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Writer: **Abdi Suryadinata Telaga**	…………………………………………… (Writer's signature)
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ABSTRACT

The risk level project (RNNP) has resulted risk level trend methodology which is very useful in monitoring the trend of major hazard risk level in Norwegian shelf. However, the method cannot be used in installation level. Therefore, there is the need of major hazard risk monitoring in single installation. This thesis proposes an approach to address the need. The approach need to be simple in calculation, not burden the operator with complex reporting scheme but sufficient to provide information for decision making

In this approach descriptive statistics method is utilized to monitor major hazard indicator. Case studies are presented to illustrate application the approach in real practice and the results are analyzed trough triangulation method to provide a broad picture of risk.

PREFACE

This report is written in spring 2010, at the University I Stavanger (UIS) to complete master degree program in Offshore Engineering department with specialization in Risk Management. I would like to thank to Professor Jan Erik Vinnem for his devoted guidance, my wife who helps me in everything, particularly correcting my English, my daughters who share their cheerful life and all my friends who encourage and supporting me to finish this thesis.

Stavanger, Norway,

15th June 2010

Abdi S Telaga

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1. INTRODUCTION

1.1 Background

Risk is a familiar word for everybody and its presence is ubiquitous. The word risk itself is neutral, but lay people always perceive it with something bad. Some people choose to preoccupy it into their mind and some others don't. Why people treat risks in different way? One illustration might help; People, who use to live in big city with hectic traffic and careless driver, will behave less panic compare with people from small city with solicitous driver when they face careless driver. What are the things that make them react differently? Does their experience make the risk lower? Or they become ignorance with the risk? The risk cannot be lower nor they become ignorance, but human race is known by its knowledge, the key differences that make us live on the earth and make other species extinct. The daily experiences from the people who live in the big city make them have more knowledge in dealing with careless driver than people from small city. The occurrences of careless driver are more than in big city. As consequence they could develop their own knowledge about the hazards and it is reflected in their behavior as they are more alert with specific information. They could judge that one situation could lead to accident and the others don't. However, we all prefer the solicitous driver than the careless one and the system has to be developed to prevent people drive carelessly. The underline of the example is the more frequent the accident the more knowledge we could learn.

How about major catastrophe? If it happens very rare and time span is very long. How could people learn and develop their knowledge? Could many small accidents indicate the future occurrence major accident? Our intuition will come to conclusion that there should be a great possibility the accident will happen. If everybody drives carelessly and there have happened a number of accidents then we will agree that someday the occurrence of major accident is only a matter of time. However, another situation could lead to bafflement. If everybody drive carefully and there has been no accident for a long time, could it be perceived that the major accident will not happen? Our intuition will come to conclusion that the major accident still could happen but it might be with the lower possibility. The Baker report (2007) noted when the accidents are occurred frequently, people are aware about the hazard. On the contrary, when the accidents are less frequent, people could easily distracted and ignore the hazard.

If the catastrophe happens in offshore industry, it will have devastating consequence, not only the economic loss but also the lives and environment. A major accident of offshore industry in the North Sea was in 1988 when the piper alpha platform accidents took 166 lives and caused the insurance loss around £ 1, 7 billion (Wikipedia). On April 20th 2010, a major accident happened in Gulf of Mexico. A massive explosion occurred in BP Installation the Deepwater Horizon, the accident which is also called Macondo blow out killed 11 platform workers and injured 17 others (Wikipedia). The oil leak which is estimated around 5000 barrel/day (Wikipedia) as a consequence of the accident makes the accident worse and creates environmental disaster. Until this thesis submitted, the company is still struggling to stop the leakage.

Because the occurrence of major hazards is extremely rare and the impact is huge, therefore we have to monitor the risk level of major hazard. The situation arise the question, how could we measure the risk level and monitor the major hazard? This chapter gives a brief introduction to historical perspective of risk level project in Norwegian petroleum sector and within this context; it outlines the research objective of this thesis.

1.2 Historical Perspective

The Piper Alpha accident has changed the safety system in offshore industry at North Sea. Lesson learned from the accident lead to a significant improvement in offshore industry safety regulation and operation in United Kingdom (UK) authority, as well as in Norway authority, with objective to prevent the major accident will not occur again in the future. However, in the latter half of the 1990s there was concern from the representatives of unions and authorities on the increasing of risk level in offshore operations in Norwegian petroleum sector, on the contrary the company management and their representatives claimed that "safety had never been better". The situation leads to mistrust between those two sides and raised the need to provide the information about the actual condition and development of risk level in Norwegian petroleum self.

The authorities, the Norwegian Petroleum Directorate (NPD) at the time, now the Petroleum Safety Authority (PSA), Norway, initiated risk level project to provide the information to all the stakeholders. The first report was produced in 2001, Norwegian authority the PSA trough the risk level project produce the risk level in the Norwegian petroleum activity (RNNP) reports based on data for the period 1996–2000. The project contributed to a universal understanding of risk level development among industries stakeholders.

The authorities base their description of the risk development on a number of aspects. Experiences from audits, reporting of accidents and near misses, investigation of major incidents and R&D activities are important sources. As regards the development of major accident risk, the results from the Risk Level Project are crucial. Specific areas where the probability of major accidents is the greatest have been identified through this project:

- Hydrocarbon leaks
- Serious well incidents
- Damage to load-bearing structures and maritime systems
- Ships on collision course

There is an accumulation of technical, operational and organizational factors under these areas, and each factor alone or in combination, can cause accident or affect a possible series of events.

During the period 1996 – 2004, these areas contributed more than 80 per cent of the total major accident risk on the Norwegian shelf. Helicopter transport also has a major accident potential, but does not form part of the major accident indicator used in risk levels - Norwegian Shelf (RNNS). The PSA since then make an effort for continuous improvement in the risk level development, to identify new methods, risks areas and other key parameters which can lead to better understanding of which risk factors are the most important to track over time.

1.3 Research Objectives

Major accidents in offshore installation are rare accidents and the time span is very long, the time interval between accidents could be 10-15 years. As a consequence, it is difficult to find the suitable measurement of the risk level related to the major accidents. Research to find indicators that could be used to reflect the risk of major hazard then attract high attention. In Norwegian shelf there has been previous study about major hazard in national level trough "Risk level" project in mid 1990s lead by Vinnem and there also another study by Øien (2001).

The PSA risk level project has developed major hazard risk indicators on a national level, and the indicators are already used in Norwegian petroleum sector. However, the report only describes the risk level on national perspective and does not specifically address to single installation perspectives. This situation creates the needs to have indicators that could be used in monitoring the risk level in single installations. The indicators for major hazard on national level from PSA risk level project could be a useful in defining the indicators and monitoring scheme in single installation. However, this condition leads to questions regarding those approaches. We formulate the questions for the research objectives in this thesis which are:

- What is the contribution of existing theories and models for monitoring major hazard in single installation?
- Which relationship can be established between risk monitoring and major hazard in single installation?

The main objective of this research is to develop indicators in single installation that can be used to monitor the major hazard in single installation. This involves exploring the theories about major hazards indicators and monitoring scheme and possibility to contribute to these theories and propose the new approach to monitor major hazard risks in single installation.

1.4 Limitation

The PSA risk level project covers all aspects of Health, Environment and Safety (HES). This thesis is focus on major accident risks, as a result all the risks will be described in major accident context and the others risks aspects are not extensively covered.

It was widely accepted that the occupational accidents could be used to indicate major accidents, but the British Petroleum (BP) Texas City refinery disaster in 2005 has created a high awareness that occupational accidents could not be used to predict major accidents in the future. This leads to questioning the lagging indicators and leading indicators in major hazard context. In this thesis we will explore the theories about leading and lagging indicators and frame the indicators in major hazard context. This will contribute to the suitability of those indicators in major hazard context.

The performance of system is influenced by many factors and as a consequence to reveal the true risk level of one system, it is not simply about finding the right indicators, but also has to be seen beyond the indicators themselves. It has been realized that accidents and errors are not merely a technical issues, one must see the risk as a consequence of social interaction between human and their environment. Therefore, the risk is about human perception of hazardous events then it has to be seen in social sciences perspectives. If we see risk from psychometric approach, for most people, risk is not merely a combination of the size and the probability of damage, as proposed by the technical-statistical approach, but also has a social and subjective dimension (Zinn:2006). In conclusion, to describe risk in broad perspectives, we will apply triangulation principles in this thesis. It means that the risk level should be viewed in many perspectives to give the broad view of risk. The triangulation approach is consists of:

- Triangulation of scientific methods,
- Triangulation of individual indicators, and
- Triangulation of the stakeholders' views.

Due to the limitation in this thesis we will exclude the stakeholders' views.

1.5 Structure of the Thesis

We divide this master thesis into 7 chapters. Chapter 1 is the introduction of this thesis which covers the background, historical perspectives, limitation and structure of the thesis. Chapter 2 covers the research methodology in this thesis. Chapter 3 covers theoretical background of the research. Thus, provides the reader the concepts which are used in this thesis. The reader will be familiarized with the risk, major hazard, and risk management in the frame of risk monitoring. Chapter 4 of this thesis provides literature survey about resilience model, risk monitoring, indicators, lagging and leading indicators in the context of risk monitoring perspectives as well as lesson learned from risk monitoring application in other industries. Chapter 5 provides the new approach, case studies illustration and the result of case studies. Chapter 6 provides the discussion and chapter 7 summarizes the thesis work in form of conclusion and recommendation for further work.

2 METHODOLOGY

This chapter describes the methodology which is used in this research. It covers the design of the research model, the formulation of research questions, and the research strategy followed.

2.1 Research model

The main objective of this research is to develop an approach to monitor the major hazard in single installation. To achieve this objective, a research model is developed based on a research model, adopting the research model from Schönbeck (2007). The research model is shown in Figure 2.1.

The research object is major hazard in single installation. This object is studied from the risk monitoring perspective, in order to achieve the objective which is to monitor the major hazard in single installation. The relevant theories and models for a risk monitoring become starting point to form the theoretical background. Therefore, firstly the exploration of a number of theories and models for risk monitoring is done. Secondly review the possibility of the theories to contribute to the major hazard in single installation is reviewed. At last, apply the combination of relevant theories and models to the risk monitoring and connecting it to the major hazard in single installation. Those steps lead to an approach to monitor the major hazard in single installation.

