and feedback from experience. A scale is implemented for each RIF based on its category to determine its state. The following table displays the established scales for each RIF according to its category, which is developed in another BORA study (BOUTELIS, 2015) and which can be used in ours case due to the relevancy.

RIFs are evaluated and assigned a score ranging from A to F, with A representing the highest industry standard, followed by B, D, and E in descending order. D and E represent average or below-average performance, while F indicates the poorest industry practice. (Seljelid, 2007)

Table 4.11: Proposed scale for assessing the status of RIFs *(BOUTELIS, 2015)*

	Human Characteristics (Personal)
Score	**Competence Score Characteristics of RIF Score**
A	Experienced and competent personnel with good qualities and perfect task execution
B	Experienced and competent personnel with satisfactory task execution
C	Competent personnel who execute tasks in a satisfactory manner
D	Moderately competent personnel with acceptable performance in task execution
E	Inexperienced personnel with poor task execution
F	Incompetent and inexperienced personnel with no training and very poor task execution
	Task Characteristics
	Fatigue Score Characteristics of RIF Score
A	Excellent physical condition of personnel, work schedules not overly burdensome with a very good rotation system
B	Very good physical condition
C	Good physical condition
D	Personnel slightly fatigued but able to perform tasks
E	Fatigued personnel

F	Overly fatigued personnel
	Time Pressure Characteristics **Time Pressure Score Characteristics of RIF Score**
A	No time pressure, supervisors provide technicians with sufficient time to execute tasks normally and within the best timeframe
B	No time pressure, given task execution time is sufficient
C	Generally, no time pressure
D	Sometime pressure, but generally does not affect task execution
E	Time pressure resulting in tasks being executed under unfavorable conditions, leading to human errors
F	High time pressure, technicians execute tasks under very unfavorable conditions
	Characteristics of RIF score for lack of tools for bridles polishing
A	Tools always available at the store, each maintenance technician has their own toolbox
B	Tools available, no shortage
C	Tools sufficiently available
D	Sometimes there is a lack of tools
E	Insufficiency of tools
F	There are no tools.
	Characteristics of technical system **Characteristics of technical system design RIF score**
A	Excellent design of equipment and barriers included in the technical system
B	Very good design of equipment and barriers included in the technical system
C	Good design
D	Not-so-good design.
E	Poor design of equipment and barriers included in the technical system
F	Very poor design
	Characteristics of RIF score for power supply
A	The electrical power supply of the technical system is in excellent condition
B	Very good condition of the electrical power supply circuit
C	The electrical power supply circuit is in good condition
D	Poor condition of the circuit but still functioning

E	Poor condition of the circuit, power cuts
F	Degraded condition of the electrical circuit, no electricity
Characteristics of RIF score for maintenance/periodic testing	
A	Excellent preventive/corrective maintenance, very good maintenance and periodic testing procedure, best inspection and calibration checklist system with very good procedure follow-up
B	Very good preventive/corrective maintenance, good maintenance and periodic testing procedure
C	Good maintenance
D	Low preventive/corrective maintenance, simple maintenance and periodic testing procedure, inspection and calibration of equipment not done in a timely manner
E	Poor maintenance procedure, periodic testing, inspection, and calibration
F	Very poor maintenance, no procedure
Characteristics of RIF score for corrosion	
A	Equipment and barriers in excellent condition, no corrosion.
B	Equipment and barriers in very good condition, no corrosion.
C	Corrosion in some equipment and barriers but does not affect the operation of the system.
D	Corrosion in some equipment and barriers with occasional shutdowns.
E	Poor condition of equipment, corrosion in the majority of system parts.
F	Very poor condition of equipment and barriers, corrosion in all equipment and barriers.
Characteristics of RIF score for corrosion	
A	Equipment and barriers in excellent condition, no corrosion.
B	Equipment and barriers in very good condition, no corrosion.
C	Corrosion in some equipment and barriers but does not affect the operation of the system.
D	Corrosion in some equipment and barriers with occasional shutdowns.
E	Poor condition of equipment, corrosion in the majority of system parts.
F	Very poor condition of equipment and barriers, corrosion in all equipment and barriers.

	Characteristics of RIF score for system complexity
A	System is very simple, no complexity and manageable by all technicians.
B	System is simple, no complexity.
C	System is simple, no notable difficulties.
D	System is complex but manageable.
E	System is very complex, not manageable by all technicians.
F	System is extremely complex.

	Organizational/operational factors **Characteristics of RIF score for absence of human operator**
A	Presence of human operator 24/7 with a very good rotation system and a sufficient number of operators.
B	Presence of human operator 24/7, good rotation system.
C	Presence of human operator, simple rotation system and sufficient number of operators.
D	Absence of some operators, but the number is sufficient in the majority of cases.
E	Remarkable absence of operators, insufficient number and weak rotation system.
F	Total absence of human operator.

	Characteristics of RIF score for communication
A	Excellent communication, information is disseminated in a timely manner.
B	Very good communication.
C	Good communication.
D	Not-so-good communication, but generally information is disseminated in a timely manner.
E	Poor communication, information does not disseminate on time.
F	No communication.

In order to determine the QI scores of the RIFs for all initiating events, and assuming that Q is the measure of status with s representing the score or status of RIF number i, we use expert judgment to determine P_{low} as the lower limit for P_{ave} and P_{high} as the upper limit for P_{ave} ((Aven, 2006)).

Based on this, we define Qi(s) as follows: (Seljelid, 2007)

If: **s** equals **A**, then Qi(s) is calculated as: **P_{low}/P_{ave}**;

If **s** equals **C**, then Qi(s) is: set to **1,**

and if **s** equals **F**, then Qi(s) is: determined as **P_{high}/P_{low}**.

The proposed mathematical model dictates that Qi, the quantitative indicator, varies with the score Si assigned to each RIF, as well as with the ratio of the lowest and average scores, P_{low}(A) and P_{ave}(A), and the highest and average scores, P_{high}(A) and Pave(A), respectively.

Specifically, if the score is A and P_{low}(A) is a is 10% of Pave(A), then Q_i takes on a 0.1 value. If the score is F and P_{high}(A) is 10 times of P_{ave}(A), then Qi takes on 10 value. Similarly, if the score is C, then Qi assumes yet 1. Furthermore, if all RIFs share the same score, then the average score, P_{ave}(A), becomes either P_{low}(A) or P_{high}(A), depending on the common score if it is equal to A or F.

To compute Qi values for Si = B, we establish a linear connection between Qi (A) and Qi (C), and apply weights to the scores of RIFs. The resulting Qi(B) can be determined as a function of these weights: SA = 1, SB = 2, SC= 3, SD = 4, SE = 5, et SF = 6.

$$Qi = \frac{Plow}{Pave} + \frac{(SB - SA).(1 - \frac{Plow}{Pave})}{SC - SA} \ldots\ldots\ldots.(IX)$$

In order to compute Qi values for S = D and E, we use a similar linear relationship between Qi (C) and Qi (F), and make use of appropriate coefficients and scores for each RIF.

$$Qi = 1 + \frac{(SD - SC).(\frac{Phigh}{Pave} - 1)}{SF - SC} \ldots\ldots\ldots..(X)$$

In order to compute Qi values for S = E, we use a similar linear relationship between Qi (C) and Qi (F), and make use of appropriate coefficients and scores for each RIF.

$$Qi = 1 + \frac{(SE - SC).(\frac{Phigh}{Pave} - 1)}{SF - SC} \dots\dots\dots (XI)$$

Evaluation of the RIF scores for the initiating event A0

$P_{ave} = 0.1$;

$P_{low} = P_{ave}/10 = 0.01$, thus $P_{low}/P_{ave} = 0.1$;

$P_{high} = 10 * P_{ave} = 1$, thus $P_{high}/P_{ave} = 10$.

For the RIF A01 Design:

S (A01) = A (1)

Consequently: Q0(A)= 0.1

For RIF A02 Periodic maintenance/testing:

S (A02) = B (2), thus, we use the formulate:

$$Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1}$$

Consequently: Q0(B)= 4

For RIF A03 Corrosion:

S (A02) = C (3)

Consequently: Q0(C)= 1

Evaluation of the RIF scores for the initiating event A11

For the RIF A111 Absence of human operator:

S (A111) = B (2), thus, we use the formulate:

$$Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1} = 0.55$$

Consequently: $\boxed{Q1(B)= 0.55}$

For the RIF A112 Communication:

S (A112) = C (3)

Consequently: $\boxed{Q1(C)= 1}$

For the RIF A123 Competence:

S (A113) = A (1)

Consequently: $\boxed{Q1(A)= 0.1}$

Evaluation of the RIF scores for the initiating event A12

For the RIF A121 Design:

S (A123) = A (1)

Consequently: $\boxed{Q2(A)= 0.1}$

For the RIF A122 Maintenance/testing:

S (A122) = D (4), thus, we use the formulate:

$$Qi = 1 + \frac{(4-3).(\frac{1}{0.1}-1)}{6-3}$$

Consequently: $\boxed{Q2(D)= 4}$

For the RIF A123 Power supply:

S (A121) = B (2), thus, we use the formulate:

$$Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1}$$

Consequently: $\boxed{Q2(B)= 0.55}$

- **Evaluation of the RIF scores for the initiating event A13**

For the RIF A131 Power supply:

S (A131) = B (2), thus, we use the formulate:

$$Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1}$$

Consequently: $\boxed{\text{Q3(B)= 0.55}}$

For the RIF A132 Maintenance/testing:

S (A142) = C (3)

Consequently: $\boxed{\text{Q4(C)= 1}}$

For the RIF A133 Diagnostic/Programming:

S (A133) = C (3)

Consequently: $\boxed{\text{Q3(C)= 1}}$

Evaluation of the RIF scores for the initiating event A21

For the RIF A211 Design:

S (A211) = A (1)

Consequently: $\boxed{\text{Q5(A)= 0.1}}$

For RIF A212 periodic maintenance/testing:

S (A222) = B (2), thus, we use the formulate:

$$Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1} = 0.55$$

Consequently: $\boxed{\text{Q5(B)= 0.55}}$

For the RIF A213 Power supply:

S (A223) = B (2), thus, we use the formulate: $Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1} = 0.55$

Consequently: Q5(B)= 0.55

Evaluation of the RIF scores for the initiating event A23

For the RIF A231 Power supply:

S (A231) = A (1)

Consequently: Q7(A)= 0.1

For RIF A232 Periodic maintenance/testing:

S (A232) = B (2), thus, we use the formulate:

$$Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1}$$

Consequently: Q7(B)= 4

For RIF A233 Diagnostics/Programming:

S (A233) = C (3)

Consequently: Q7(C)= 1

Evaluation of the RIF scores for the initiating event A24

For the RIF A241 Power supply:

S (A251) = A (1)

Consequently: Q8(A)= 0.1

For RIF A242 Periodic maintenance/testing:

S (A252) = B (2), thus, we use the formulate:

$$Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1}$$

Consequently: $\boxed{\text{Q8(B)= 4}}$

For RIF A243 Diagnostics/Programming:

S (A253) = C (3)

Consequently: $\boxed{\text{Q8(C)= 1}}$

Evaluation of the RIF scores for the initiating event A25

For the RIF A251 Power supply:

