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Weather Risk In Marine Operations: An Approach For Using Risk Indicators From Offshore Environment Perspective

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Abstract

The safety of marine operations is largely dependent on the weather conditions. The conditions which exist at the location of operations, during the period when the operations are planned for execution, determine the feasibility of preforming them successfully.

Weather events are difficult to predict and have a potential to cause great damage. Weather forecasts, environmental load design and weather monitoring are some tools which provide valuable information but all these methods have uncertainties associated with them. Also, many other sources of information can be used to reduce the possible damage.

Risk to which any system or operation is exposed can be described with the help of risk indicators. One single indicator is not sufficient to describe the risk in any activity. Development of multiple indicators, which cover all the aspects of risk in marine operations, is necessary.

Indicators specific to weather risk in marine operations are described. A model to evaluate the total risk indicator, which uses knowledge from multiple indicators from different sources, is suggested for presenting the actual total risk picture.

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Shivam Avasthi

Stavanger, June 2016

Contents

Index of Figures

Index of Tables

ABBREVIATIONS

A	Event
ARCO	Atlantic Richfield Company
C	Consequence
CC	Coping Capacity
E	Exposure
FPSO	Floating Production Storage and Offloading
H	Hazard
K	Knowledge
R	Risk
S	Susceptibility
T_C	Contingency Time
T_R	Reference Period
TR	Total Risk
T_{POP}	Planned Operation Period
U	Uncertainty
UNISDR	United Nations International Strategy for Disaster Reduction
US	United States
USGS	United States Geological Survey
V	Vulnerability
WMO	World Meteorological Organization
£	Great Britain Pound

1 Chapter One: Introduction

1.1 Background

In today’s world, where technology is advancing at a pace faster than ever before, key to become a successful organizer is providing efficient and safe solutions to the growing need of the society. Safety is one of the major parameter which determines the credibility of an organization. If safety procedures are neglected, they may lead to catastrophic results. When we talk about safety, the first thing which comes to mind is risk. When an organization decides to take up a task or a project, there is always a risk involved in it. Two main categories in which it can be divided are accidental risk and economic risk. Traditionally, the activities which involve risk were performed by references to a pre-defined standard or code regarding the activity. According to (Aven 2012), in the current scenario, the focus is laid on the output required, instead of the procedures which are used in achieving it. In this kind of setup addressing the risk related to the activity is of prime importance.

Human beings have mastered many aspects of science but still a significant amount of it remains unexplored. We have the power of knowledge already available from numerous research undertaken and continuous effort is being made to increase this knowledge-pool to understand the complex phenomenon which occur in the nature. It can be convincingly said that we have achieved a substantial understanding of a lot of phenomenon covering a wide range of subjects. But, a major portion of research is still required to for obtaining control on some phenomenon of the nature which play a vital role in affecting the society. This control can be viewed as a control over the severe damage caused to asset and life, and its reduction.

A natural disaster can be defined as a disastrous event which is a product of a natural hazard. It disturbs the smooth functioning of the society, directly or indirectly. It may directly affect the society or the environment surrounding the society. Generally, intervention of the government bodies is necessary to mitigate the disastrous effects of the event, for bringing the life of the affected community back to normal (WMO 2005).

Hazard is defined by (UNISDR 2009) as “a dangerous phenomenon, substance, human activity, or condition that may cause loss of life, injury, or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.” And a natural hazard is defined as, “a natural process or phenomenon that may cause loss of life, injury, or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.”

Weather directly influences the environmental conditions in any region. This happens due to various phenomenon which take place and change regularly. Most of these phenomenon can be predicted with the help of the technology currently in use. But, still a significant amount of uncertainty is involved in the prediction methods and in the methodology followed in putting the predictions into use. Communication also plays a vital role in the scenarios having an influence of weather. Decision making in such scenarios is dependent on the quality of information made available and also on how early that information is available.

An important aspect which takes importance before the processing the information commences is, ensuring that methodology followed for processing the information should cover all the aspects of the risk associated with the hazard.