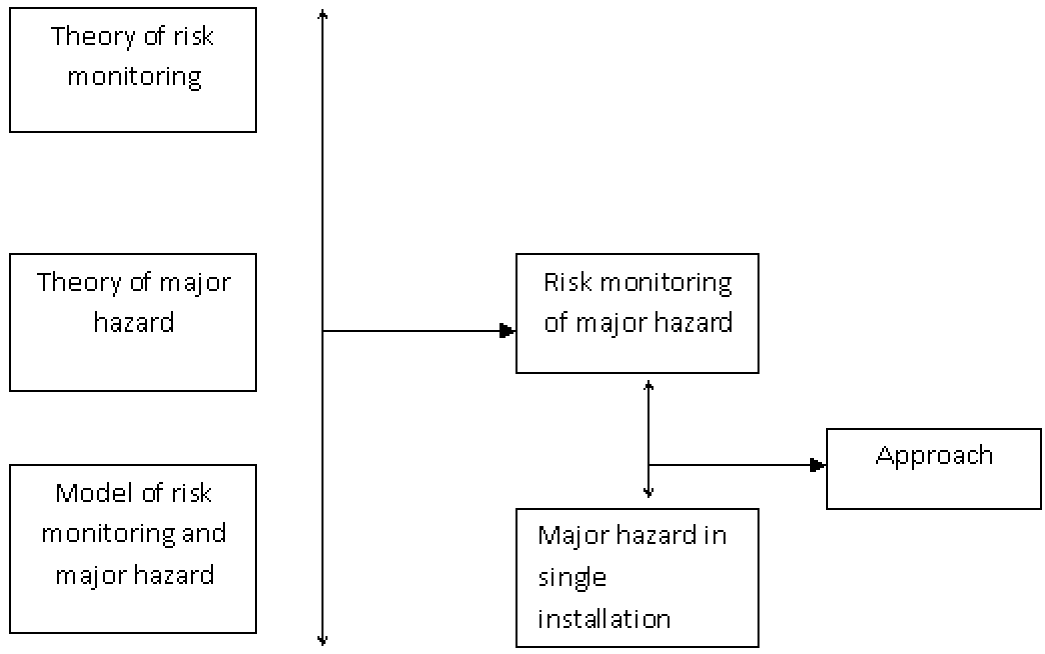

Figure 2-1 Research Model

2.2 Research questions

This research model is the cornerstone to formulate the research questions. the model then is divided into different parts to be more focus on a research question. The first part of the model, shown in Figure 2.2, leads to the first research question:

1. What is the contribution of existing theories and models for monitoring major hazard in single installation?

The second part of the model, shown in Figure 2.3, leads to the second research question:

2. Which relationship can be established between risk monitoring and major hazard in single installation?

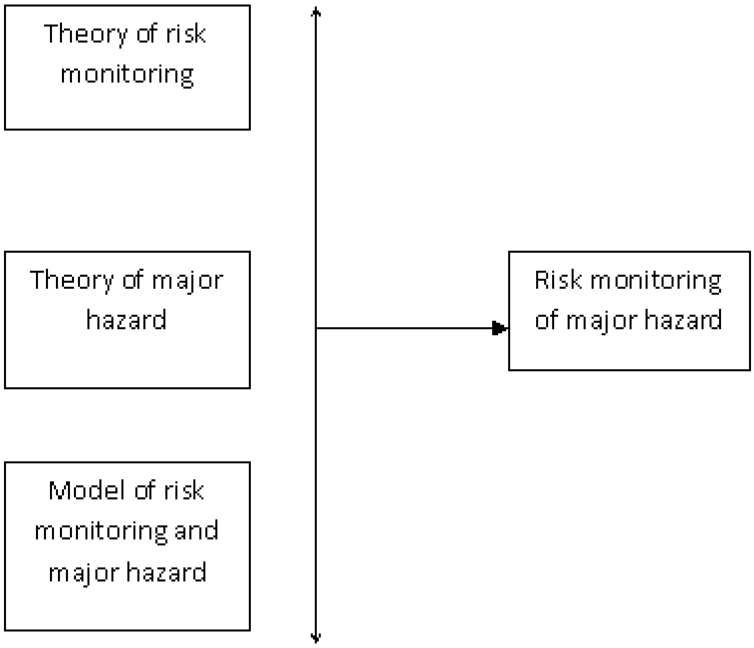

Figure 2-2 Part of the research model leading to research question 1

Next step, these research questions are divided into sub questions. The objective is to have more focus research questions then indicates what knowledge is required to answer those questions. These leads to the following questions and sub questions:

1. What is the contribution of existing theories and models for monitoring major hazard in single installation?

    - What do relevant theories say about the risk monitoring on major hazard?
    - Which relevant theories for major hazard?
    - What is the possible contribution of these theories and models to the monitoring of major hazard in single installation?

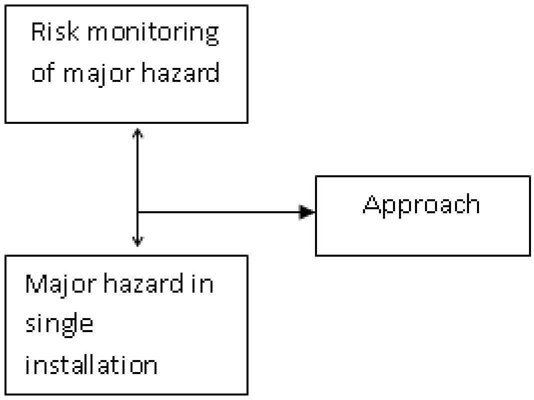

Figure 2-3 Part of the research model leading to research question 1

2. Which relationship can be established between risk monitoring and major hazard in single installation?

   - What is the major hazard in single installation?
   - Which relationship can be established monitoring major hazard and major hazard in single installation?

2.3 Research strategy

To answer those research questions, a particular research strategy then must be developed and followed. Those contain decisions about the type of research and the way to conduct the research. Based on the objective of research and research questions, the most suitable approach is a theoretical approach based on scientific literature. This means that the work will consist of comparison of existing theories and models then adapted to create something new. The relevant literatures are studied particularly from the point of research questions view. The result then is applied to develop a new approach for risk monitoring for major hazard in single installation. In conclusion, this theoretical research approach is more than a literature review.

The sources of scientific literatures for this research are mainly papers from established scientific journals (e.g., Reliability Engineering and Safety Science), as well as conference proceedings and a number of books. Although it is not a comprehensive overview, those sources together contribute all relevant parts of the research area, In addition to the scientific literature, several books about of risk analysis (e.g., Aven, 2003; Vinnem, 2007) have provided valuable knowledge of understanding risk.

3 THEORETICAL BACKGROUND

This chapter will clarify the terms and explain the supporting theories which are used in this report. The readers are familiar to all the terms in this report and I believe that they already have intuitive understanding of “risk”, “indicators” and “risk monitoring”. However, if they take their understanding for granted, it could lead to ambiguity and the view difference could lead this report into different perspective.

A study from F.M Christensen et al. (2003) cogitates that the terminology becomes the source of ambiguity and often distract the discussion from the main issues. Following the advice from the researcher, this chapter is aimed at clarifying and describing the terminology concepts which are used in this thesis such as risk, hazard, major accident, etc. Some definitions are adopted and supported in this report as a base of writer view and some others are left undefined and should be seen from many aspects.

3.1 What is Risk?

There is no unified definition of “risk”. The word is used in everyday life and everybody has their own understanding of the word. The word “risk” is always been associated in negative view by lay people. However, the experts might define risk depend on how they put risk on the context of one particular situation. Therefore, we might be better to look some definitions of risks and support the definition which is best suit for this report. Definition from Aven (2003) defines that a risk is the possibility of a surprisingly bad, or surprisingly good, specified future event. The works from F.M Christensen et al. (2003) discern two fundamental understandings of risk, which are:

1. *Combination of probability of consequence/effect on the considered objects; severity and extent of consequence/effect under given specified circumstances.*
2. *Probability of a given consequence/effect of a given severity and extent under given specified circumstances.*

All the definitions share the common ideas which are “the probability” and “the consequences”.

One might need to express risk quantitatively and there are many ways to express the risk quantitatively. The share idea of risk is probability, then this lead to question of "what is the probability ? " and how do we use it in risk context? Probabilities are usually used if we consider an event that there are many possible outcomes will occur in the future and we do not know in advance which outcomes will occur. This condition is called stochastic, by contrast, deterministic approach determine the outcomes in advance. The probability measures the chance of outcome occurs from an event and the value lie in interval [0, 1].

The value just a number, then what does exactly the probability measure? A ris definition from Aven (2003) explains the relation between events A and their outcomes C (Consequences) with uncertainty, therefore risk is defined as combination of:

- Events A, and the consequences C of these events, and
- The associated uncertainties U about what the outcome will be.

Risk is defined as function of (A, C, U). In this perspective, the observable quantities are the focus in expressing the state of event, i.e. quantities of physical reality or nature which are unclear at the beginning of analysis but will take some value in the future. The uncertainty U about these observable quantities is the main component of risk (Bjornal, 2009).

Another question pop up from our mind, in this stochastic view, the probability is assigned and the value is different from one person to other person. What does the thing that makes it difference? One risk definition from OECD (OECD, p: 67) defines that risk is a mental construction of mind, therefore someone will view risk on one event differently depends on his/her mental model. The mental model represents their subjective knowledge of one hazardous event and as a result will assign different value.

In recent news, when the volcano in Iceland erupted and the ash made all the flight across the Europe turned into chaos. Many passengers did not understand why the plane could not fly for many days; it was not very big eruption which thrown massive materials. One might think the safety agency was overprotective, but the authorities keep closed the airport and stopped the flight and left the passengers wandering.

Is the different understanding just a matter of perception? What make the perception differ from the lay people and the experts? Our intuitive will say the different lies in the knowledge of lay people and the experts about the object. It is aligned with (A, C, U) perspective. In this perspective, the uncertainty is understood as lack of knowledge about the occurrence of events A and what will the consequences C be, if an activity is carried out or a system is put into operation ((Bjornal:2009) adopted from Flage and Aven:2008). In this approach, to express uncertainty the probabilities P is assigned which means from the view of the assessor, the possibility of one event occurred is based on his/her background knowledge. For example, if the assessor assigns the probability of one event occurs P (A|K) = 0.1, the uncertainty is compared to drawing one ball out of 10 balls in an urn. Following this reason, in this chapter we will consistently use this risk definition from Aven (2003) which define risk as a function of (A, C, U).

3.2 Risk and Hazard

Many people misuse risk and hazard in their daily life. As mentioned above, risk explain the relation between an event and consequences of outcomes, therefore the term risk has neutral view. By contrast, the hazard has negative view. The tendencies of individual to associate risk with bad outcomes make them confuse the words in everyday use.

Some definitions of hazard conclude the negative perspective. Definition from UK HSE defines a hazard as something (e.g. an object, a property of a substance, a phenomenon or an activity) that can cause adverse effects (UK HSE Website). Hazard is also defined as a situation that poses a level of threat to life, health, property, or environment (Wikipedia). One definition form Cambridge dictionary defines hazard as “something that is dangerous and likely to cause damage “(Cambridge: 2008) they share the common idea that hazard is used to describe something that has potential to make harmful situation.

We already agree to define risk as function of (A, C, U). Refer to the risk definition, hazard could be seen as an event/ situation A that has possibility to cause bad consequences C. Therefore, we can measure the risk of hazard by observing the likelihood of bad consequences of an event. Quantitatively, according to our definition, we could compare the likelihood by probabilities and frequency of occurrence of hazardous event. As conclusion, in term of hazard we would like support the risk definition as "*Risk is a combination of the likelihood of an occurrence of a hazardous event or exposure(s) and the severity of injury or ill health that can be caused by the event or exposure(s)*" (OHSAS 18001:2007).

3.3 Risk Management

Individuals do not like extremely bad outcomes. Recent chaotic air travel in Europe which was caused by volcanic ash had created massive losses too many individuals. People were stranded and they could not go home on time, business meetings were cancelled, football teams had to travel by trains and even the impacts reached as far as the tourism resorts in Indonesia. The airlines industries around the world had lost more than £1.1bn. People were complaining in the television, newspaper and even in the social networking telling that they had to spend much more money and time to travel. One football manager after one match said "I am not responsible if the team had to travel by train, I am not the man in the volcano". However, they understood that the situation was unavoidable, it was nature. They do not like the massive economic or life losses as a consequence of the bad occurrence.

Behaviour of dislike bad outcomes shows our aversion of risks. It has been well understood that we cannot eliminate the risk. We have to live with the risk side by side and hazardous event could happen unnoticed. Therefore, the risk has to be managed to avoid the occurrence of hazardous event. The airport closing was the action to avoid the hazardous event occurred in the air travel. However, in safety investing context, the reason is not risk aversion attitude, but the willingness to protect our assets again uncertainties. This principle is cautionary which means to reduce uncertainties against extremely bad occurrence to protect the assets.

This view is well expressed by the definition from Aven and Vinnem (2007) which define risk management as " *the process of ensuring that adequate measures are taken to protect people, the environment and assets from harmful consequences of the activities being undertaken, as well as balancing these measures with other factors such as costs and earnings* " . The definition implies that we have to measure the hazardous events adequately before we could use the result. This process is an iterative process and has purpose as a decision making tools. Picture 3-1, which is adapted from ISO 31000 (2007), Aven and Vinnem (2007) and the AS/NZS 4360 standard, illustrates the iterative risk management process.