S (A251) = A (1)

Consequently: $\boxed{\text{Q9(A)= 0.1}}$

For RIF A252 Periodic maintenance/testing:

S (A252) = B (2), thus, we use the formulate:

$$Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1}$$

Consequently: $\boxed{\text{Q9(B)= 4}}$

For RIF A253 Diagnostics/Programming:

S (A253) = C (3)

Consequently: $\boxed{\text{Q9(C)= 1}}$

Evaluation of the RIF scores for the initiating event A31

For the RIF A311 Power supply:

S (A311) = A (1)

Consequently: Q10(A)= 0.1

For RIF A312 Periodic maintenance/testing:

S (A312) = B (2), thus, we use the formulate:

$$Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1}$$

Consequently: Q10(B)= 4

For RIF A313 Diagnostics/Programming:

S (A253) = C (3)

Consequently: Q10(C)= 1

Evaluation of the RIF scores for the initiating event A32

For the RIF A321 Power supply:

S (A321) = A (1)

Consequently: Q11(A)= 0.1

For RIF A322 Periodic maintenance/testing:

S (A322) = B (2), thus, we use the formulate:

$$Qi = \frac{0.01}{0.1} + \frac{(2-1).(1-\frac{0.01}{0.1})}{3-1}$$

Consequently: $\boxed{Q11(D)= 4}$

For RIF A323 Diagnostics/Programming:

S (A323) = C (3)

Consequently: $\boxed{Q11(C)= 1}$

- **Adjustment of the average frequency of basic event A0, and the average probabilities of failure of barriers A1, A2, A3, A4** (Seljelid, 2007)

This step is performed following the next equation:

$$Pprev(A) = Pave(A). \sum_{t=1}^{n} Wi.Qi \dots \dots \dots (XII)$$

Knowing that: $\sum_{t=1}^{n} Wi = 1$

Where:

"P_{rev}(A)" = "Adjusted (Revised) Probability".

"P_{ave}(A)" = "Average Probability".

"W_i" = to "Weight of the RIF for event A".

"Q_i" = to "RIF score measurement, and n is the number of RIF, here”.

Table4.12 : Final results – Scenario A

	Initiating/basic event	P_{ave}	Rifs	W_i	$W_{i\,normalised}$	S_i	Q_i	Mf	P_{rev}
A0	**A0** Loss of containment	1×10^{-2}						0.69	2.23×10^{-2}
			A01 Design	2	0.125	A	0.1		
			A02 Periodic maintenance/testing	6	0.425	B	0.55		
			A03 Corrosion	10	0.45	C	1		
A1	**A1** Surveillance system failure	1×10^{-2}							5.2×10^{-3}
	A11	1×10^{-2}						0.52	5.2×10^{-3}
	Operator failure		A111 Absence of human operator	2	0.2	B	0.55		
			A112 Communication	8	0.375	C	1		
			A113 Competence	10	0.425	A	0.1		
	A12	1×10^{-3}						1.84	1.84×10^{-3}
	Alarm failure		A121 Design	2	0.2	A	0.1		
			A122 Maintenance/testing	4	0.4	D	4		
			A123 Power supply	4	0.4	B	0.55		
	A13	5×10^{-4}						0.82	4.1×10^{-4}
	Logical processing unit failure		A131 Power supply	4	0.4	B	0.55		

			A132 Maintenance/testing	2	0.2	C	1		
			A133 Diagnostics/ Programming	4	0.4	C	1		
A2	**A2** Surveillance system failure	1.044×10^{-2}							2.2×10^{-2}
	A21 Pressure transmitter failure	1.31×10^{-3}						0.46	6.02×10^{-4}
			A211 Design	2	0.2	A	0.1		
			A212 periodic maintenance/testing	4	0.4	B	0.55		
			A213 Power supply	4	0.4	B	0.55		
	A22 Analogue input failure	7×10^{-4}						0.64	4.84×10^{-4}
			A221 Power supply	2	0.2	A	0.1		
			A222 Maintenance/testing	4	0.4	B	0.55		
			A223 Diagnostics/ Programming	4	0.4	C	1		
	A23 CPU	2×10^{-3}						0.64	1.28×10^{-4}
			A231 Power supply	2	0.2	A	0.1		
			A232 Maintenance/testing	4	0.4	B	0.55		
			A233 Diagnostics/ Programming	4	0.4	C	1		
	A24 Digital output failure	7×10^{-4}						0.64	4.84×10^{-4}
			A241 Power supply	2	0.2	A	0.1		

			A242 Maintenance/testing	4	0.4	B	0.55		
			A243 Diagnostics/ Programming	4	0.4	C	1		
	A25	9.14×10^{-3}						2.34	2.14×10^{-2}
	ESD valve failure		A251 Design	2	0.167	A	0.1		
			A252 Periodic maintenance/testing	4	0.333	C	1		
			A253 Corrosion	10	0.5	D	4		
A3	**A3** Relief valve Failure	8.92×10^{-3}							2.14×10^{-2}
	A31	2.84×10^{-3}						1.84	5.22×10^{-3}
	Structural deterioration		A311 Design	2	0.2	B	0.55		
			A312 Maintenance/testing	6	0.425	C	0.55		
			A313 System complexity	4	0.375	D	4		
	A32	6.1×10^{-3}						2.66	1.62×10^{-2}
	Relief valve fail to open		A321 Design	2	0.167	B	0.55		
			A322 Periodic maintenance/testing	4	0.333	C	1		
			A323 Corrosion	10	0.5	D	4		

4.3.10. Step 08: Calculation of the revised leak frequency Fave (A) of the consequence of scenario A

By incorporating the RIFs, the resulting revised frequency provides a more reliable understanding of the barriers' efficiency. To quantify the revised frequency of the generic undesirable consequence associated with accident scenario A, the approach entails multiplying the revised initiating event frequency by the probability of barrier failure (PFD) as follow: (Seljelid, 2007)

$$\mathbf{Fave\ (A) = F_{rev}\ (A0).\ PFD_{rev}\ (A1).\ PFD_{rev}\ (A2).\ PFD_{rev}\ (A3)} \ \ldots\ldots \text{(XIII)}$$

$$\mathbf{Fave\ (A)} = 5.45 \times 10^{-8}\ \mathbf{(/year)}$$

4.3.11. Result's discussion

To summarize the results obtained in this study in order to compare the initial values with the revised values incorporating risk influencing factors (RIFs); the initial PFD values for the barriers were 1×10^{-2} 1.044×10^{-2} , and 8.92×10^{-3} for the first, second, and third barrier, respectively.

Upon considering the RIFs, the revised PFD values for the barriers showed notable variations. The first barrier had a revised PFD value of 5.2×10^{-3}, indicating a substantial improvement in its performance. The second barrier experienced a significant increase in its revised PFD value, which became 2.2×10^{-2}. Similarly, the third barrier showed an increased revised PFD value of 2.14×10^{-2}. These revised values indicate a higher level of risk associated with the second and third barriers.

The revised frequency of the initiating event, which was initially 1×10^{-2}, also experienced a significant change and increased to 2.23×10^{-2}. This increase can be attributed to the consideration of additional factors that contribute to the frequency estimation, providing a more comprehensive understanding of the scenario.

By recalculating the revised frequency of the scenario based on the updated data, incorporating both the revised PFD values and the revised frequency of the initiating event, a revised frequency of 5.45×10^{-8} per year was obtained. This result indicates a notable increase in the overall risk associated with accident scenario A when considering the failure of the barriers as the shown in the graph where the changes in the risk profile can be more effectively communicated, allowing for a better understanding of how the revised data and considerations of RIFs have impacted the risk assessment.

However, from a safety perspective a frequency of 5.45×10^{-8} per year is considered within an acceptable risk range.

4.4. Scenario B: Fire at Thermodyn centrifugal compressor C03

4.4.1. Description du scénario B

Scenario name	Fire at Thermodyn centrifugal compressor C03
General description	Fire at centrifugal compressor C03 because of Compressor rotation speed poorly studied (Human error on a procedural type action).
Initiating event	Compressor rotation speed poorly studied (Human error on a procedural type action).
Existing safety barriers	Fire can be prevented if the following barriers functions are implemented: - Alarm + human intervention: TT tempurature alarm + operator (control room); -Automatic Emergency; Shut Down: ESD

Following the same steps as we did with the first scenario.

4.4.2. Step 02: Elaboration of event tree

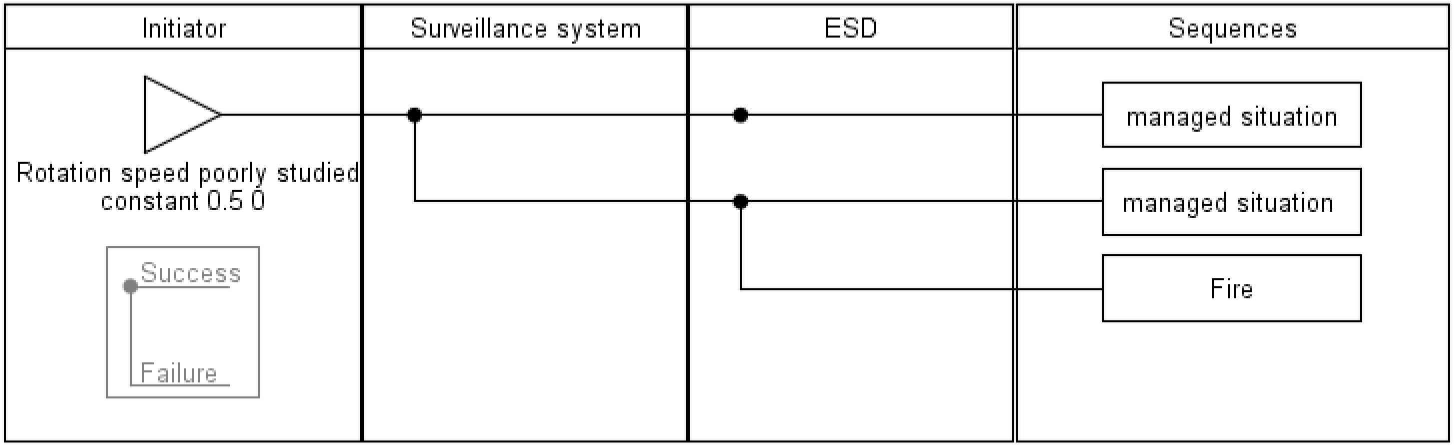


Figure4.20: Event tree for scenario B

4.4.3. Elaboration of safety barrier failure trees

The figures below are obtained by the GRIF software and the table 11:

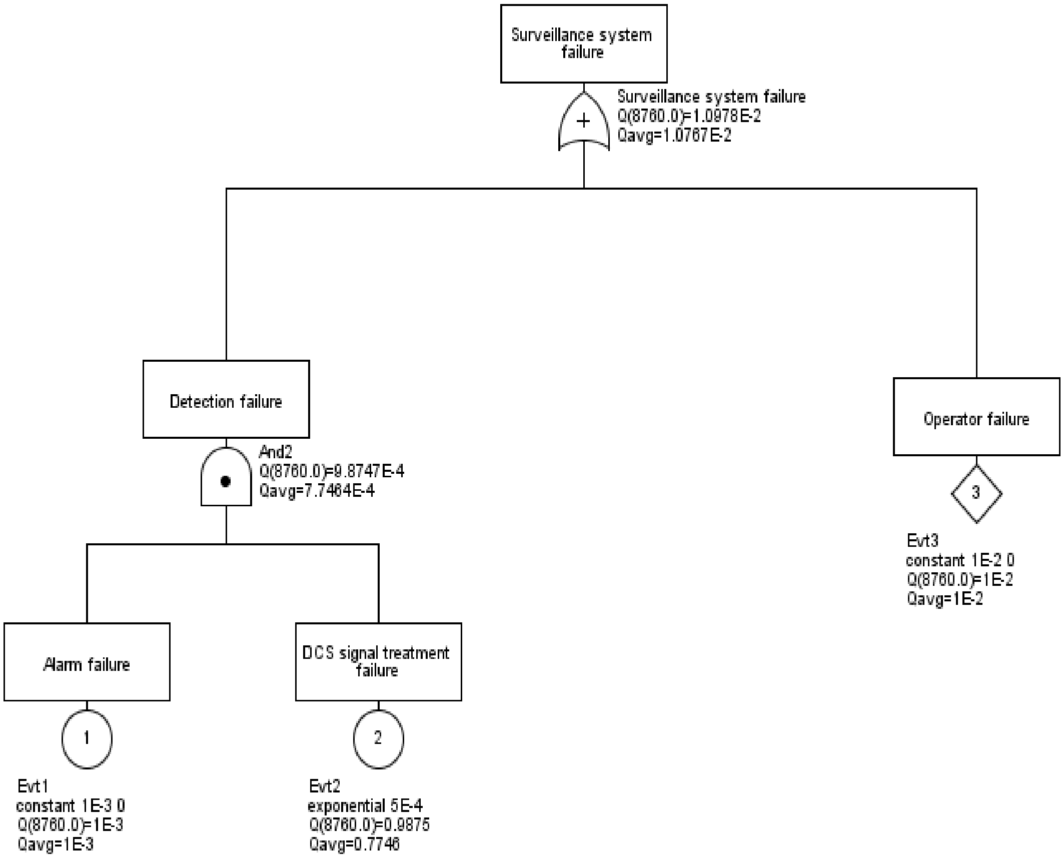


Figure 4.21: Fault tree of barrier 1

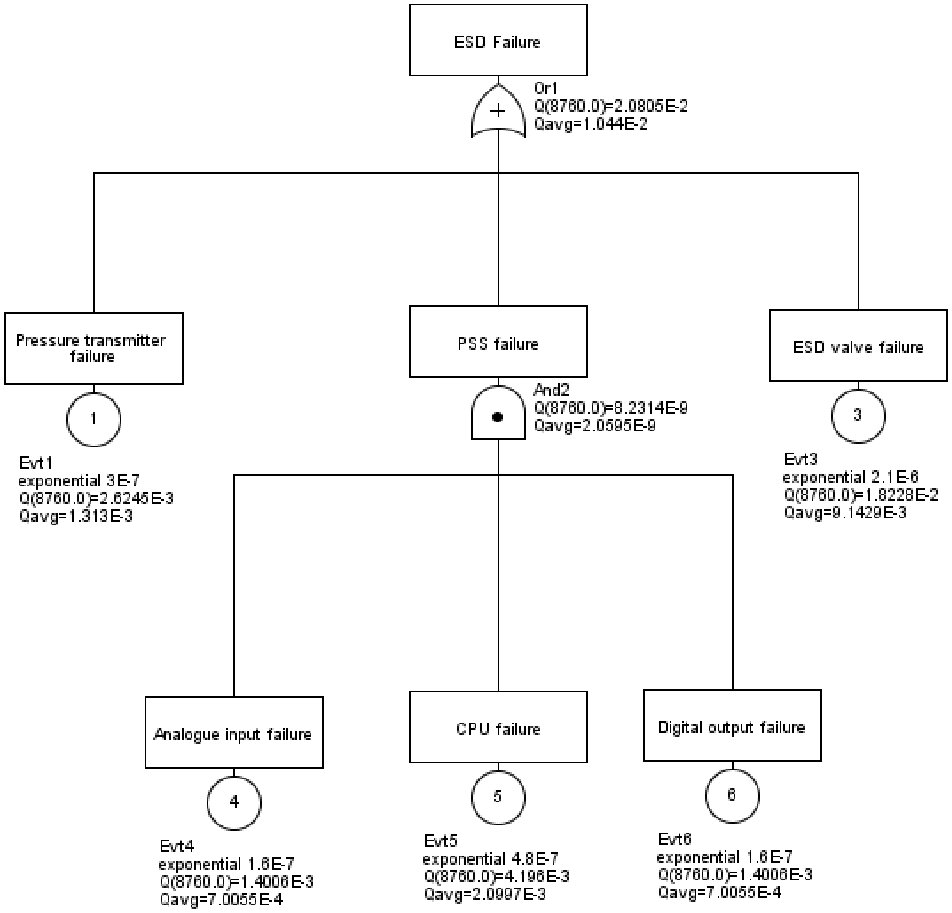


Figure 4.22 : Fault tree of barrier 2

- **Basic events probabilities**

the probabilities of the basic events (B1) and (B2) are similar to the previous scenario of (A1) and (A2) respectively.

4.4.4. Step 04: Calculation of the average leak frequency F_{ave} (B) of the the consequence of scenario B

The quantification of the frequency of the generic undesirable consequence arising from accident scenario B is accomplished through the equation:

$$\mathbf{F_{ave}\ (B) = F_{avg}\ (B0).\ PFD_{avg}\ (B1).\ PFD_{avg}\ (B2)\ \ldots..}\ \text{(XIV)}$$

$$\mathbf{F_{ave}\ (B)} = 2.28 \times 10^{-6}\ \mathbf{(/year)}$$

4.4.5. Step 05: Developing influence diagrams of the initiating events and basic scenario B

For the initiating event B0:

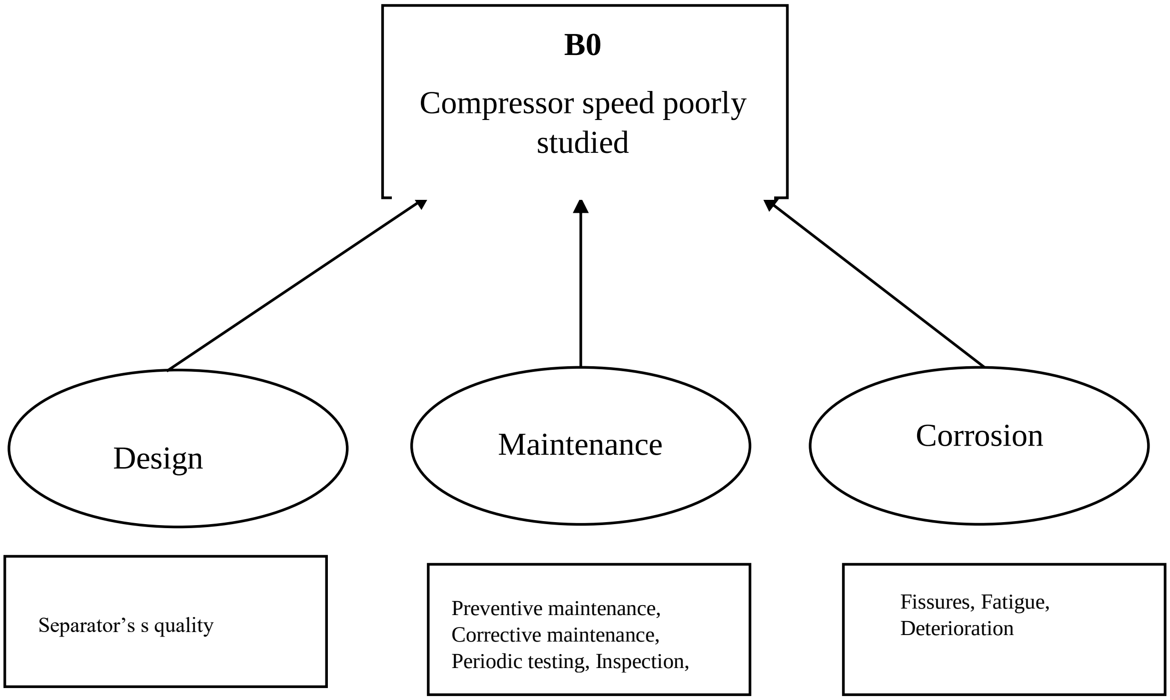


Figure4.23: Influence diagram for B0

- **For barrier B1**

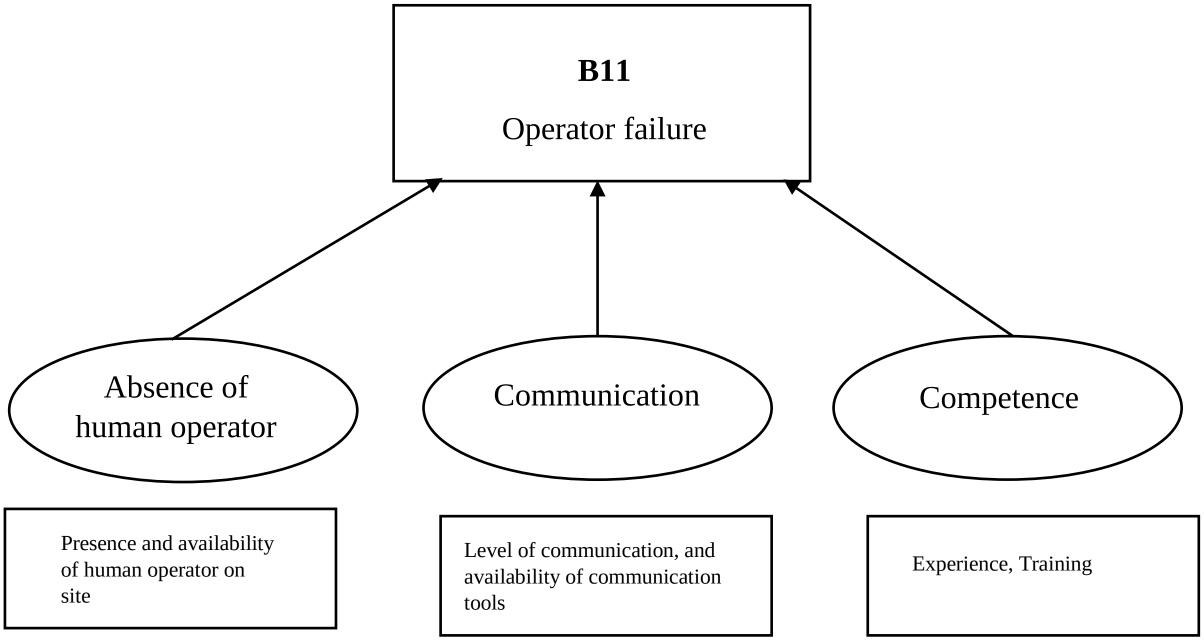


Figure 4.24: Influence diagram for B11

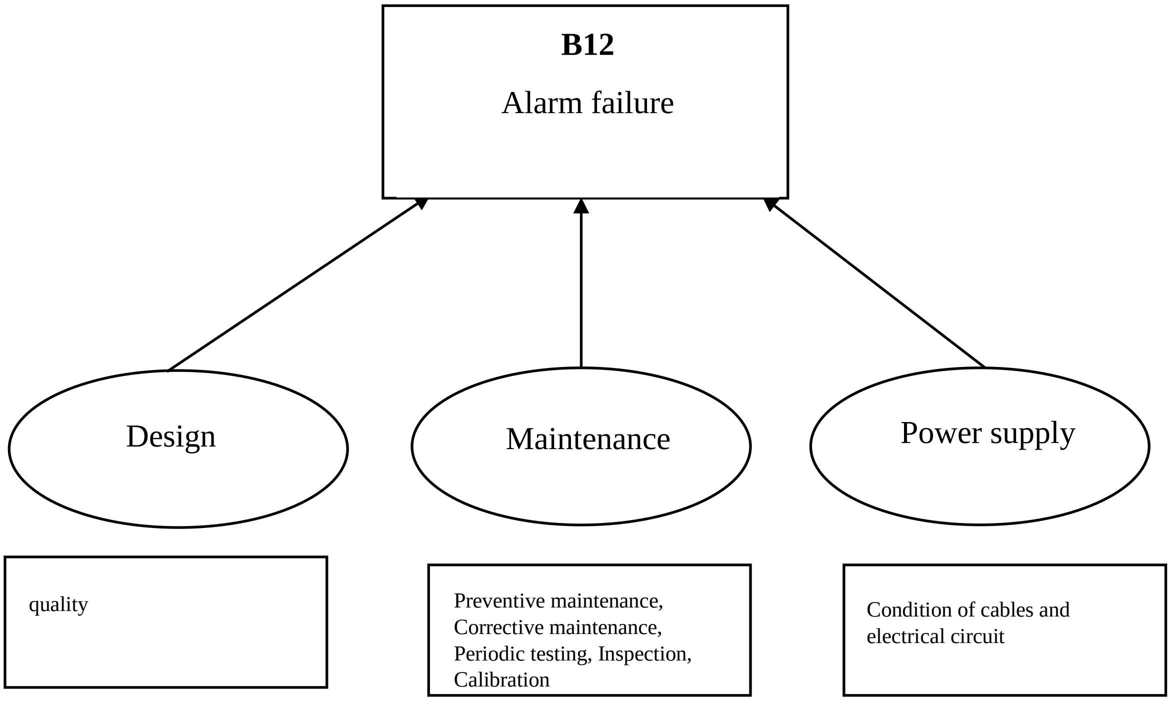


Figure 4.25: Influence diagram for B12

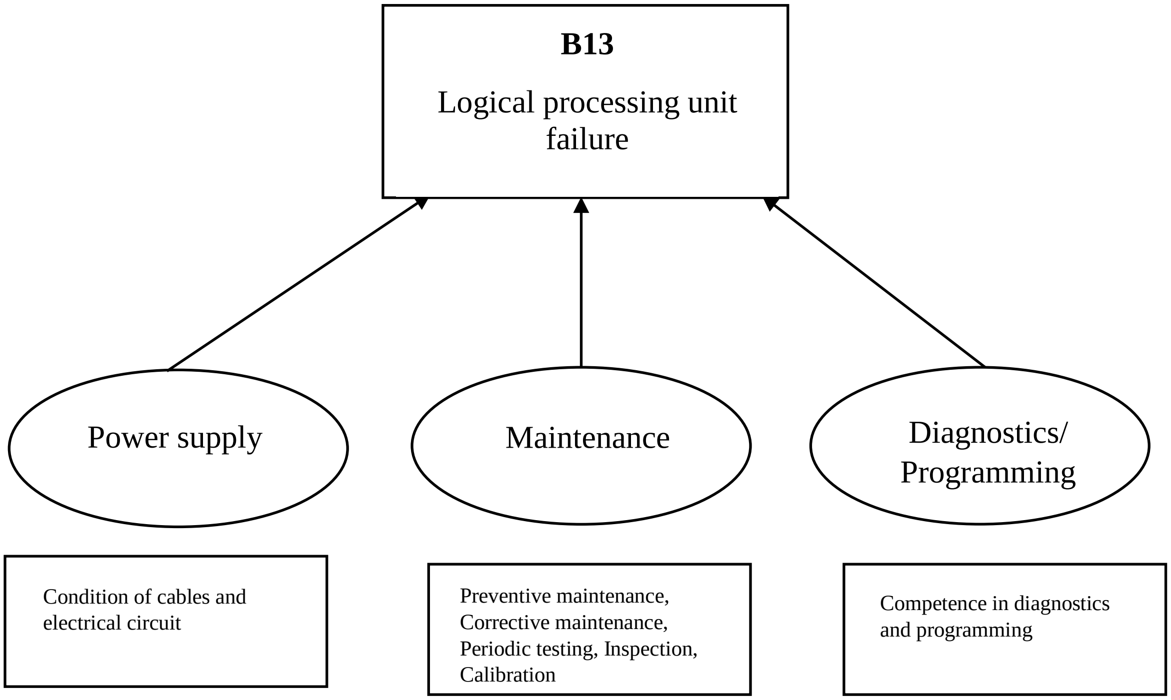


Figure 5.26: Influence diagram for B13

- **For barrier B2**

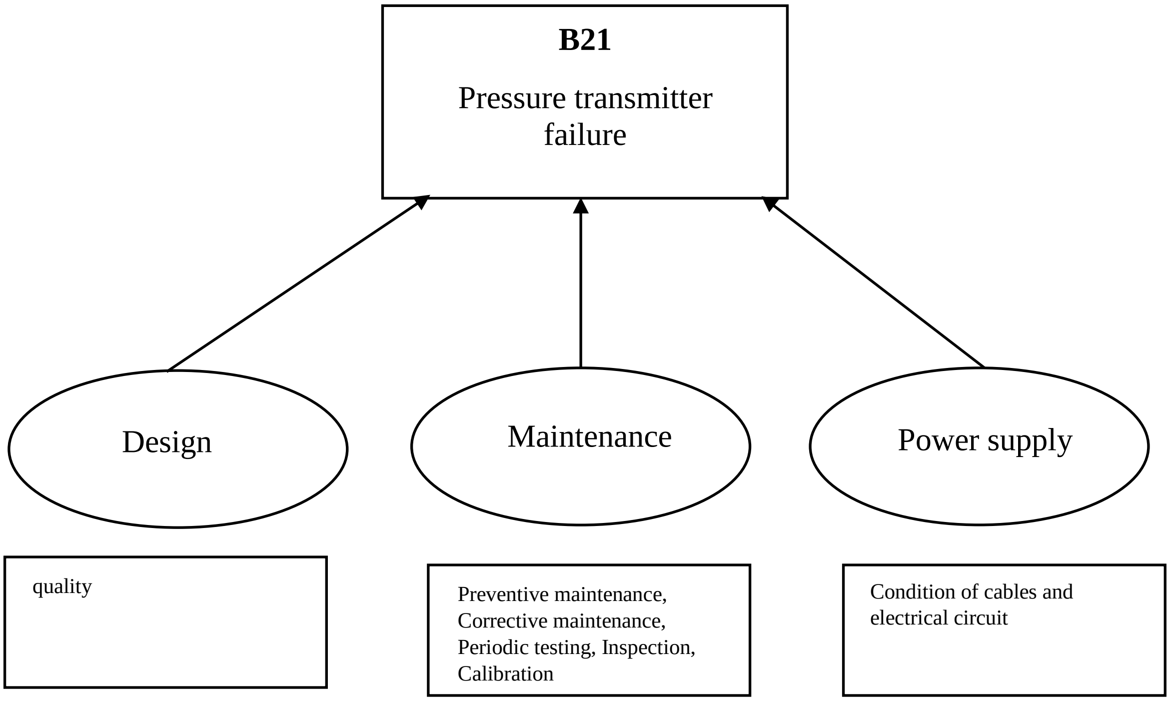


Figure 4.27: Influence diagram for B21

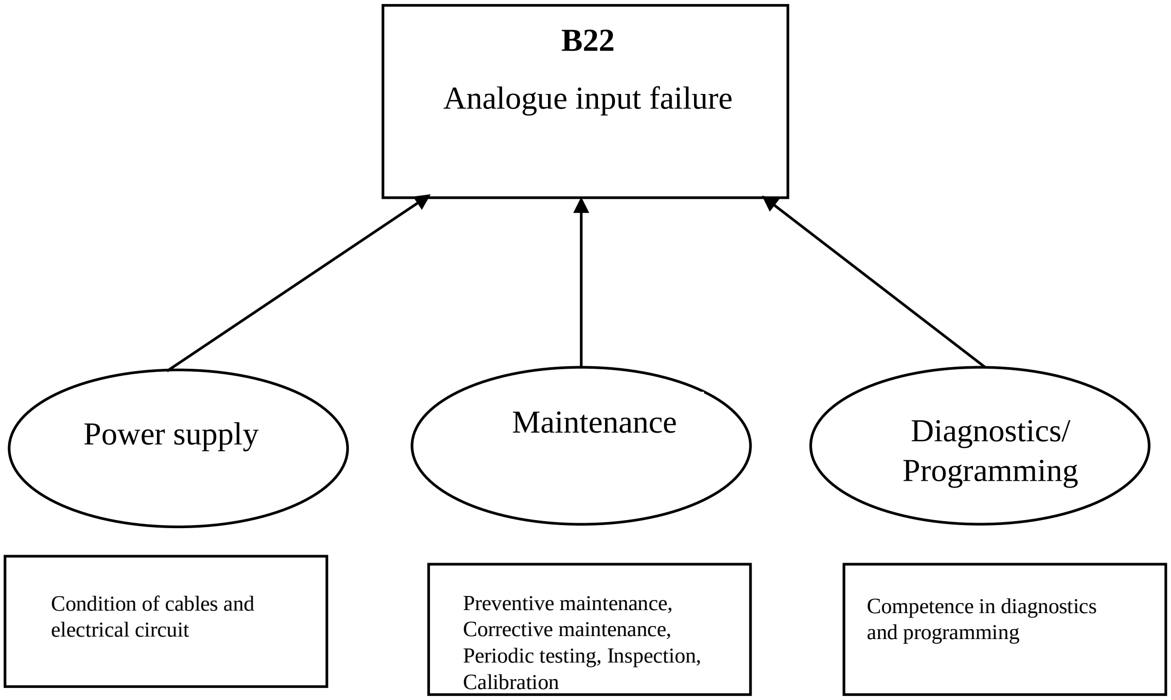


Figure4.27:Influence diagram for B22

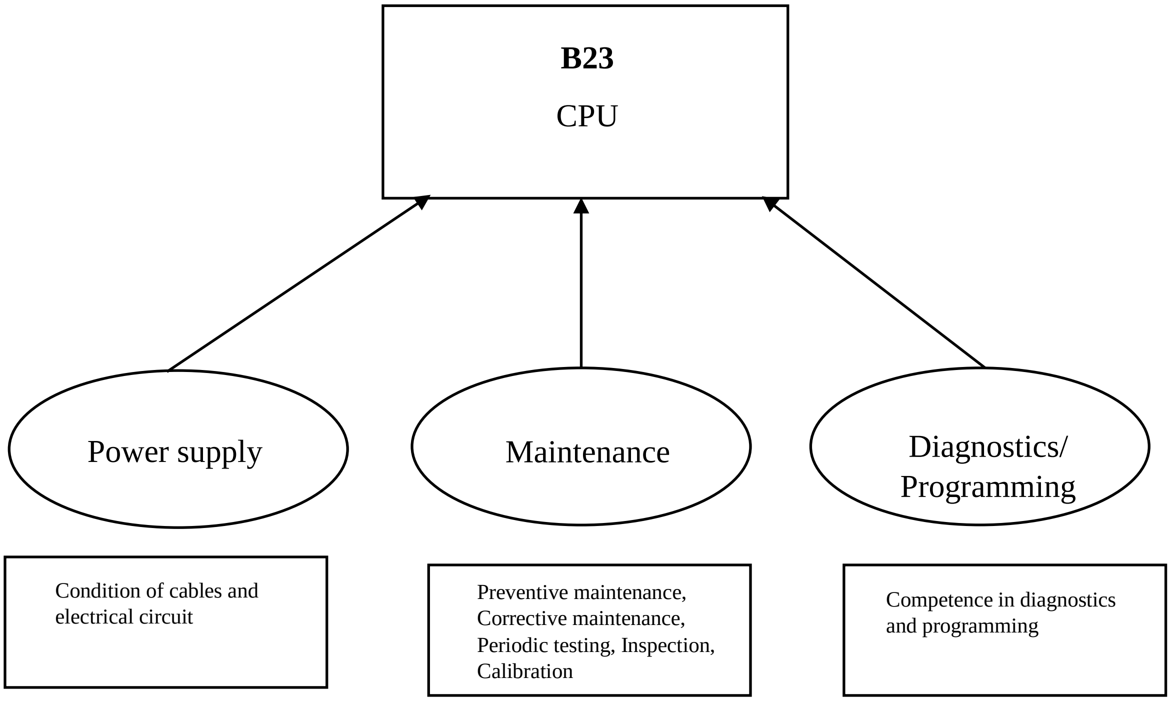


Figure 4.28 : Influence diagram B23

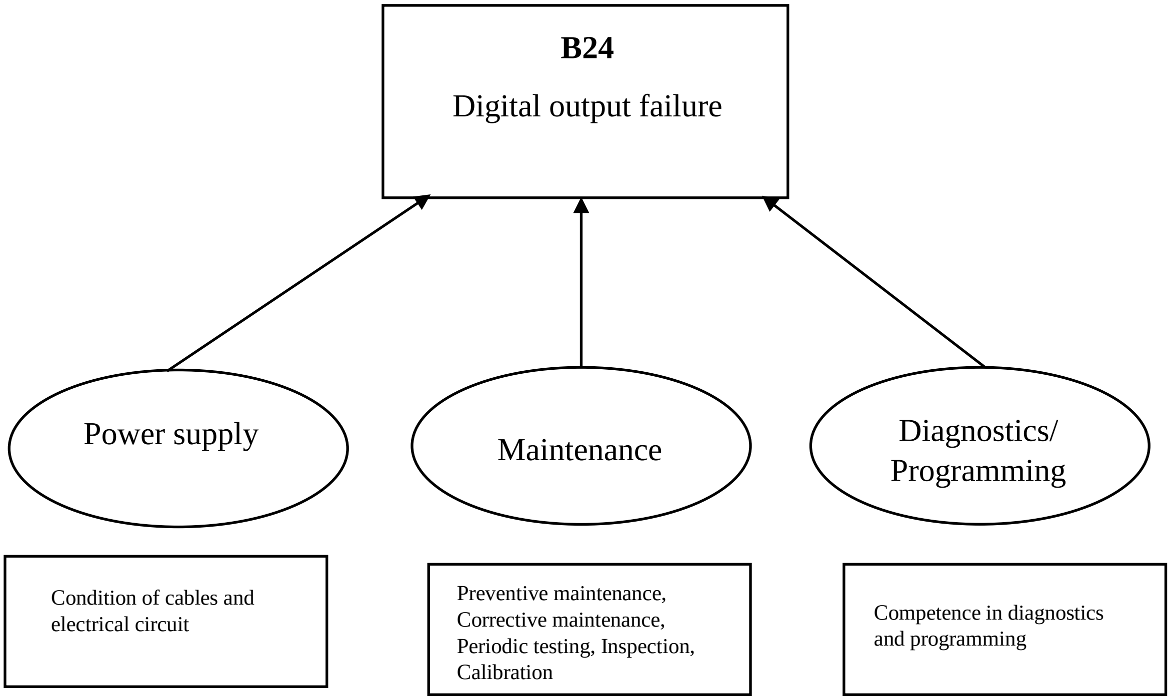


Figure 4.29: Influence diagram for B24

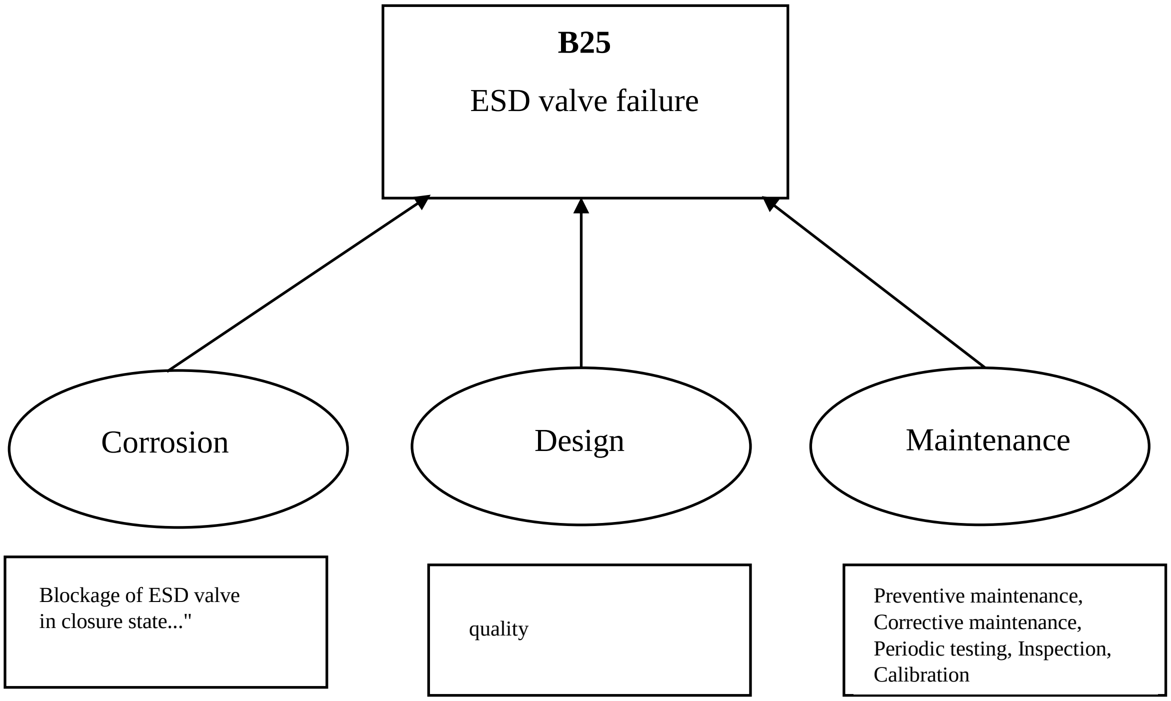


Figure4.30 : Influence diagram for B25

Table 4.13 : Final results -Scenario B

	Initiating/basic event	P_{ave}	Rifs	W_i	$W_{i\,normalised}$	S_i	Q_i	Mf	P_{rev}
B0	**B0** Loss of containment	1×10^{-2}						0.69	2.23×10^{-2}
			B01 Design	2	0.125	A	0.1		
			B02 Periodic maintenance/testing	6	0.425	B	0.55		
			B03 Corrosion	10	0.45	C	1		
B1	**B1** Surveillance system failure	1×10^{-2}							5.2×10^{-3}
	B11	1×10^{-2}						0.52	5.2×10^{-3}
	Operator failure		B111 Absence of human operator	2	0.2	B	0.55		
			B112 Communication	8	0.375	C	1		
			B113 Competence	10	0.425	A	0.1		
	B12	1×10^{-3}						1.84	1.84×10^{-3}
	Alarm failure		B121 Design	2	0.2	A	0.1		
			B122 Maintenance/testing	4	0.4	D	4		
			B123 Power supply	4	0.4	B	0.55		
	B13	5×10^{-4}						0.82	4.1×10^{-4}
	Logical processing unit failure		B131 Power supply	4	0.4	B	0.55		

			B132 Maintenance/testing	2	0.2	C	1		
			B133 Diagnostics/ Programming	4	0.4	C	1		