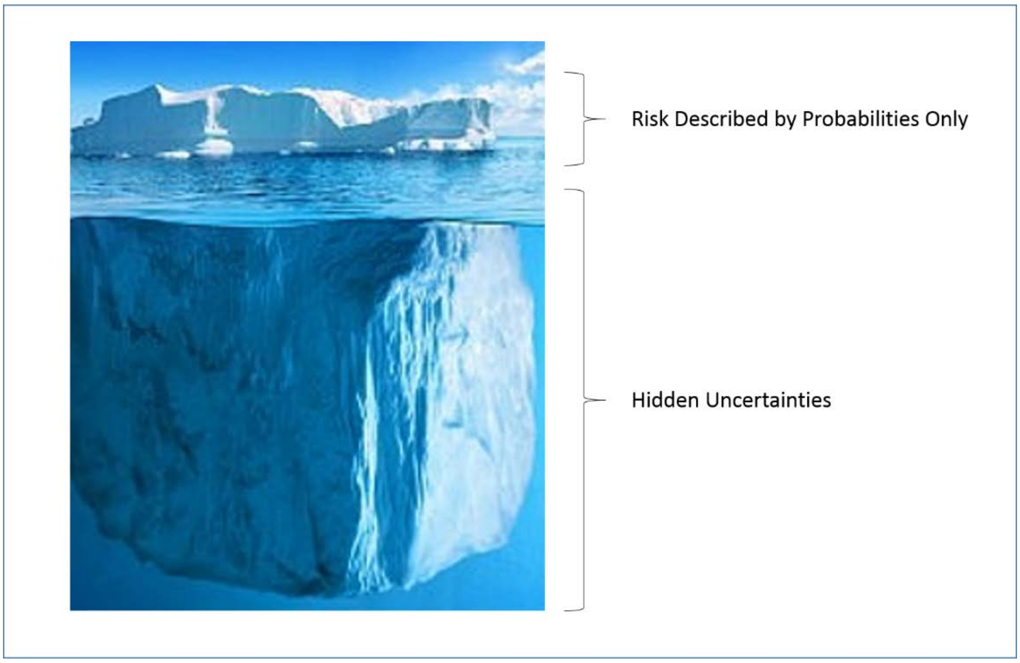

Figure 1: Risk and Hidden Uncertainties

Use of statistical data obtained from monitoring sources does not present the correct picture of the risk involved in any activity. As shown in Figure 1, uncertainties can be very critical in weather related events and a proper framework is necessary to account for them during the analysis.

1.2 Aims and Objectives

Objective of this thesis is to perform a qualitative study of the risk posed by weather conditions in the offshore environment. Weather phenomenon which influence the marine operations will be discussed. Also, an attempt will be made to present a model to evaluate the risk quantitatively taking the background knowledge about the marine operations into consideration.

1.3 Scope

This thesis covers the aspects of marine operations which are affected by weather conditions in offshore locations. The offshore marine operations are assessed to determine the factors which influence the risk involved in their execution. Weather conditions will be considered as the only source of risk in this thesis.

1.4 Thesis Structure

In this thesis Chapter Two gives an overview of the accidents which were caused due to severe weather conditions covering various industries and explains why weather conditions pose are critical in offshore conditions. Chapter Three provides an insight on how marine operations are influenced by weather conditions. Chapter Four deals with the concepts of risk which are applicable for weather related hazards. Chapter Five presents the characteristics of severe weather events and a model for evaluating risk due to hazards posed by weather conditions in offshore scenarios is discussed. Discussion about the use of knowledge from marine operations in evaluation of risk is also presented in this chapter. Chapter Six summarizes the approach presented in the thesis with the conclusions. Lastly, the documents used as reference for presenting and supporting the arguments in the thesis are listed in Chapter Seven.

2 Chapter Two: Literature Review

2.1 Accidents Due to Severe Weather Conditions

A number of accidents have taken place as a result of severe weather conditions in the offshore environment. Some of these accidents which give an overview of the unpredictability of these events and the severity of their consequences are presented in this section.

2.1.1 COSL, Norway

In the North Sea, an accident due to extreme weather was reported in December, 2015. The accident took place at Troll field, located on the west of Bergen. In this accident one personnel was killed and two were severely injured. The cause of this accident were storms which developed in the North Sea and caused giant breaking waves which in turn posed a great danger for the workers and assets. Accommodation module of the rig was also damaged due to the huge waves (Statoil 2015).

Apart from the hazard caused by the huge waves generated due to the storms, a barge was also set loose from a tugboat, which posed a danger to other offshore installations in the surrounding fields. The barge drifted near Valhall field operated by British Petroleum. This set off an evacuation in the installations which were exposed to danger due to the barge which was adrift and could have caused heavy damage.

Figure 2 shows the COSL rig where the accident took place in the Troll field.

Figure 2: COSL Rig in Troll Field (Statoil 2015)

Bad weather also hampered the emergency evacuation procedures as the helicopters were not able to land on the rig and personnel had to be lifted from the rig, thus increasing the overall risk in the procedure.