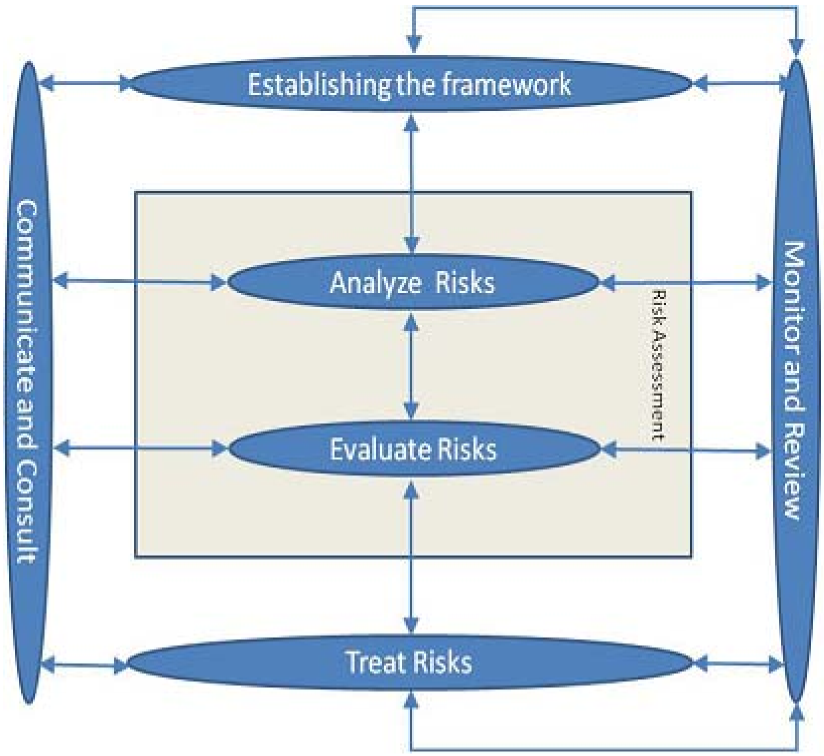

Figure 3-1 Risk Management Activities (Reproduced from ISO)

The figure describes the process of the risk management activities which consists of risk assessment and risk treatment. Risk assessment is a process to identify the hazard and threat, cause analysis, consequence analysis and risk description in order to provide adequate information for the next step. Following the figure, in ISO 31000 (2007) risk assessment is defined as the process of risk analysis and risk evaluation, where:

- A risk analysis is a systematic use of information to identify initiating events, causes and consequences of these initiating events, and to express risk.

- A risk evaluation is the process of comparing risk against given risk criteria to determine the significance of the risk, and is used to assist the decision making process.

All the processes need to be monitored and reviewed in order to elicit risk from the events and ensure the information is useful for decision maker to treat the risk.

3.4 Major Hazard

Major accidents is very rare in occurrence but has a massive catastrophe. When we talk about major accidents, our mind will think about something which is related with natural disasters such as earthquakes, volcano eruptions, floods, hurricanes or other acts of God. We also might think manmade disaster, for example Chernobyl reactor disaster; Bhopal disasters; World trade centre attack and many more events. Due to media coverage and political benefit of nuclear disaster, lay people associate the manmade disaster with nuclear power accidents. Even though, any industries have potential to experience major accident. People who involve in offshore industries will never forget the accident of piper alpha which caused massive numbers of lives and economic lost.

Experience taken from offshore activities has shown that the risks are inherent in the industries. The Piper Alpha disaster on British continental shelf in 1988 demonstrated the scale of major accidents consequences of an offshore installation could bear. Although, the last major accident on a facility was in 1986 when the shallow gas blowout on the mobile facility West Vanguard, the recent incidents in Norwegian shelf installations have indicated the potential in causing major accident.

We, in this thesis will focus on major hazard in offshore installation under Norwegian authority. Therefore to limit the understanding of major accident, we will use a definition from Norwegian authority which defines a major accident as "*an acute incident, such as a major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets* ". (PSA Website). Furthermore, we would like to define a major hazard as a hazard which could cause a major accident.

3.5 Risk Analysis in Major Hazards Perspective

In human perspective, a major accident will have large impact on society at large. For those who are affected by the accident, the loss will be far larger than what is presented in the figures, the value of a life cannot be expressed in money. The research from von Winterfeldt et.al (1981) showed that the risks with a low probability but high consequences would be perceived as more threatening than more probable risks with low or medium consequences. Therefore, major accident risk reduction becomes an important reason for the formulation of existing health, safety and environment regulations. Risk analysis, then should be taken adequately to identify major hazard and treat it regarding the balance of safety and cost.

The result of risk analysis as mentioned from the work of Apostolakis (2004), will never be a single factor to make decisions, but provides a basis for risk-informed decisions. Therefore, there is still a need for managerial review and judgment to disclose many aspects which could not be captured in risk analysis process (Bjornal ,2009 adopted from Eidesen, 2008).

Risk analysis is also about identifying the occurrence of events in the future, and risk analysis by definition above is a systematic use to identify event and predicting the occurrence and its consequence in the future. However, we cannot measure accidents or incidents in the future; by contrast we can observe incidents and accidents that has happened. Although we can use the historical events to estimate the risk in the future, we cannot simply use them, otherwise the figures will barely the extrapolation of historical events. We therefore should consider the uncertainty between the risk estimation and the true risk, Bjornal in his dissertation stated that in many approaches to risk analysis for major hazards, the purpose is to provide an estimate of an underlying "true" accident probability (Bjornal, 2009). This is meant to reveal the knowledge and lack of knowledge of risk analysis. This perspective is in-line with (A, C, U) principle and will be used in this thesis.

3.6 Major Hazard Risk Monitoring in Risk Management Perspective

Risk analysis is a resource demanding process, however to produce a suitable risk information which can serve as a basis to make decisions is a challenging task. As many other activities, There are a number of constrains in doing the activity, such as workloads; time; skills and many other factors. Risk is dynamic, once risk has been identified, another risk will emerge. However, the AS/NZS 4360 emphasises that "few risks remain static" (Bjornal:2009) , therefore there is a need for continuous activities to monitor the risk. Framing the monitoring purpose in major hazard context will rise a question "how can major hazard monitoring support risk management process? "

Monitor from the Cambridge advanced learner dictionary has meaning as "to watch and check a situation carefully for a period of time in order to discover something about it". This is just broad meaning of monitor, but it has important message which is the activity must be done in a period of time. Risk monitoring activities then, must be done periodically to provide the information of current risk status to the management. In the case of major accidents, simply monitoring the risk merely base on accidents occurrence will give no value, since the periodic time is very long. Therefore, we have to extent the scope to the precursor of accidents.

Bjornal in his dissertation (2009) stated that the accidents is not directly manageable and the manager needs to see whether the accidents are the result of processes and conditions in the organization. Lesson learned from The Baker report and Hopkins (2007), noted that before the accidents, there had been a number of fires and several hundred losses of containment. The report, further argue that monitoring the incident could have been a valuable input for plant safety management. Moreover, (Bjornal (2009) adopted from Reason (2000))and others show that to have an effective safety management, the focus must be on the manageable processes and conditions which influence the major hazard risk.

The picture below which is reproduced from Bjornal dissertation (2009) illustrates the accident chain. This picture describes the manageable process and condition prior the accidents; activities, barrier performances and occurrence of incidents are often occurred before the accidents.

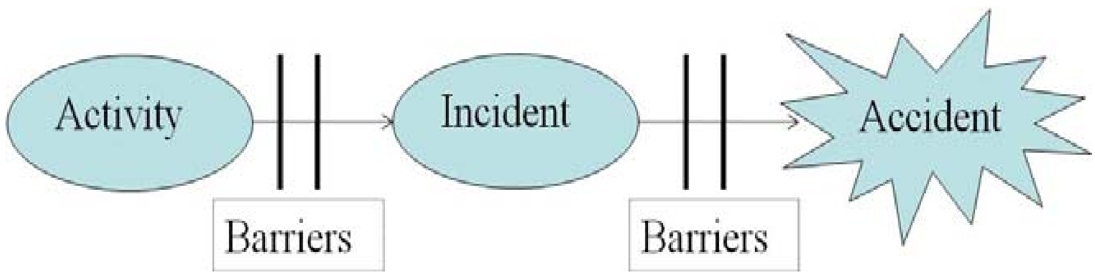

Figure 3-2 A Typical of accident chain adapted from Bjornal (2009)

Monitoring these manageable process and view them along with the influencing factors such as time constraints, skills, workloads etc could produce a broad picture of safety performance of system. Seeing in this perspective, this risk monitoring scheme could be a helpful complement to the risk analysis and other decision support tools (Bjornal: 2009). As mentioned above, risk analysis is meant to provide information for decision making and risk monitoring activities as a complement therefore could only provide the information as well. Uncertainty is needed to be placed to judge the outcomes and caution should be used before starting further action for example risk reduction measure when there is uncertainty linked to the consequences (Aven and Vinnem:2007). These minimum requirements are important because we should not do an analysis beyond what can be justified under the method limitations.

3.7 Safety Barrier

Humans use safety barriers to protect their lives and property against natural hazard and/or enemies since the beginning of human existence. Ancient South East Asian people lived in the elevated house to protect them against animal and flood; Ancient Rome build The Hadrian Wall in North of England to protect them against their enemies and as far as in China, The Chinese Empire made the famous man made safety barrier which is The Great Wall of China, a lengthy and gigantic wall which meant to protect them against Mongol invasion. As the human being entered the industrial age, they develop safety barrier against hazard which arose from industrial hazard. It was an interesting fact that, how people has developed their understanding between accidents and safety barrier.

Safety barrier concept has been applied widely and covered many areas, therefore the understanding of safety barrier concept are often limited to the objective to the industry where the safety barrier is applied. Sklet (2006) has studied carefully about safety barrier concept crosswise the industries and stated that there is no common terminology applicable crosswise the industries. Therefore in the context of industrial safety, He bespoke that safety barriers are defined as “physical and/or non physical means planned to prevent, control, or mitigate undesired events or accidents”. This definition is not to be confused with barrier system which realizes the function. Furthermore, a barrier function is defined as “a function planned to prevent, control, or mitigate undesired events or accidents” and barrier system is defined as “a system that has been designed and implemented to perform one or more barrier functions “. We in this thesis would like to use the definitions above to limit the understanding of safety barrier, barrier function and barrier system and use it in the context of offshore industries.

3.8 Accidents and Safety Barrier

Following the definition above, the safety barrier has function to prevent, control, or mitigates the accidents, but the accident is still occurred. What makes the safety barrier fail to perform its function? Reason(1990), developed the Swiss cheese model based on human behavior and organization theory. This model use cheese slices to represent the barrier and the holes in each slice represent the weakness of barrier system against particular hazard.

The barrier act like dynamic cheese slices where each slice has holes vary in size and location. The accident, then will happen if all the holes in cheese slices are in-line which mean all the vulnerability of safety barriers are exposed and the hazard passes through the holes and create the accident (Figure 3). The holes in the system arise from two conditions which are latent failures and active failures. Active failures are the failures which come from individuals who have direct contact with the accidents. Latent failures are the hidden failures which come from the condition which can influence the individual to perform the task or the system ability to deal with the situation.