B2	**B2**								
	Surveillance system failure	1.044×10^{-2}							2.2×10^{-2}
	B21	1.31×10^{-3}						0.46	6.02×10^{-4}
	Pressure transmitter failure		B211 Design	2	0.2	A	0.1		
			B212 periodic maintenance/testing	4	0.4	B	0.55		
			B213 Power supply	4	0.4	B	0.55		
	B22	7×10^{-4}						0.64	4.84×10^{-4}
	Analogue input failure		B221 Power supply	2	0.2	A	0.1		
			B222 Maintenance/testing	4	0.4	B	0.55		
			B223 Diagnostics/ Programming	4	0.4	C	1		
	B23	2×10^{-3}						0.64	1.28×10^{-4}
	CPU		B231 Power supply	2	0.2	A	0.1		
			B232 Maintenance/testing	4	0.4	B	0.55		
			B233 Diagnostics/ Programming	4	0.4	C	1		
	B24	7×10^{-4}						0.64	4.84×10^{-4}
	Digital output failure		B241 Power supply	2	0.2	A	0.1		

		B242 Maintenance/testing	4	0.4	B	0.55		
		B243 Diagnostics/ Programming	4	0.4	C	1		
B25	9.14×10^{-3}						2.34	2.14×10^{-2}
ESD valve failure		B251 Design	2	0.167	A	0.1		
		B252 Periodic maintenance/testing	4	0.333	C	1		
		B253 Corrosion	10	0.5	D	4		

4.4.6. Calculation of the revised leak frequency F_{ave} (B) of the the consequence of scenario B

The quantification of the frequency of the generic undesirable consequence arising from accident scenario B is accomplished through the equation:

$$\mathbf{F_{rev}\ (B) = F_{rev}\ (B0).\ PFD_{rev}\ (B1).\ PFD_{rev}\ (B2)} \ldots.\ \text{(XV)}$$

$$\mathbf{F_{ave}\ (B)} = 2.55 \times 10^{-5}\ \mathbf{(/year)}$$

4.4.7. Results discussion

In scenario B, the revised frequency of the initiating event was determined to be 2.28×10^{-6} . By recalculating the revised frequency of the scenario based on the revised data, resulting in a revised frequency 2.55×10^{-5} per year.