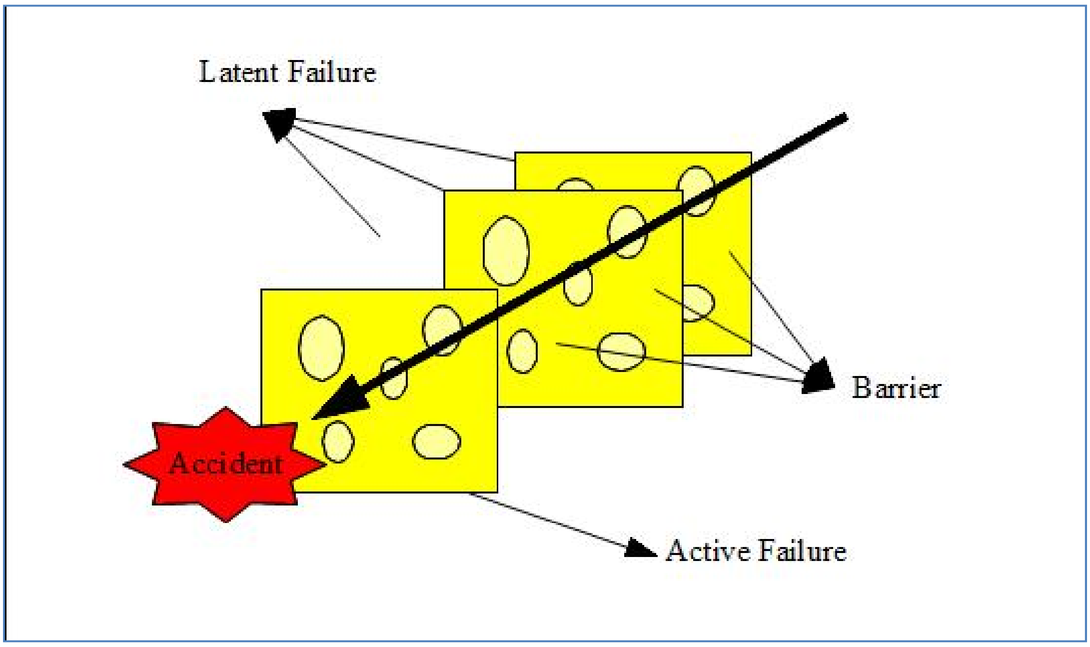

Figure 3-3 Swiss-Cheese Model (Adapted from Reason :1990)

Within this model, the accident might happen if all the safety barriers at one moment, fail to perform their functions and at the same time the operator in the frontline who perform the task made an error. The model could explain how the safety barrier performance might prevent accident as a good safety barrier will have less holes and as a consequence will minimize the occurrence of active failure and influence factor.

The barriers could be weakened and have more holes or bigger holes as a consequence of system which constantly changes. As an example, the brake system in the car is meant to be as a safety barrier, but the brake might not perform as it required if the car maintenance is not good. The deteriorating brake represents the growing of cheese hole. Therefore, monitoring the safety barrier performance will have an added value for safety management system. This, could provide early warning for the stakeholders if the barriers are weakened

4 LITERATURE STUDIES

The previous chapter has already provided the reader about the importance of monitoring the risk. But, how could we monitor the risk? We therefore need a point of reference to tell us that some events or things are hazardous and some others are not. But, monitoring the risk is a challenging task. The reader has been informed that the risk monitoring is a dynamical process. Once the hazard has been identified and safety barrier has been implemented, the new hazard emerges. The process then will make a circular loop until the adequate information has been achieved. However, the information will never be enough, one should state that their own limitation in connection with budget, time limit, regulation and other factors.

Within this chapter, we will provide the result of our literature studies to the reader to describe resilience engineering, lagging and leading indicators, risk monitoring methods and activities. We are also interested in learning from other industries about monitoring the risks, in order to find the ideas which could be useful in connection with major hazard risk monitoring.

4.1 Resilience and Accident Model

4.1.1 Resilience and Swiss-cheese Model

Accepting the accident model is not just has a consequence how we understood the accident but how we see other related terminology under the model. We are interested in defining the resilience terminology within this thesis. Resilience is important as we are interested in developing the monitoring scheme to attract management to be more aware in maintenance activities.

Resilience according to the Cambridge dictionary is defined as "*able to quickly return to a previous good condition*". However, Hollnagel (2006) defines resilience in Swiss-cheese model or complex linear model, resilience is the ability to maintain the effective barriers which can resist the impact of harmful agents and the degradation which is a result of latent conditions. The definition from Honagel is very different from the meaning in dictionary. He argues that Swiss-chess model is still a linear model which can only explain the chain of accident and cannot explain the resilience of system to return to previous good condition. Therefore, the resilience of system under this model depends on the ability of the barrier to withstand. The model cannot explain why the holes eventually in-line? The activities of sliding the cheese slices to prevent the accident according to him can be seen as non-linear activities.

We, in some extents agree with him to view the accident as a complex non-linear system with many factors affecting the occurrence of accident. However the Swiss-cheese model explains the occurrence of accident in perspective of safety barrier and we find this is still relevant in explaining a specific situation for example the causality of accident in offshore industries, particularly in explaining the hydrocarbon leaks of technical barrier. The inability of this model to explain the occurrence of holes alignment becomes the limitation of this model.

4.1.2 Technical Barrier System Dynamics Model

The cheese holes vary in place and size. The size can grow and move as a result of latent condition and the harmful agents. Based on the limitation in Swiss-cheese model, we would like to propose simple model based on the system dynamics to explain the resilience of technical barrier. Following this reason, we, in this thesis still define the resilient as its basic meaning according to the dictionary. This definition also provides the pro-active perspective in risk monitoring.

This system dynamics model which is shown in figure 4-1 is only a basic system dynamics model; we do not take into account other factor such as delay and is intended mainly to show the effect of technical barrier maintenance. It starts from initial technical barrier condition, the lower technical barrier condition, the level of risk is increasing and the company has to increase the maintenance activities to keep the condition of technical barrier in acceptable level. Hence, the system will create a circular loop. The risk monitoring process here which is represented in level of risk in installation, serve as the feedback for preventive maintenance which controlling the technical barrier to be always stable in high availability state.

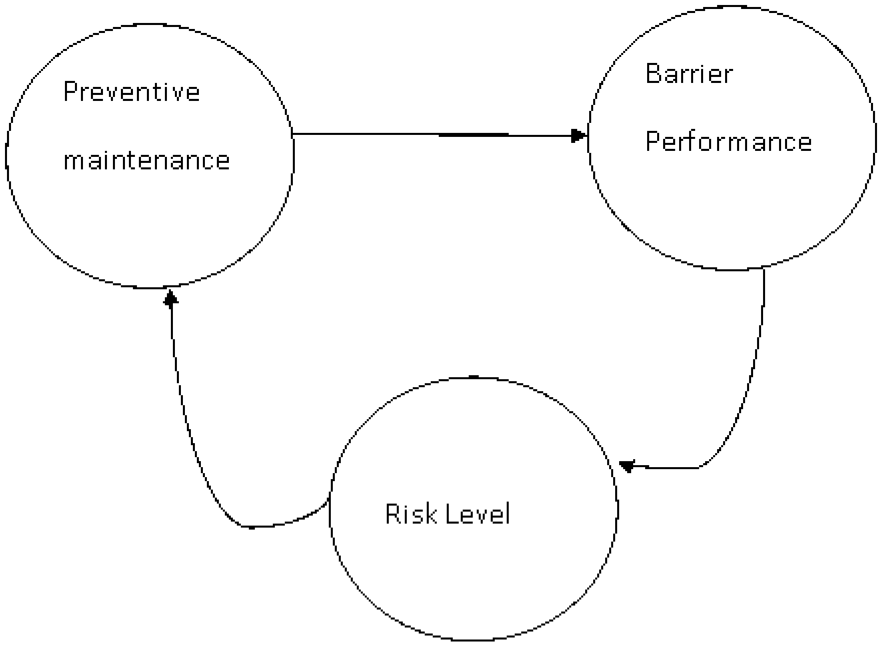

Figure 4-1 Basic Model of Technical barrier and preventive maintenance

4.2 What is Risk Monitoring?

It has been mentioned above that risk management is an iterative process. Therefore monitoring process is needed to ensure that the process goes into the objective direction not in the opposite direction. There are many definitions of risk monitoring.

In connection with risk management process, the end result of the activity is to provide risk information. Following this, we support the definition from Bjornal (2009) which defines risk monitoring as an activity that involves reviewing, tracking, evaluating and reporting on the status of the risks. Many people misunderstood that to set the risk level is barely about finding the set of risk indicators. By contrast, Vinnem (2009) stated that there are no single indicators that may express all the relevant aspects of health, environment and safety and there will always be a need for parallel illustrations by invoking several approaches

4.3 Learning From Risk Monitoring in Banking Industries

4.3.1 Risk Monitoring Activities

Banking industry is an example of industry which risk monitoring activities has already widely applied. Basel accord II provides the international standard for banking regulator to create regulations regarding the amount of capital which should be allocated to guard the banks against the risk that might arise from financial and operational risks. Basel II has three pillars concept – (1) minimum capital requirements (addressing risk), (2) supervisory review and (3) market discipline. In this thesis, we would like to consider the first pillars, in this pillars the capital requirement is meant to address three major components of risk that a bank faces which are: credit risk, operational risk and market risk.

With the objective of measuring risk, the bank develops two kinds of indicators which are: Key Risk Indicator (KRI) and Key Performance Indicator (KPI). KRI has objective to measure the riskiness of an activity while KPI has purpose to measure how well the performance of the system. Those indicators have different function, the function of KRI is to measure operational risk, whereas the KPI is to measure credit and market risk. While the latter is an indicator of how well something is being done, the former is meant to indicate the future harmful impact [Wikipedia]. In contrast with credit and market risk which have profit objectives, the operational risk has different objective, which is risk reduction.

The operational risk (Basel:2006) in banking industries context is defined as "*the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events* ". This definition accommodates the understanding that minimizing the internal failures could minimize the catastrophe. Inevitably, in the long-term, internal failures are often lead to a major catastrophe.

With regards of industrial safety, the focus of measuring operational risk seems more suitable to indicate major accident than focusing on system performance. The premise is similar with the reason in banking industry, which is managing the internal processes, people and system could reduce major accident risk. Therefore, developing KRI for monitoring operational risk will be an added value for major hazard risk monitoring activities. However, to obtain the total risk picture in one installation, we must also take into account the historical performance indicators.

4.3.2 Operational risk monitoring

The purposes of risk monitoring activities in banking industries are to monitor and predict operational events. They, therefore act as complement of a self-assessment process to continually monitor the effectiveness of controls. Utilize them together with escalation criteria, will provide information for management about emerging issues. Placing the risk indicators under operational risk management framework, the risk indicators serve as one of main tools to support risk assessment and risk monitoring.

Risk indicators are used to monitor activity and control the environmental status of a specific business area for particular category of operational risk. Risk indicators also maintain the operational risk management process dynamic and the risk profiles are always updated. However, as the use of risk indicators becomes integrated into a risk management process, indicator levels/measures must have a frame of reference, which commonly referred as escalation criteria or trigger levels. These levels represent thresholds of an indicator or a tolerance that, when passed, require management to step up its actions.

4.4 What is Indicator?

4.4.1 Indicator Definition

There is no unified definition of indicator in safety science, some definitions defines indicator under particular business processes or industries. Indicator is defined by Øien (2001) as a measurable or operational variable that can be used to describe the condition of a broader phenomenon or aspect of reality. Other definition from Vinnem (2003) which defines risk indicator as a measurable quantity which provides information about risk.

Learning from risk monitoring activities in banking industries, they use risk indicator to provide information for risk monitoring and risk assessment. We therefore agree with that and will support the latter definition and use it in this thesis, as we will use it to provide information and it is also in line with (A,C,U) principles (Bjornal:2009).

4.4.2 Indicator Requirements

After defining the indicator, the next challenge is how to create effective indicators. The indicators have to be in-line with the objectives. Since one of indicator goal is to track the progress of objectives then they must give insight into the objective changes, as our goal is to provide risk information, the indicators should be consistently in-line with changes in losses suffered and, ideally, give insight into the risk of one categories or process relative to another.

Researching the important point of risk indicators, Kjellén (2000) describes a set of requirements for risk indicators to have effective risk monitoring, which are:

- A risk indicator must be *robust against manipulation.*
- The methods for data collection, analysis and presentation must be *easily understood and acceptable* to the involved parties.
- The information that is presented to the decision maker must be *relevant and comprehensible* to avoid overwhelming the decision makers with data.
- The risk indicator must be *sensitive to changes*, allowing for early warning by capturing changes in an industrial system that have significant effects on risk.
- There should be a reasonably *cost-efficient* relationship between resources spent on the monitoring system and the benefits of the system.

Indicators have certain limitations, as we already mentioned, many indicators are specific to an individual risk and many of them specific to a certain process or business. Therefore, it is a challenging task to design a framework which is consistent across risks. Some categories have more difficulties then others, resulting challenging environment to create risk indicators. For example, creating risk indicator for human and organizational risk is harder than technical risk indicator.

Another important aspect of indicator is data requirement of indicators. The information which we would like to produce is relying on the quality of data and correlation between the data and the purpose of indicator. A research from Andrew Hale (2009) suggests the relation between indicators data requirement and their purpose which are summarized in table 1.

Purpose	Indicator data
Monitoring safety level of a system	• Reliable data can show valid trends in safety. • No need of causally linked to safety outcomes, as long as the correlations stay high and the numbers are big enough to show trends
Decision support of action.	• Indicators must show the causal links which can be proven or at least are strongly believed to the catastrophe. • Indicators manipulation will result safer systems.
Motivating person to take necessary actions	• Indicators must be seen as being relevant from the person. • Indicators are able to be influenced by the person.

Table 4-1 Data requirement for indicator purpose

4.5 Lagging Indicators

Dyreborg (2009) wrote the importance to make a distinction between lag and lead indicators. In the context of risk monitoring, Rasmussen and Svedung (2002) suggested that lead and lag indicators must be defined under the proactive monitoring strategy. However, the definition of lagging indicator rarely becomes a discussion subject among safety science experts as the understanding of the terms is obvious. They share the idea that lagging indicator is the indicator which is based on historical performance of the system. Therefore, the focus of this indicator is measurement of outcomes and occurrences.

Another perspective differentiates indicator being lagging or leading is by seeing them in reference of objectives. Lagging indicator is used to measure the achievement of objectives whereas leading indicators is used to track progress of the objectives. Nevertheless, all the ideas are the same, lagging indicator must be measured after one system has completed its task. We, in this thesis, will define lagging indicators as event based indicators which reflect the performance of system in the past.

4.6 Leading Indicator

By contrast of lagging indicator, the definition of leading indicators becomes a discussion subject in safety sciences. The research result from Herrera and Hovden summarizes a number of different definitions about leading indicators (Herrera & Hovden, 2008) which are:

- *Type of accident precursors, conditions, events or measures that precede an undesirable event and have some value in predicting the arrival of an event (Construction Owners Association of Alberta, 2004)*
- *A form of active monitoring focused on few control systems (HSE, 2006)*
- *"Activity" indicators that show if the organization is taking actions believed to lower risk (OECD, 2003)*
- *Indicators that measure variables that are believed to be indicators or precursors of safety performance so that safety outcome is achieved (Baker,2007).*

The first and the latter definition indicate the leading indicator is used to track the objective progress while the second and the third indicate leading indicator as a sign of future event. Different perspective comes from Ale (2009) which states that in connection of leading indicator, no indicator can be leading if the value is established by observation over time, moreover the indicator value is the value at the time of the indicator was observed. If we follow this definition, then there will be no leading indicators unless the values are real time.

We therefore are not in a position to support Ale definition. This is not only because the result will be no leading indicator, but also since we have placed the risk indicator in the risk management process objectives. The objective of risk management is to provide information for decision making process. Hence, we would like to define leading indicator under pro-active perspective then we support a definition which is used in economics which define that leading indicator is indicator that changes before the economy changes; this definition is also supported in Vinnem paper (2006).

Driving a car is a good illustration to illustrate MTO interaction to provide lagging, leading indicator in safety context refer to our definition above. One event can be seen as lagging or leading indicator depends on the objective of the indicator. In one situation, a car with 90 km/hour speed in motorway has been forced to brake in order to hide the reindeer which cross the street 50 m ahead. Speed and distance is a time variant variable, one might be interested in making it as a leading indicator. However, those variables are not suitable in safety context, but the brake as a safety barrier is more suitable in this situation. If the brake function as it required, then the accident has large probability to be prevented. Viewing this situation to create indicators, a number of brake failures which has caused accidents could be used as a lagging indicator. As the car in operational mode, the likelihood of car having an accident can be judged from the current brake status. For that reason, within the context of car safety, current safety barrier status is useful in providing information of future accident, therefore satisfies the definition of leading indicator.

4.7 Leading vs. Lagging Indicators

We should differentiate risk indicators with performance measures. In banking industries, the purpose of risk indicators and the reporting framework is to monitor the effectiveness of controls and efficiency. By contrast, performance measures are typically more global, historically focused, and tied to a balanced scorecard which mainly influences compensation. Understanding them in the context of lagging and leading indicator, it is obvious that the former is leading indicator and the latter is lagging indicator.

In context of major accident in installation, the success criteria of indicators are having zero major accident. Hence, the idea behind this is to have pro-active indicator which could be used to maintain motivation and awareness to prevent major accident. The indicators should change before the risk level change. In term of historical major accidents data availability, the lagging indicators can only give little information about the installation performance in the past, since the accidents are very rare. The availability data of major accident precursor events is also very rare. Base on experience of all installations in the Norwegian shelf, the occurrence of precursor event in one installation is only around one per year, therefore in the term of data availability, the lagging indicators are not suitable to predict a major hazard accident. The leading indicators then are more suitable in giving signal of major hazard than lagging indicators. However, the challenge is to find indicator which has enough amounts of data to show the trend as it required in table 4-1. The motivation of using leading indicators is also showed in banking industries which applying leading indicators for operational risk in order to predict the downturn of economy and resulting in hinder the economic loss.

4.8 Indicator for Major Hazard in Installation

We have presented the reader why the leading indicators are preferred over lagging indicators. Hence, this sub chapter is providing the leading indicators of major hazard in Installation. This sub chapter is to answer research question no 2.

4.8.1 Major hazard in Installation

Refer to risk level project, Vinnem (2010) stated that the amount of hydrocarbon leaks in installation could be precursors of accidents; this argument is also supported by the Baker Report (2007) which mentioned several leaks were occurred preceding the Texas BP accident. In Norwegian, the authority makes a strict differentiation between the leaks of hydrocarbon below 0, 1 kg/s and over 0,1 kg/s. Only the latter is considered as precursor of major accident. Hence, the idea behind the barrier as leading indicator is based on the ability of barrier to prevent hydrocarbon leaks over 0,1 kg/s which can be interpreted as preventing the major accident. The main focus of barrier to prevent HC leaks are in the following:

- Barrier function for maintaining process system integrity.
- Barrier function for preventing ignition
- Barrier function for reducing cloud and spill size.
- Barrier function for preventing escalation.
- Barrier function for preventing facilities.

4.8.2 Barrier as Indicator

The leading indicators have been included in the Risk level project and those indicators have been comprehensively discussed by Vinnem (Vinnem et al, 2006). Those indicators are:

- Indicators based on performance of barriers that are installed in order to protect against major hazards.
- Indicators based on assessment of management aspects of chemical work environment exposure.
- Indicators reflecting quality of operational barrier elements, based on questionnaire surveys.

In this thesis, we consider the first indicator and the two latter are not considered any further.

Developments of barrier indicators in the RNNP project are based on barrier element periodic test. The tests are part of preventive maintenance schemes, the barrier element is tested using 'man made' activation signals or stimuli (such as test gas releases) and are carried out without any coupling to increased risk. Because it is part of preventive maintenance, the barrier test result could be considered as leading indicator according the definition from Kjellén (Vinnem:2010).

4.8.3 Suitability of Barrier Test Result as Indicator

Indicators, to be used to monitor safety level and motivate people to take necessary action as presented in table 4-1 must have big amount of data, relevant and able to be influenced by indicators themselves. Barrier test indicators satisfy the first reason by having sufficient data from the testing barrier elements (Vinnem: 2010). The barrier elements are seen as being relevant in preventing the HC leaks over 0.1 kg/s which is according the regulation is a precursor of major accident. The performances of the barrier elements depend on its maintenance, therefore seeing this as an object of maintenance personnel; the barrier is able to be influenced by the person. As a result, the variations of data according to barrier periodic maintenance will attract people and motivate them to focus on barrier preventive maintenance. The data for this thesis is from installations from RNNP which collecting data 2008 for the barrier as follow:

- Fire detection
- Gas detection
- Emergency shutdown valves on risers/flowlines
    - Closure tests
    - Leak tests
- Wing and master valves (X-mas tree valves)
    - Closure tests
    - Leak tests
- Downhole Safety Valves (DHSV)
- Blowdown Valves (BDV)

- Pressure Safety Valves (PSV)
- Blowout Preventer (BOP)
- Deluge valves
- Fire pump start

4.8.4 Risk Monitoring in Single Installation

It has been noted, until now there is no method which specifically address to monitor the risk in installation level. The Risk level project for monitoring the trend of risk level is not suitable to be used in monitoring risk in installation level, since the method is aggregation from all installations in Norwegian shelf. We therefore, would like to propose the new approach to monitor risk in installation level. The approach will use barrier testing result as an indicator of major hazard in single installation as we have argued in chapter 4.8.3. The detail of new approach will be presented in the next chapter.

5 NEW APPROACH

This chapter will provide the reader about methodology of new approach of risk monitoring in installation, the case study and the result of case study. The motivation of the new approach is based on the premise of monitoring the risk to encourage preventive maintenance, to keep the awareness of the stakeholders to prevent major accident in single installation. Following the literature survey from section 4.4, the manipulation of indicator must show the safer system; hence we propose the new approach of monitoring risk level in single installation.

5.1 Development of New Approach

The risk in one installation can be quantified by comparing the same risk with other installation in the same industries Aven (2003). Following the statement, we develop the new approach based on descriptive statistics calculation. The descriptive statistics means straightforward presentation of facts. The reason behind this is because we try to measure the performance of safety barrier among all the installation. This method is similar with comparing performance of football strikers in the World Cup. The average goal of striker per game can summarize the performance of striker in the competition. However, this method reduces some important data into simple summary, for example the average does not differentiate between scoring against strong team or weak team. Therefore an explanation is required before drawing the conclusion from the data. Nevertheless, despite of its limitation the descriptive statistic is still powerful tool to measure the performance.

The assumptions have to be made before we can use the descriptive analysis. In this thesis, all the installations are treated the same, disregard the type and age of installation. With this assumption, we move to the next step by proposing the approach to calculate the performance of barriers. Firstly we define the reference or threshold which is used to escalate the information to the management. The risk level threshold is the average value from all installations in Norwegian shelf. This threshold is chosen since the mean value represent the average risk in this industry. Secondly, the standard deviation of installation barrier test result is used, the premise is that how deviation measure how far the risk in installation deviate from average risk. All the formulas used in calculation are presented in appendix A. The complete algorithm is described in the following:

- Calculate the installation barrier test and national average of barrier test.
- Calculate the deviation of the installation barrier test from national average of barrier test.
- Scoring the deviation according to the list in table 5-1.
- Calculate the total risk installation using the scoring average. There are two options of calculating the average which are the simple average and weighted average.

The idea to perform different average calculation method is based on the reality that some leaks are more dangerous than others which correlate with some barriers have higher risk than others. This fact is translated into weighting system which is assigned to the barrier elements. Those weights are included in calculating average to form overall risk score. However, in this thesis we do not perform the study to define the weights, because the objective of this thesis is to show how this method is applied to monitor risk. The basis for defining the weights will be a subject of discussion.