These findings indicate a notable change in the risk profile of accident scenario B after considering the RIFs and revised data. The revised PFD values reflect an enhanced understanding of the decrease of the barriers' performance and their effectiveness in preventing the undesired consequence. The significant increase in the revised frequency of the initiating event underscores the importance of accounting for updated data and RIFs to obtain a more accurate estimation.

Part02: Converting BORA methodology to BN (Medkour, 2017)

4.5. The Drive for Converting BORA methodology to a Bayesian Network

The conversion of BORA (Barrier and Operational Risk Analysis) to a Bayesian network emerges from the pressing need to overcome inherent limitations and elevate risk analysis methodologies.

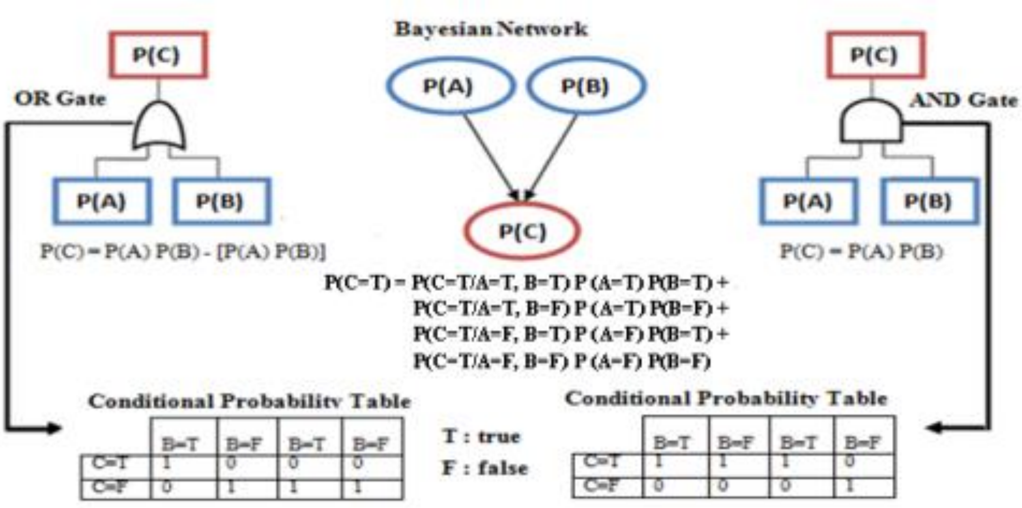
A critical requirement in risk analysis is the quantification of uncertainties, an aspect that BORA typically addresses through expert judgment. However, this approach may lack the rigor and precision necessary for robust risk assessments. The integration of BORA principles into a Bayesian network overcomes this limitation by providing a formal probabilistic framework. This enables the quantification of uncertainties, thereby facilitating more precise assessments of risks and their potential consequences. The enhanced quantification capability significantly reinforces the reliability and validity of the risk analysis, fostering greater confidence in the decision-making process.

4.6. Methodology of converting BORA to BN (Medkour, 2017)

The conversion from BORA to a Bayesian network is based on the principles of fault trees and event trees, utilizing the final results obtained through the GRIF software, which incorporates Risk Importance Factors (RIFs). This approach ensures a fair and comprehensive comparison by considering the end outcomes of the analysis. By including RIFs in the Bayesian network structure, the significance and impact of different risk factors can be accurately evaluated, providing a more detailed understanding of the overall risk landscape. The inclusion of RIFs highlights their crucial role in risk analysis, enabling decision-makers to prioritize mitigation strategies and allocate resources effectively based on the relative importance of various risk factors.

The process of constructing a Bayesian network from a fault tree entails the conversion of the fault tree's graphical representation into a Bayesian network structure. While fault trees employ events and logic gates (AND, OR) as their fundamental elements, Bayesian networks employ nodes to represent events and arcs to model the dependencies between events, as well as causal relationships.

Subsequently, the process of constructing a Bayesian network from a fault tree revolves around the estimation and quantification of probabilities. This step involves assigning a priori probabilities to the root nodes, representing the occurrence probabilities of basic events (primaries) in the fault tree. However, for induced events (intermediate) and final events (dreaded), the associated probabilities are estimated through the calculation of conditional probabilities. Various studies have delved into the transformation of fault trees into Bayesian networks, and the specific steps of this transformation can be found in the referenced works. Figure 1 illustrates the algorithm employed for the conversion of a fault tree into a Bayesian network.



	B=T	B=F	B=T	B=F
C=T	1	0	0	0
C=F	0	1	1	1

	B=T	B=F	B=T	B=F
C=T	1	1	1	0
C=F	0	0	0	1

Figure 4.31: Graphical and digital transformation of Fault tree into Bayesians network *(Medkour, 2017)*

4.6. Conversion of BORA to BN in the turbo compressor system

4.6.1. GeNie Lab software (BaysFusion, 2023)

GeNIe Modeler is a user-friendly software with a graphical interface (GUI) that facilitates interactive model building and learning. Originally designed for Windows, it can also be used on macOS and Linux with the assistance of Wine compatibility software. Since its initial release in 1998, GeNIe has undergone extensive field testing and gained widespread acceptance in both academic and industrial settings, boasting a large user base around the world.

One of the key principles driving the development of GeNIe and other related products is the freedom to create comprehensive models without being limited by available modeling tools.

GeNIe does not force users to conform their models to pre-existing constraints; instead, it enables modeling across various domains according to the specific demands of the application. In instances where exact algorithms are unavailable for certain types of models, GeNIe provides a collection of approximate stochastic sampling algorithms. These algorithms are capable of solving any models created by users, ensuring the software's adaptability and flexibility.

Scenario A: Explosion at Separator S-05

4.6.2. Introducing nodes and gates

- **For barrier 01**

Table 4.14: nodes and gates related to A1

Event of A1	Nodes	Probability	Gate
Surveillance system failure	A1		OR
Operator failure	A11	5.2×10^{-3}	
Detection failure			AND
Alarm failure	A12	1.84×10^{-3}	AND’
Logical processing unit failure	A13	4.1×10^{-4}	AND’

- **For barrier 02**

Table 4.15: nodes and gates related to A2

Event of A2	Nodes	Probability	Gate
ESD failure	A2		OR
Pressure transmitter failure	A21	6.02×10^{-4}	
PSS failure			AND
Analogue input failure	A22	4.84×10^{-4}	AND’’
CPU	A23	1.28×10^{-4}	AND’’
Digital output failure	A24	4.84×10^{-4}	AND’’

ESD valve failure	A25	2.14×10^{-2}

- **For barrier 03**

Table 4.16 : nodes and gates related to A3

Event of A3	Nodes	Probability	Gate
Relief valve failure	A3		OR
Structural deterioration failure	A31	5.22×10^{-3}	
Relief valve fail to open	A32	1.62×10^{-2}	