Score	Explanation	Criteria	Scoring
A	Status corresponds to the best standard in industry	Value < National average – 1.5 SD	10
B	Status corresponds to a level better than industry average	National average – 1.5 SD < Value < National average- SD	8
C	Status corresponds to the industry average	National average - SD < Value < National average	6
D	Status corresponds to a level slightly worse than industry average	National average < Value < National average + 0.5 SD	4
E	Status corresponds to a level considerably worse than industry average	National average + 0.5SD< Value < National average + SD	2
F	Status corresponds to the worst practice in industry	Value < AVG + SD	0

Table 5-1 Risk Scoring Table

The risk scoring system in table 5-1 is still subjective; the grading system put big difference from C to B. It is barely intended to show that massive effort is needed in order to achieve a very good risk reduction. For the same reason as weighting system, this scale is still needed to be explored further. In addition to the first reason the nature of the data in this thesis is not suitable to provide a good judgment in using percentile.

5.2 Observation from case studies

It must be noted that the case study is an illustrative example and mainly intended to show how the method is applied to quantify safety barrier performance, in order to monitor the major hazard risk. As it has been mentioned before, this method use the deviation of barrier test results from the national average, to produce the risk scoring. The results therefore could be interpreted as warning signal for major hazard. In this method we are not interested in using the exact value of the results, but we will use them together with risk level trend to give a more meaningful risk picture. Nevertheless, the quality of test result data and the volume of data are very important to give some variations and attract awareness of stakeholder. There are a number of things to discuss from this method which could produce uncertainties from the result, limitation and space for manipulation.

5.2.1 Data modeling

The data which is used in this thesis is from two installations; these installations represent the new and the old installations. The premise of this data is to make a contrast of those two installations, then highlighting that the more fault of safety barrier corresponds to higher risk in installation. Installation A is an old installation and produce more faults in safety barrier tests, the data are presented in table 5-2. Installation B is the new installation and produce less faults in safety barrier tests, thus presented in table 5-3. However, installation B does not have all the safety barrier data, therefore to calculate the total risk score, only the available data are taken into account in calculation. These data are not intended to be incomplete, as they are taken from the real data, however these could give an illustration how the data incompleteness could be used as a room for manipulation.

Year/Category	2004	2005	2006	2007	2008
Fire detection	1332-4	936-4	292-0	1109-1	1114-1
Gas detection	1400-4	334-3	414-2	712-12	840-2
Riser ESDV	3-0	4-2	9-2	8-0	12-1
				4-0a	6-0a
				4-0b	6-1b
W&M isolation valves	74-1	60-0	144-1	136-2	128-8
				68-0a	46-4a
				68-2b	82-4b
DHSV	0-0	106-6	167-9	176-15	151-7
BDV	0-0	22-0	222-19	71-8	162-17
PSV	0-0	241-16	288-13	235-6	304-9
BOP	0-0	0-0	194-0	355-1	368-5
Deluge	102-0	81-0	57-1	27-1	52-1
Fire pump start	312-0	232-0	155-0	155-1	156-0

Table 5-2 Barrier tests data of Installation A (Reproduce from Vinnem(2010)))

Year/Category	2003	2004	2005	2006	2007	2008
Fire detection	1065-17	1122–12	1091-6	1135-17	1135-1	1140-0
Gas detection	539-19	543-9	547-5	568-9	569-0	561-1
Riser ESDV	17-1	17-0	48-5	62-1	248-1	160-0
					124-0a	80-0a
					124-1b	80-0b
BDV	0-0	33-4	103-0	90-0	153-1	111-2
PSV	0-0	0-0	277-17	472-14	312-6	304-20
Deluge	58-0	45-0	32-1	48-0	32-0	55-0
Fire pump start	208-0	208-2	155-0	103-0	104-0	104-0

a Closure test.

b Leak test.

Table 5-3 Barrier tests data of Installation B (Reproduce from Vinnem(2010)))

In order to provide standard deviations, we generate the artificial data for other installations. Those data are presented in appendix A. Although the data are not covered all the installations in Norwegian authority, the data are reasonable enough to illustrate the variation of installation's barrier tests data in Norwegian shelf.

5.2.2 Risk Scoring

The risk scoring process gives interesting results as are shown in table 5-4. As it was predicted, the installation A which is the old installation has four categories fall into unacceptable level of safety risk, whereas the new installation has none. Despite of those unacceptable levels, installation A has four categories safety risk better than industry average which are: fire detection, gas detection, PSV and fire pump start, in comparison the installation B has safety risk better than industry average almost in all categories, except in PSV which has considerably worse than industry average. The installation B does not have data for wing and master valves and DHSV categories; therefore we cannot compare the results.

The results show that base on the barrier test result, the installation B has lower risk in term of gas leakage. Moreover, since the gas leakage could be used as a precursor of major hazard (Vinnem: 2010) then it corresponds to less risk in having major hazard. This conclusion seems logical, because the installation B is newer installation, then the installation were designed to meet the new safety standard. Moreover, the components in installation A have younger age than installation B, so that in term of component function degradation, they should perform better. However, there is need more evidence to support the second conclusion, because the degradation of components function are related with maintenance performance in the installation. The low score and the down trend of risk level in installation could be a good sign the need of improvement in installation maintenance performance.

There is the difference between the predictions and the result, the PSV in installation B has less safety level compare with the PSV in installation A. Furthermore, if we look into the raw data, there is no difference in number of tests, both have 304 tests but the installation A has only 6 faults whereas installation B has 20 faults. These results must be perceived as a warning signal for the operator of installation B to do an improvement of PSV safety level as safety level risk is considerably worse than the industry average.

Category	Installation A	Installation B
Fire detection	B	B
Gas detection	B	B
Riser ESDV	F	B
- closure test	-	-
- leak test	-	
Wing & Master valves	F	-
- closure test	-	-
- leak test	-	-
DHSV	E	-
BDV	F	B
PSV	B	E
Isolation w/BOP	E	B
Deluge valve	F	B
Fire pump start	B	B

Table 5-4 Risk score of installations

We should note that there are significant differences of barrier test frequencies between those two installations. Therefore, we should put uncertainties base on the variation of test frequencies among installations. The number of riser ESDV tests between those two installations differs significantly. Installation A only has 12 tests and by contrast installation B has 160 tests. It is logical that increasing the number of tests will create lower unavailability rates. This situation will give room for data manipulation and could lead to produce false signal of major hazard. Therefore, there must be a standardization of number of tests which are acceptable to produce a good data. However, it could vary from one installation to another installation due to the differences in safety barrier equipment.

5.2.3 Data Availability

As we use the standard deviation to calculate the risk score, the quality and availability of barrier test data in installations is very important. We have mentioned above that we use artificial data to calculate the standard deviation and national average. Therefore, we generate the artificial data in order to reflect the data availability condition in Norwegian authority. Table 5-5 shows the data conditions of each installation. The table presents mean fraction faults of the installation.

Category	Installation A	Installation B	Installation C	Installation D	Installation E	Installation F	Installation G
Fire	0.000897	0	0.0008952	0.0026809	-	0.0008952	0.0051502
Gas	0.002380	0.001782	0.0038461	0.0058479	-	0.0043668	0.0344827
Riser ESDV	0.08333333	0	-	-	-	0.00515464	-
- closure	0	0	-	-	-	-	-
- leak	0.166666	0	-	-		-	-
Wing & Master valves	0.0625	-	0.00277778	0.00621118	0.04	0.00192308	0.00492611
- closure	0.086956	-	-	-	-	-	-
- leak	0.048780	-	-	-	-	-	-
DHSV	0.046357	-	-	0.0126582	0.0476190	0.0147058	-
BDV	0.104938	0.018018		0		0.0285714	-
PSV	0.029605	0.065789	0.0434782		0.0204081	0.0909090	-
Isolation	0.013586	0	-	-	-	-	-
Deluge	0.019230	0	-	0.0014705	0.0047846	-	-
Fire	0	0	-	0.0026881	-	-	-

Table 5-5 Mean fraction of faults of installations

In case of various type of installation and data dispersion, the closure test and leak test of wing and master valves only have data from installation A, although the total data are available, if the data is more detail, then we would have better analysis. The riser ESDV data shows that test result from installation A dominates other installations. The faults in installation A is around 16 times larger than installation D whereas installation B has none fault. Because one installation dominate the value, then the dispersion curve will bigger and contribute to larger standard deviation which might not really reflect the true deviation of all installations safety performance. In this case, the riser ESDV data is from the low number of tests therefore it supports the previous statement to have standardization of number. However in other case, the deluge valve tests the number of tests between installation A and B are almost same which are 52 and 55 whereas the installation D and E, by calculating the mean fraction of faults correspond to a value of 1 fault out of 680 and 1 fault out of 209. We, therefore cannot judge the previous statement base on the number of test differences. However, if the number of tests is in the same range, the analysis will have a judgment.

5.2.4 Calculation Method Analysis

We would like to compare the calculation methods. The idea is to simulate which method is suitable for calculating average. Table 5-6 shows the results of each method. We use three different methods to calculate the average risk. The first method is simple average method; in this method each category has same weight. The second method is weighted average, in this method we assign different weight for each category, the premise is that the difference of hazard magnitude in the area. We, therefore examine two different weight systems, this is intended to show how the change of weight affect the average risk. The weights in the first method are assigning subjectively for simplicity reason, so that the sum total of score after weight normalization would be the average risk. The second method uses the weights base on Vinnem (2010). Both weight values are presented in table 1 at appendix.

	Simple Average		Weighted Average		Weighted Average 2	
Category	**Installation A**	**Installation B**	**Installation A**	**Installation B**	**Installation A**	**Installation B**
Fire detection	8	8	0.8	0.8	0.44	0.44
Gas detection	8	8	0.8	0.8	1.33	1.33
Riser ESDV	0	8	0	1.6	0.00	1.33
- closure test	-	-	-	-	-	-
- leak test	-	-	-	-	-	-
Wing & Master	0		0	-	0.00	-
- closure test	-	-	-	-	-	-
- leak test	-	-	-	-	-	-
DHSV	2		0.1	-	0.11	-
BDV	0	8	0	0.4	0.00	0.89
PSV	8	2	0.4	0.1	0.89	0.22
Isolation	2	8	0.1	0.4	0.11	0.44
Deluge valve	0	8	0	0.8	0.00	0.89
Fire pump start	8	8	0.8	0.8	0.44	0.44
Average	3.6	7.25	3	7.125	3.33	6.75
Average Risk	E	C	E	C	E	C

Table 5-6 Comparison of Risk Average

The calculation of average risk is straightforward, the average is the sum total of category values divide number of categories. In weighted average method, because the weights are already normalised, then the total sum of values become the average. Since the installation B does not have the complete data, then we only include the categories which have value into the calculation, therefore in weighted average method, the divisor is the sum of total weights.

Following the result from all three methods, the installation A has risk average considerably worse than industrial average, whereas the installation B has risk average corresponds to the level of industrial average. As shown in the table 5-6, there are differences in risk average score among the three methods. Installation A, has low value for the categories which has more weight in weighted average 1, therefore the result is considerably lower than the value in simple average method. Installation B has the same case in weighted average method 2 which gives considerably lower score compare with its value in simple average method.

Observing the result from the average calculation method, the simple average method has advantage in term of scoring manipulation, since all weights are the same. However, assign all the safety barrier with the same weight do not make any sense, as we know that the safety barrier has different consequence in creating major accident. On the contrary, it is more reasonable to use weighted average as a calculation method due to the nature of difference in safety barrier consequence to major hazards. But, this method has weakness aspect as it is more prone to scoring manipulation.

For the reporting purpose, one could assign the low weight for lower score and more weight to the bigger score, then could produce the good result. Moreover, people are more attracted in putting more effort to the categories which have more weight than others, as it is reasonable to produce improvement report which come from indicators that have more weight. Therefore, in addition to standardisation of number of tests, there should be also the standardisation of weights in order to have the proper risk average score which has benefit to be used as information for decision making purpose. Another room for manipulation is the reporting mechanism as mentioned in Vinnem (2010). The operator can have different number of faults depend on their failure modes. Those faults which would prevent a safety critical function would be reported, while the faults which are not related with safety critical function such as for an isolation valve to close on demand would not be appeared in the report. Thus, Vinnem (2010) suggests the verification of failure mode classification.

The thing to be considered in this method is the capability limit of the method. This calculation method are simple and straightforward, the calculation only base on test result of safety barrier, without take into account the structure of safety barriers. For that reason, we cannot interpret the differences in safety barrier structure.

5.2.5 Rolling Average

As we discussed above, analyze the installation risk barely rely on the average score data itself is not sufficient. The score only tell the relative of installation's risk compare to other installation which cannot tell the future risk. We, therefore propose to use the risk scoring method together with Rolling three years average. The Rolling average method was adopted first for RNNP project in term of lagging indicators. The study from Heidi and Vinnem (2008) shows, that this method is applicable for barrier indicators. The reason behind this method is the low volume of faults in barrier tests for the installation with reliable system.

Figure 5-1 and 5-2 show the rolling average for installation A and B respectively. The values are not normalised as we are only interested in showing the risk trend. The analysis is based on assumption that all the data are valid; despite some years do not have data. The missing data in the first year of rolling average then will create an illusion of the increasing risk trends; however the purpose of this analysis, again, is only as a case illustration, we will omit the phenomenon.

The case in installation B, BDV and deluge valves categories have risk level better than average, but has negative risk trend which means the risk on those categories are increasing. These facts could be used to attract management awareness, as the improvement should be made in order to maintain the good risk level. While The same case also occurs in installation A, the BDV, wing and master valve and deluge valve have negative trend level. With the facts that all the categories with negative trends do not comply with the industry standard, the management then has to make a big improvement to increase the safety level.

The authorities in Norway have stated clearly that only the hydrocarbon leaks over than 0, 1 kg/s are considered to have the potential to cause major accidents. However, in an installation, the occurrence of major hazard precursor is also very rare. Lesson learned from RNNP project, for a company which have a few installations on the Norwegian shelf, there are only five precursors were registered in 5 years. This condition has created the challenge to have the proper lagging indicators. In the RNNP project, they used data from barrier tests result to form lagging indicators. The reason was, the barrier tests result has sufficient volume and variety of data, therefore are useful to show the safety performance trend. This idea was supported from the work of Hale (2009) which stated that there is no need of causally linked to safety outcomes, as long as the correlations stay high and the numbers are big enough to show trend.

In term of historical accidents data availability, the lagging indicators can only give little information about the installation performance in the past, therefore cannot be used as a sign of major hazard accident. The leading indicators then are more suitable in giving signal of major hazard than lagging indicators. However, as it has been shown in the case study that the use of barrier tests as lagging indicators has benefit in giving the information to management.

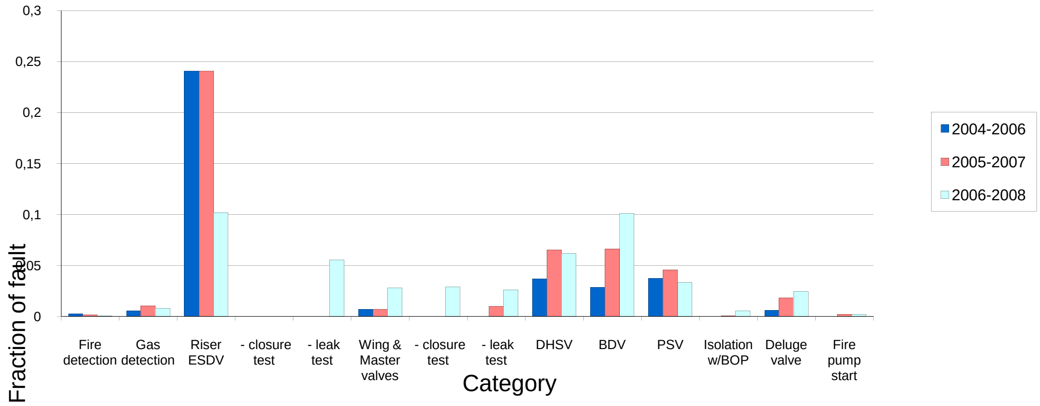

Figure 5-1 Rolling Average of Installation A

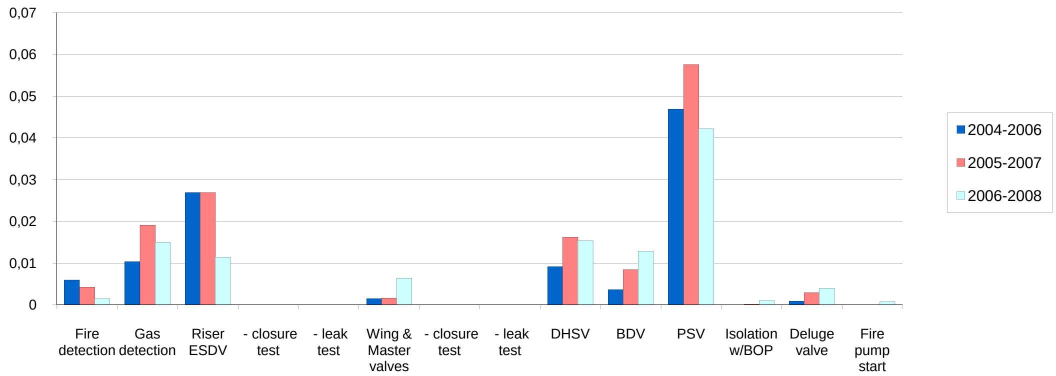

Figure 5-2 Rolling Average of Installation B

5.4 Barrier Tests as Leading Indicators

Following the definition of leading indicator in previous chapter, we support a definition which is used in economics which define that leading indicator is indicator that changes before the economy changes; this definition is also supported in Vinnem paper (2006). Therefore, we are in position against the definition from Ale (2009) which stated that any indicator which is viewed in perspective of time could not be used as leading indicators. If we follow that definition, it has consequences that there will be no leading indicator which could be applicable in any industry. The indicators in our perspective are seen as pro-active indicators which are used to give a signal to management to be more focus in maintenance process.

The hydrocarbon leaks has been perceived as precursor of major accidents, therefore viewing in pro-active indicator perspective, any barriers change related to prevent hydrocarbon leak could be perceived as sign of change in major hazard. Therefore barrier performance can be seen as leading indicators. The important requirements which are needed to be leading indicators are significant reporting volume and sensitivity to change. As mentioned above, the barrier test has enough volume of data which is essential to show some variations in indicators and could be a useful way to attract attention and maintain awareness (Vinnem: 2010). Another advantage of the barriers test data is that they change periodically according to their maintenance periods. Therefore, the overall indicator will be a combination of slow change indicators and fast change indicators. This mechanism is expected to attract the management to focus on maintenance process as the indicators change depend on maintenance schedule.

From the case study, the results of risk scoring calculation show the relative risk in one installation from the national risk. All the overall calculation method shows that the risk level installation A is significantly below the industrial average risk level which could be perceived to be more prone to major accident, whereas the installation B has the same risk level as industrial average's. The result could be used to tell the installation an operator to increase their risk level with focus on individual indicators which has score below C. In installation B, the result could tell the operator that the installation has same risk to major accident as other installation, but there is need safety improvement for safety barrier which has score below C.

Following the result from case study, the overall risk score indicate the current risk level of installation, the score then will be updated frequently according to the test period of the barrier tests. Therefore, the installation will always have the current risk level, as the maintenance of fast indicators are normally less than six months. This scheme force the operator to have continuous monitoring in order to keep the installation has the recent status. In conclusion, the overall risk score then is more suitable to be used to anticipate the major accidents in the future than the historical performance as it always tell the current risk level of installation. These indicators could serve as a basis for installation KRI, allowing more categories to be added into the overall score.

5.5 Premises for Successful Use

This method base on the idea that the bigger deviation of one installation's safety barrier than the national average, correlates with the bigger risk level of major hazard relative to industrial average. The case studies show that the volume and variety of barrier tests data are sufficient to provide lagging and leading indicators to the operators. The leading indicators could become KRI and lagging indicators become KPI.

The risk score calculation method should be use together with the risk level trend. The calculation method which only refers to national average can only tell the risk level relative to other installation. The risk level will move according to the national average change. This has a positive side, which motivate the installation operator to be better than other operator, and it is expected will pull the trend to be positive. On the contrary, if the industrial average becomes worse than the method cannot provide the information.

To counteract the weakness side, the risk level trend can give the performance trend of an installation. As it has been shown in case study, if the overall risk score look good, but the performance trend is decreasing then the operator have to be aware. Another purpose of using both results in the same time is to motivate the operators to achieve better score every year. One installation test results could look worse, if the barrier test results are constant and national average is decrease and as a consequence will lead to bigger deviation. This condition is expected to be a pressing environment to motivate the operators to perform better every year.

The overall risk score of leading indicators currently are produced from ten single indicators. This is due to in RNNP, only those ten indicators were included in calculating the risk level. However, as these indicators could serve as a basis for KRI, more indicators should be added later to provide broader risk picture in installation.

There are two companies which covers more than 80 % installation in Norwegian sector, have more extensive lists of the indicators and reporting schemes for barrier indicators. The other companies only have simple scheme which include a limited extend of system and not in continuous monitoring mode. As there are 10 companies which have production operation in Norwegian sectors, the adoption of barrier indicators in industry is still low. Therefore, there should be a regulation to follow-up of barrier indicators, and it is expected that more companies will adopt similar schemes in the future.

5.6 Future Development of the Approach

The case studies, involving variety of barrier test data have shown a promising result. The data are sufficient to provide information for operator in form of lagging and leading indicators. The method is straight forward, simple and will not burden the operator with complex reporting schemes. Yet, the method is still helpful and sensitive to change. However, there are limitations and the need to cover uncertainties from the data which are described above which could lead to future research to improve this method.

Until now, the operators more focus in technical aspect of installation. However, in reality human and organizational factor is very important to cause major accident. There have been some effort to establish indicators for operational barriers, but there are few success stories. The challenge of this work, mainly because there is no clear and easy ways to measure these levels. The method is also labor intensive, which requires audit scheme which may consist of observation, questionnaire, and interview scheme of company operation. These will require time and from the experience, the interval between two audits schemes could take years, therefore those indicators will become slow change indicators and as a result could not be good indicators. However, the needs of human and organizational indicators are eminent to provide broad picture of operational risk in installations. This will be a good candidate for further research.

6 DISCUSSION

The objective of this thesis is to find new approach to monitor the risk of major hazard in single installation. In previous chapter, the readers are already familiarized with the proposed method. In real practice, the company has to balance the operational condition between safety and production. Therefore the method should be able to address the safety issue on major hazard and at the same time not to burden the company with cost and time consuming calculation. The method is simple and not likely will burden the company, then, the only question left is "is the method able to address the safety issue on major hazard?" This chapter provides the discussions which are important in addressing the issue.

6.1 Can the approach prevent major accidents from occurring?

The premise of the approach is to encourage the barrier preventive maintenance. Based in the model presented in figure 4-1, monitoring scheme has function as a feedback control to maintain the barrier works at best level. The case studies result shows that the risk level of one installation depends on average risk level of all installations which means the risk level is always in dynamic state. If all installation performs better then automatically the threshold of risk level is higher, As a result, the installation which does not perform well will find its risk level lower.

The situation presses the management to focus on maintenance activities of the installation technical barrier to maintain the level of installation risk. As the barriers are very important to prevent HC leaks, then the good state of barrier performance implies lower risk of major accident. Lesson learned from the latest major accident, the Macondo blow out has showed that the accident was caused by the failure of barrier system. At the time of accident, BOP system which is the barrier system failed to cut off the oil flow as it required (Wikipedia).