4.6.3. Bayesian network graphical representation for scenario A

- **For barrier 01**

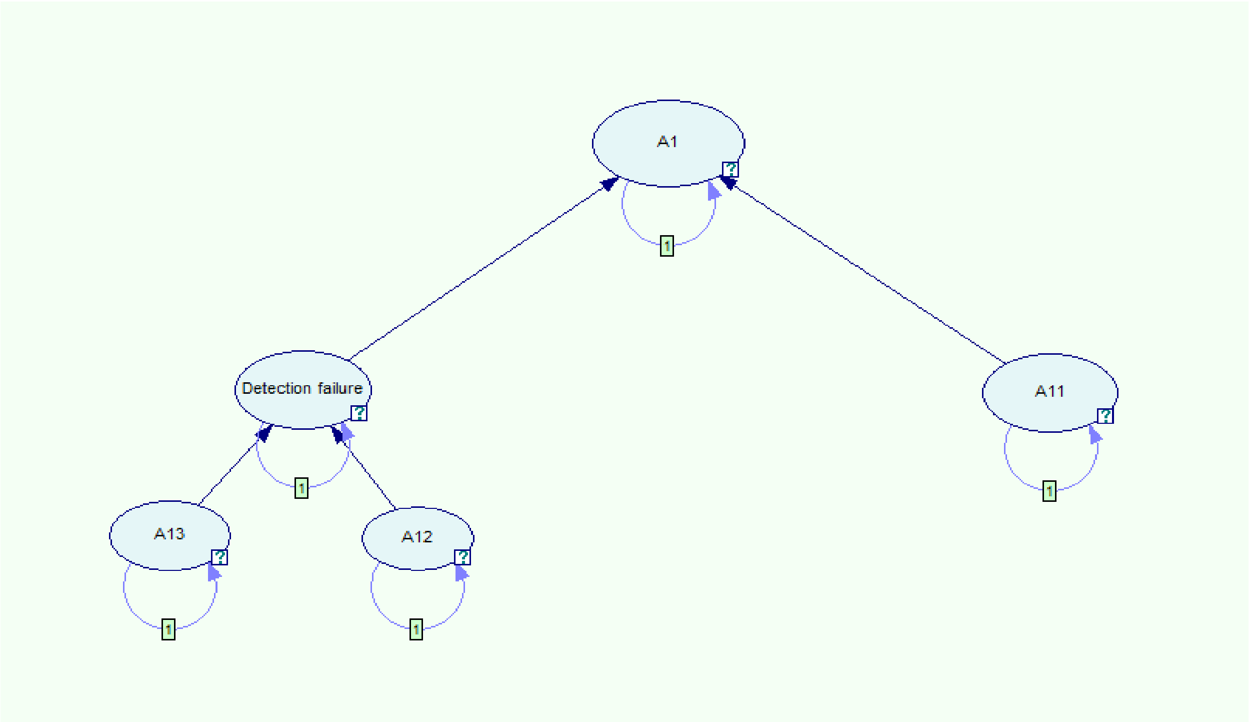


Figure 4.32 : Bayesian network of A1

- **For barrier 02**

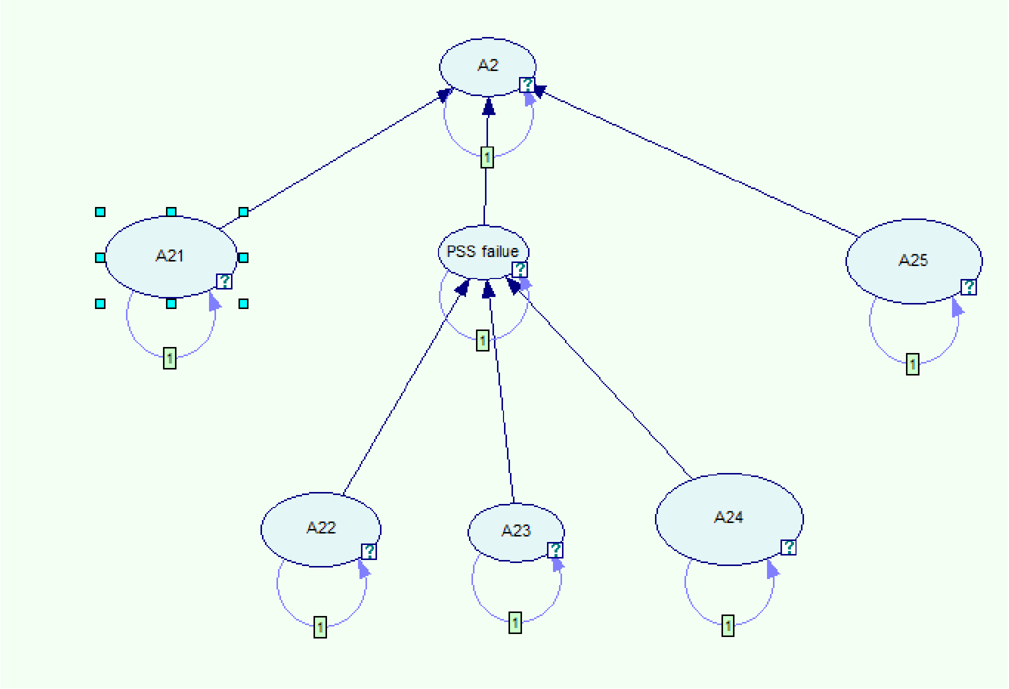


Figure 4.33 : Bayesian network of A2

- **For barrier 03**

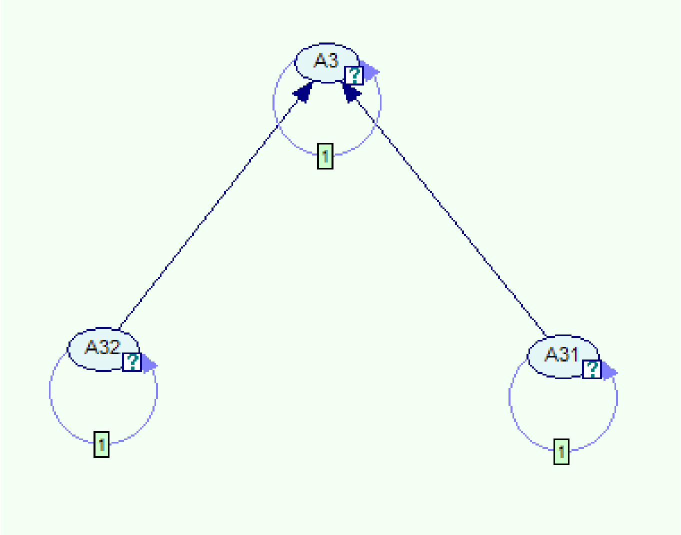
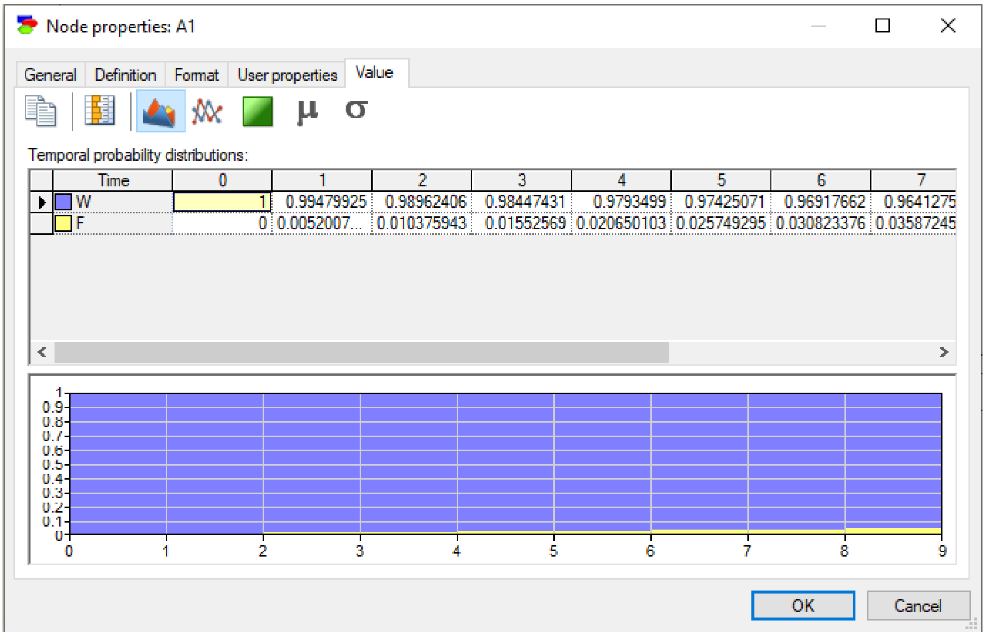


Figure4.34 : Bayesian network of A3

4.6.4. Bayesian network results for scenario A

The results of probabilities represented bellow are obtained by Genie software

- **For barrier 01**

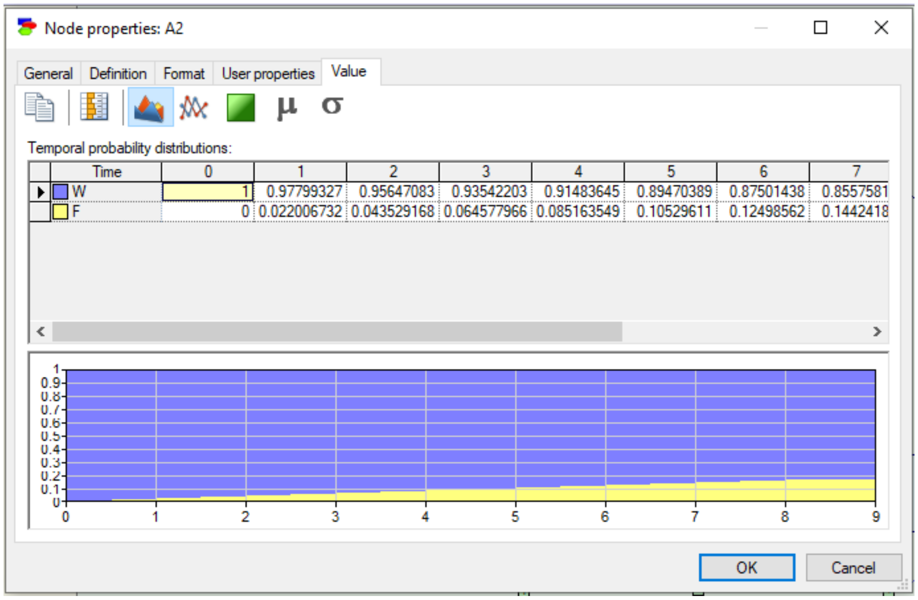


Temporal probability distributions:

Time	0	1	2	3	4	5	6	7
🟦 W	1	0.99479925	0.98962406	0.98447431	0.9793499	0.97425071	0.96917662	0.9641275
🟨 F	0	0.0052007...	0.010375943	0.01552569	0.020650103	0.025749295	0.030823376	0.03587245

Figure 4.35: A1 probabilities and graphical illustration

- **For barrier 02**

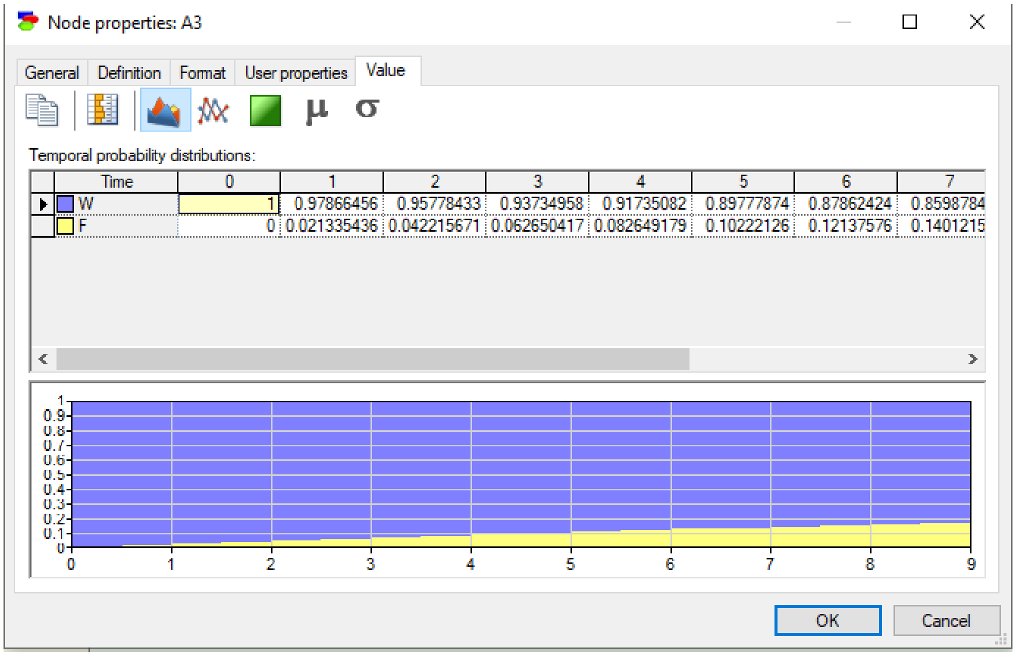


Temporal probability distributions:

Time	0	1	2	3	4	5	6	7
🟦 W	1	0.97799327	0.95647083	0.93542203	0.91483645	0.89470389	0.87501438	0.8557581
🟨 F	0	0.022006732	0.043529168	0.064577966	0.085163549	0.10529611	0.12498562	0.1442418

Figure 4.36: A2 probabilities and graphical illustration

For barrier 03



Temporal probability distributions:

Time	0	1	2	3	4	5	6	7
🟦 W	1	0.97866456	0.95778433	0.93734958	0.91735082	0.89777874	0.87862424	0.8598784
🟨 F	0	0.021335436	0.042215671	0.062650417	0.082649179	0.10222126	0.12137576	0.1401215

Figure 4.37: A3 probabilities and graphical illustration

Bayesian network conversion for scenario B

4.7. Scenario B: FIRE at Compressor C-03

4.7.1. Introducing nodes and gates

- **For barrier 01**

Table 4.17: nodes and gates related to B1

Event of B1	Nodes	Probability	Gate
Surveillance system failure	B1		OR
Operator failure	B11	5.2×10^{-3}	
Detection failure			AND
Alarm failure	B12	1.84×10^{-3}	AND’
Logical processing unit failure	B13	4.1×10^{-4}	AND’

- **For barrier 02**

Table 4.18 : nodes and gates related to B2

Event of B2	Nodes	Probability	Gate
ESD failure	B2		OR
Pressure transmitter failure	B21	6.02×10^{-4}	
PSS failure			AND
Analogue input failure	B22	4.84×10^{-4}	AND’’
CPU	B23	1.28×10^{-4}	AND’’
Digital output failure	B24	4.84×10^{-4}	AND’’
ESD valve failure	B5	2.14×10^{-2}	