Another lesson learned from Piper Alpha explosion also showed how important the barrier system, not only the technical side but also the human and organizational barrier. The accident was resulted from a series of barriers failure. Firstly, the failure of organizational barrier resulted in the lost of work permit and paralyzed the water pump. Secondly, the technical barriers failure contributed to the explosion and ruptured the platform. The messages from those accidents are obvious, the performance of barrier is ultimately important to prevent major accident. Hence monitoring the performance of the barriers to motivate maintenance of safety barriers to be at their best state will minimize the occurrence of major accident.

This approach itself has not been tested in real practice yet, and the implementation of the approach is only illustrated in case studies. Therefore, the validity of the approach is still need to be explored. However, the approach is based on the method which has been implemented in Risk level project, and the data which is used to illustrate case studies are taken from installation which operates in Norwegian shelf. This, at some extend could provide a judgment to be applied in real practice.

6.2 What should be acceptance limits for high reliability barrier elements when testing on an installation?

As the barrier system now become more complex, implementation of barrier system in installation required certain Safety Integrity Level (SIL) which is regulated in international standard IEC 61508. The SIL is based on FMEA studies combined with risk acceptance criteria to achieve the required SIL. Table 6-1 shows probability of failure on demand (PFD) and the probability of a dangerous failure per hour (PFH) corresponding to the safety integrity levels. As the barrier in operational mode, the operational SIL is lower than the design SIL. This is due to the influence of human and organizational factor to operational condition of barrier. According to Schönbeck (2007), the design SIL can only be achieved if the barrier operates according to the ideal condition as its design. Furthermore, Schönbeck (2007) quoting from Duijm & Goossens (2006), wrote that reliability of technical system cannot be improved by safety management system; by contrast reliability of system can worse as a result of bad management system. This statement implies that the maximum operational SIL is the design SIL.

SIL	PFD	PFH
4	10−5 to < 10−4	10−9 to < 10−8
3	10−4 to < 10−3	10−8 to < 10−7
2	10−3 to < 10−2	10−7 to < 10−6
1	10−2 to < 10−1	10−6 to < 10−5

Table 6-1 SIL Table

This monitoring approach does not specifically address the SIL issue as performance measure of barrier element reliability. However, the risk scoring method which categorizes the major hazard risk according to the barrier deviation performance could indicate the relative barrier reliability of one installation to other installation. This is based on the assumption that the installation was designed according to the regulation which resulting certain SIL has been achieved. This fact implies that indirectly, the scoring system could roughly represent the operational SIL of barrier elements as the barrier test performance is measured in operational mode.

As it has been mentioned, the categorization of risk scoring is only for illustration purpose; therefore, there are still some further steps needed to find the relation between SIL and risk score. Firstly, this method itself still needs further research to find the right value to categorize risk level. Secondly, extend the research to find the relation between the SIL and scoring level. However, since in this method, the categorization depends on the average of all installation, finding the correlation between exact SIL as it shown in the table 6-1 and risk score as it shown in table 5-1 could be a challenging task. The possible solution, therefore is applying the similar calculation method as described in chapter 4 to score the installation operational SIL and corresponding it with the risk level. In conclusion, based on some senses, if we disregard the SIL issue, the high reliability barrier in this method is achieved if the score is more or equal then C which means the risk level is better or same with the industry average.

6.3 Why focus on technical barriers when human errors are the main cause of accidents?

In reality, human and organizational (MTO) factors have influenced the barrier performance. They started from the beginning of the barrier project and will continue to influence along with barrier lifecycle. This calculation method, because it barely focuses on the barrier test result, does not take into account those influence. However, as the barrier test is part of preventive maintenance process, the MTO barrier has already been included. The barrier such as standard operating procedures, manual and regulation of maintenance process already serve as barriers in the barrier testing process. In addition, the regulation requirement of high reliability barrier equipment also may have reduced the human error. Therefore, some MTO influence indirectly might have been measured in the test result.

Following Duijm statement in sub-chapter 6.2, that safety management system cannot improve the reliability, this statement is parallel with the maximum barrier performance can only be achieved when the MTO is maximum which is as it required in the design. Therefore, if we formulate it in the mathematical form, the performance of technical barrier can be explained as:

$$\text{Operational barrier performance} = \boldsymbol{\alpha} \times \text{Design barrier performance} \quad (6\text{-}1)$$

$$\alpha = \text{MTO influence}, \; 0<\alpha<1$$

From the formula above, it can be concluded that to increase the positive influence of MTO, the technical barrier must be kept in perfect condition. The Macondo and Piper alpha accidents show that inadequate technical barrier such as BOP and safety valve were consequences of inadequate organizational barrier.

Other reason to focus in technical barrier is the availability of data; the data is relatively robust against manipulation, and easier to be gathered, in comparison with MTO barrier data. The main sources of MTO barrier data is from audit activities. As it has been known, the audit activities require time and massive effort and in some extent depend on the willingness of people to provide the data. This situation leads to the need of well train auditors to assure the reliability of data (Guldenmund et.al: 2005). However those facts cannot be a judgment to not include the MTO barriers into the calculation method. Further research in human and organizational barrier is necessary in order to have a complete KRI for operational risk. The technical barriers indicators then become the first step to build operational risk KRI in single installation and the next step will be the MTO barriers.

6.4 How to choose what barrier elements are most important to monitor?

In this approach, we have presented the readers with the idea that each barrier element has different degree in causing major accident. This is translated by introducing weight for each barrier element to be included in calculating average. As presented in case studies, the weighting system is prone to manipulation. Therefore, the proper weight must be assigned to hinder the manipulation. Moreover, the ultimate benefit of weighting system is to help management to monitor the most important safety barrier.

In this thesis, the weight has not been researched yet. However, the possible solution is using the bow-tie diagram to identify the influence of safety barrier to major accident. In the recent years, bow-tie diagram becomes a popular tool to illustrate the influence of safety barrier to the accident. Using bow-tie diagram, different major accident scenario can be modeled. The prevention barriers which act to prevent the cause is placed in the left side and mitigation barriers side which act to mitigate the consequence of accident are placed in the right side. One success story of using that diagram is the ARAMIS project

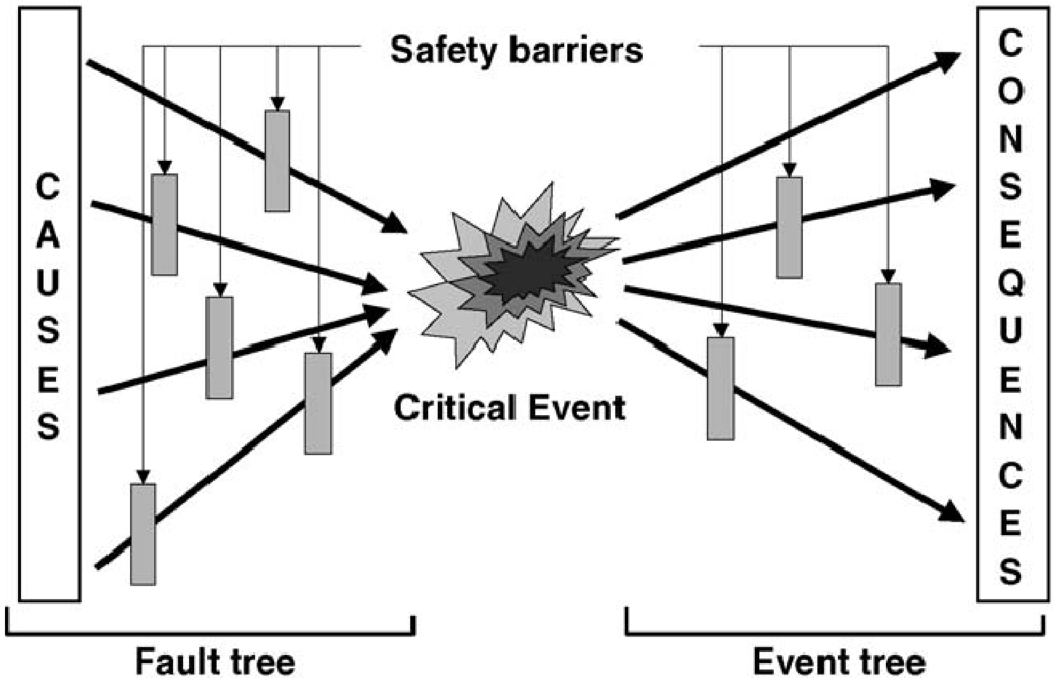

Figure 6-1 General Scheme of Bow-tie diagram of major accident

(Adapted from Dianous & Fi´evez:2005)

Following the bow-tie diagram, it makes some senses that prevention the cause of major accident is preferred than mitigate the accident as it is in-line with zero accident philosophy. Once again, lesson learned from major accident, as the mitigation barrier is a barrier after the occurrence of accident such as in Piper Alpha, it might be too late to prevent the major accident. In conclusion, the more weight should be addressed in prevention barrier compare to mitigation barrier. Therefore BOP should have more weight than deluge system. Expert judgment and quantitative risk analysis (QRA) studies can serve as a basis to do further research in defining weight.

7 CONCLUSION

What we really are looking for in this study is to create an approach to monitor major hazard risk in single installation. This chapter concludes the work in this thesis. Illustration from the case studies shows a promising result. Barrier test results as the raw data are suitable to be used as indicators. The risk monitoring method which use descriptive statistic is straight forward, simple and is likely will not burden the operator with complex reporting schemes. However, in analysis explanation is needed to give more meaning from the result.

Following the discussion, this approach might be able to prevent major accident by motivating management to maintain the safety barriers to be always at their best state. As a consequence, the occurrence of major accident will be minimized. However, providing the SIL as a measure of safety barrier reliability state is a limitation of this approach. Therefore, the high reliability barrier in this method is achieved if the score is more or equal then C which means the risk level is better or same with the industry average.

As the MTO influence is very important for performance of safety barrier, the need to do further research in MTO barriers is eminent. Although in this approach the MTO influence might have reflected, there is no specific method to address this issue. Therefore, the analysis cannot be applied under the issue. However, focuses on technical barrier indirectly require the management to focus also on MTO barriers. Another important issue is the weighting system, as it creates the room for report manipulation but on the other side has benefit to management to prioritize of barrier monitoring. Following the issue, the bow-tie diagram can be a helpful method to address this issue. Based on the method, it makes some senses that prevention the cause of major accident is preferred than mitigate the accident as it is in-line with zero accident philosophy. Therefore, the more weight should be addressed in prevention barrier compare to mitigation barrier. However, to have the proper weighting system, further research is a necessity.

Nevertheless, to end the conclusion, this approach is useful to monitor major hazard risk in single installation. The data availability, the method is light, yet still provides relevant information for management to make a decision.

APPENDIX

$$\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i$$

Formula 1. Average

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i}.$$

Formula 2. Weighted Average

$$s_n = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \overline{x})^2}.$$

Formula 3 Standard Deviation

Category	**Weight 1**	**Weight 2**
Fire detection	0.1	0.06
Gas detection	0.1	0.17
Riser ESDV	0.2	0.17
- closure test		0.00
- leak test		0.00
Wing & Master valves	0.2	0.11
- closure test		0.00
- leak test		0.00
DHSV	0.05	0.06
BDV	0.05	0.11
PSV	0.05	0.11
Isolation w/BOP	0.05	0.06
Deluge valve	0.1	0.11
Fire pump start	0.1	0.06

Table 1 Category Weight (Normalization)

Abbreviations and acronyms

BDV	Blowdown Valves
BOP	Blowout Preventer
BP	British Petroleum
DHSV	Downhole Safety Valves
ESDV	Emergency Shut Down Valve
HES	Health, Environment and Safety
KPI	Key Performance Indicator
KRI	Key Risk Indicator
MTO	Humans, Technology and organization
NPD	Norwegian Petroleum Directorate
PSA	Petroleum Safety Authority
PSV	Pressure Safety Valves
QRA	Qualitative Risk Analysis
RNNP	Risk level in the Norwegian petroleum activity
RNNS	Risk levels - Norwegian Shelf

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