4.7.2. Bayesian network graphical representation for scenario B

- **For barrier 01**

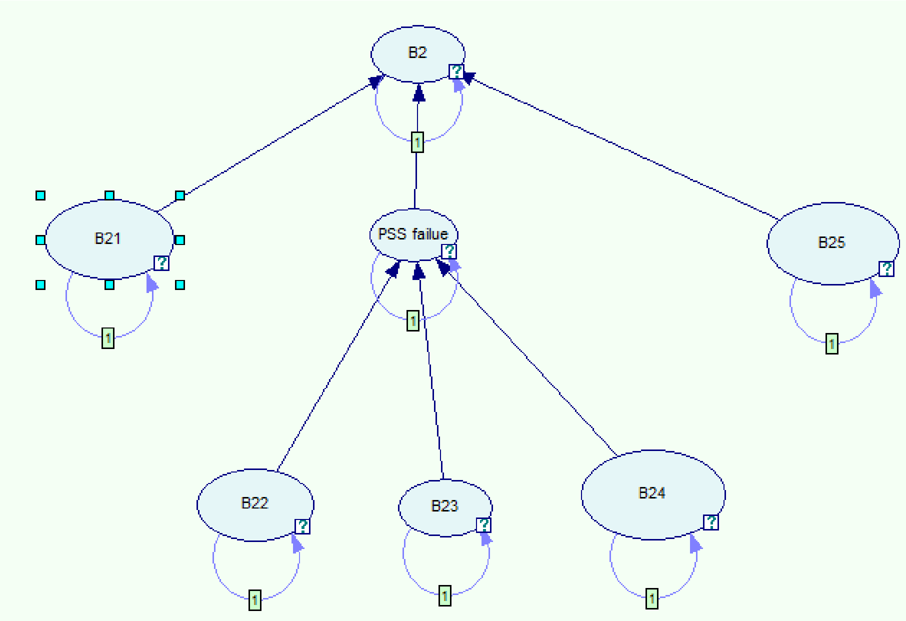


Figure4.38: Bayesian network for B1

- **For barrier 02**

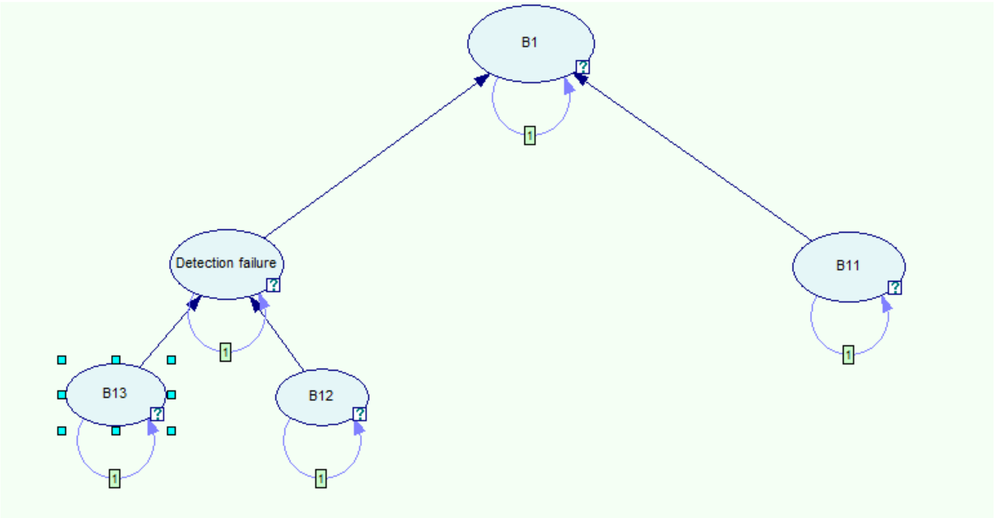
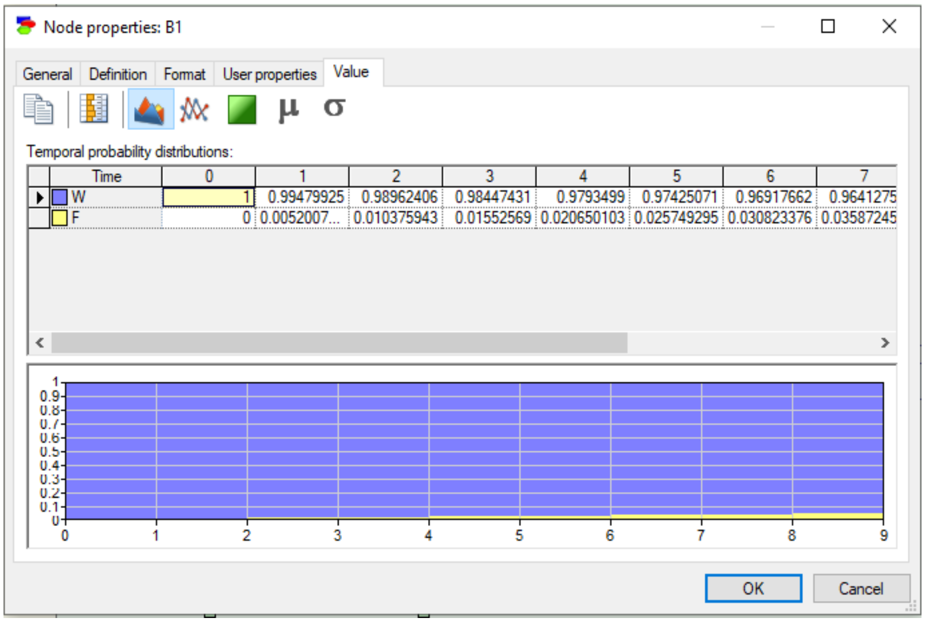


Figure 4.39: Bayesian network for B2

4.7.3. Bayesian network graphical representation for scenario A

- **For barrier 01**

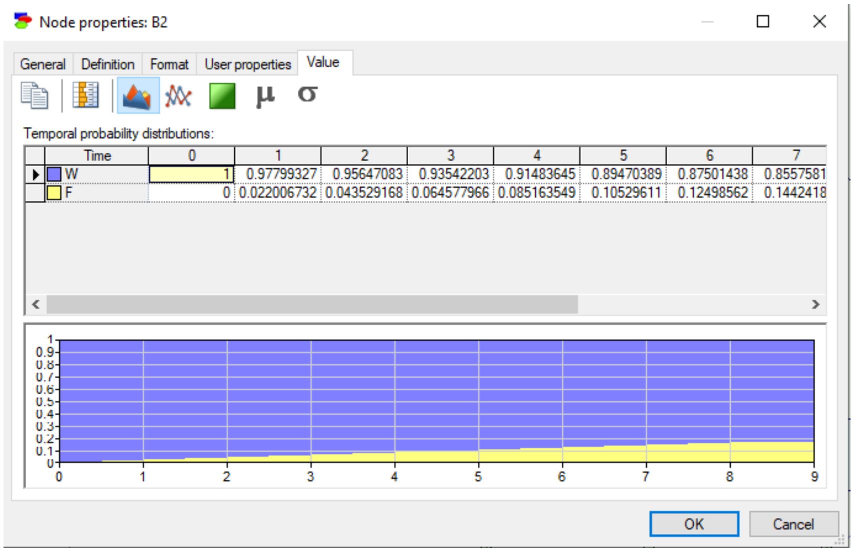


Temporal probability distributions:

Time	0	1	2	3	4	5	6	7
🟦 W	1	0.99479925	0.98962406	0.98447431	0.9793499	0.97425071	0.96917662	0.9641275
🟨 F	0	0.0052007...	0.010375943	0.01552569	0.020650103	0.025749295	0.030823376	0.03587245

Figure 4.40: B1 probabilities and graphical illustration

- **For barrier 02**



Temporal probability distributions:

Time	0	1	2	3	4	5	6	7
🟦 W	1	0.97799327	0.95647083	0.93542203	0.91483645	0.89470389	0.87501438	0.8557581
🟨 F	0	0.022006732	0.043529168	0.064577966	0.085163549	0.10529611	0.12498562	0.1442418

Figure 4.41: B2 probabilities and graphical illustration

4.8. Results' discussion

The results obtained by Bayesian network in the figures in comparison with BORA results are almost similar.

The close alignment of the results obtained from the BORA analysis and the converted Bayesian network highlights the accuracy and reliability of the risk analysis process. The consistent findings across both methodologies validate the soundness of the risk assessment approach and instill confidence in the obtained results therefore the risk is considered acceptable for scenario A and in need for improvement in scenario B in terms of safety.

Conclusion

In conclusion, the practical chapter of this thesis employed Bayesian network analysis and compared the results with those obtained from Barrier and Operational Risk Analysis (BORA). The findings reveal a close alignment between the results obtained by both methodologies, indicating the accuracy and reliability of the risk analysis process. This validation of the risk assessment approach instills confidence in the obtained results, ultimately leading to informed decisions regarding risk acceptability.

For scenario A, the results from both the Bayesian network and BORA analyses suggest that the risk is considered acceptable in terms of safety. This implies that the existing barriers and preventive measures are effective in mitigating the identified risks, thus maintaining an acceptable risk level.

However, for scenario B, the risk analysis results indicate a need for improvement in terms of safety. The existing barrier in scenario B, which focuses on fire prevention, requires additional measures to enhance its effectiveness. Recommendations for improving the safety in scenario B include implementing the following barrier functions:

- Functional Safety Assessments: Conduct regular functional safety assessments of the Safety Instrumented Systems to verify their ongoing performance, including verifying the integrity of safety functions, evaluating failure rates, and identifying potential areas for improvement.
- Fire Suppression Systems: Implement effective fire suppression systems, such as automatic sprinkler systems, water mist systems, or clean agent systems. These systems can quickly suppress or extinguish fires, preventing them from spreading and causing significant damage.

GENERAL CONCLUSION

In conclusion, our thesis has explored the integration of barrier and operational risk analysis in the oil and gas industry through the application of Bayesian networks. The evolving nature of risks in this industry necessitates effective risk assessment and decision-making processes. By combining these two approaches and utilizing Bayesian networks, this research has made significant contributions towards enhancing risk analysis methodologies and improving safety and operational efficiency.

Through a comprehensive literature review, we have gained a deep understanding of the key elements of barrier and operational risk analysis in the oil and gas industry. We have identified the importance of proactive measures, such as physical and organizational barriers, in mitigating potential incidents and accidents. Additionally, we have recognized the significance of operational risk analysis in evaluating the risks associated with day-to-day operational activities.

By converting barrier and operational risk analysis into a Bayesian network model, we have achieved a more holistic and integrated framework for risk assessment. The application of Bayesian networks has facilitated the modeling and analysis of complex dependencies and uncertainties, enabling a more accurate understanding of the relationships between barriers, operational activities, and potential risks. This has empowered decision-makers in the industry to make informed choices and prioritize risk mitigation efforts effectively.

The findings of this thesis have highlighted the benefits of utilizing Bayesian networks in risk analysis within the oil and gas industry. The ability to capture and quantify uncertainties, support reasoning under uncertainty, and facilitate risk prediction has demonstrated the value of Bayesian networks as a powerful tool in risk assessment and decision-making processes. However, it is important to acknowledge the challenges associated with data availability, model validation, and computational complexity that arise when implementing Bayesian networks in practice.

By addressing the research questions and hypotheses formulated at the beginning of this study, we have achieved our primary objective of developing a framework for converting barrier and operational risk analysis to a Bayesian network model. This research has provided a solid foundation for further advancements in risk analysis methodologies within the oil and gas industry.

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