Hence, bad weather caused loss of life, damage to asset and loss of production.

2.1.2 Fire at the Ardrossan Wind Farm, Scotland

In December, 2011 strong winds at Ardrossan, Scotland caused a fire accident in one of the 15 turbines installed on the hills facing the coast. The turbine was 100 metres high and caught fire because the wind was having force of the level of a hurricane, which caused the turbine to spin at a very high speed. This resulted in the engine of the turbine catching fire and the smoke damaged the blades. Cost of the turbine was £2 million and apart from monetary loss, it damaged the wind farm which supplied green electricity to 20,000 homes in Scotland (Telegraph 2011).

Figure 3 shows the fire which destroyed the wind-mill in the Ardrossan wind farm.

Figure 3: Fire at the Ardrossan Wind Farm (Telegraph 2011)

2.1.3 Seacrest Drillship Disaster, South China Sea, Thailand

In November, 1989 a disaster took place in the South China Sea due to sudden generation of severe weather conditions. The Seacrest Drillship, operated by Unocal was anchored at the Platong gas field and drilling operation was being performed when the accident took place. According to (Kable 2014), the ship was hit by the Typhoon Gay, which capsized the vessel and produces waves which were 40 feet in height.

The drillship had 97 crew members onboard when the disaster took place and 91 of them lost their lives due to the sad event. There was no distress signal reported from the vessel and it was found floating upside down the next day by the search team. Hence, it was believed that the incident took place in very quick period of time giving no time to respond and execute safety operations.

Although the ship had some drawbacks as far as its seaworthiness is concerned, it can be clearly observed that the extreme weather events have a potential of huge destruction and in a very small time period.

Figure 4 shows the aerial view of the Typhoon Gay which generated in the South China Sea. Figure 5 shows the Seacrest Drillship which met the disaster.

Figure 4: Typhoon Gay storm in the South China Sea

Figure 5: The Seacrest Drill Ship (Thai Wreck Driver 2011)

2.1.4 Ocean Ranger Oil Rig Disaster, Canada

The Ocean Ranger was a self-propelled semi-submersible offshore drilling rig which was operated by Mobil Oil at Hibernia field. This field is located in the North Atlantic Sea off the coast of Newfoundland, Canada. The Ocean Ranger weighed 25,000 tonnes and was one of the biggest rigs of its time and the largest of its kind when it was launched.

According to (Kable 2014), at the time of disaster, 84 personnel were present on the rig. Bad weather was forecasted for the period when the disaster took place, the crew was alert and signals were sent in advance to the nearby installations to prepare for evacuations. A severe storm struck the rig which broke the porthole window of the ballast control room. This led to flooding of the room and ballast control panel malfunctioned and ceased to operate. Wind of speed 190km/h and waves of height 20m were generated by the storm.

Figure 6 shows the location of the Hibernia oil field in the Atlantic Ocean. Massive size of the Ocean Ranger semi-submersible can be appreciated from its profile shown in Figure 7.

Figure 6: Location of Hibernia Oil Field Relative to Newfoundland and St. John's (Kirby 2010)

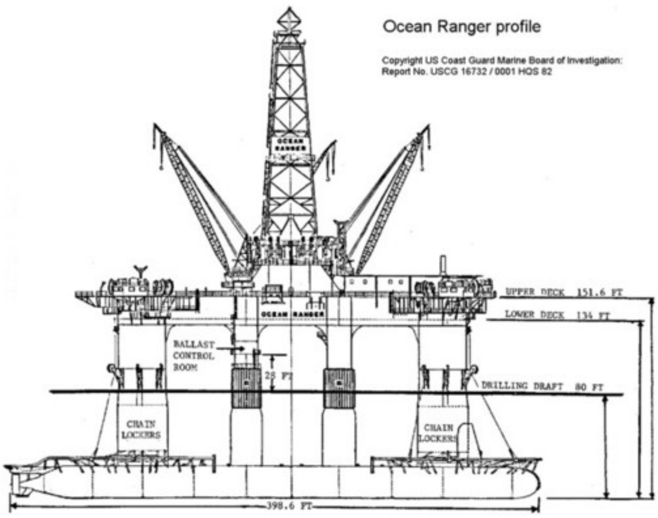

Figure 7: The Ocean Ranger on the Hibernia Oil Field (USCG 1983)

The crew members had to abandon the rig when the situation worsened and the rig started to become unstable. It was reported that only one lifeboat could be launched before the rig sank. Due to harsh weather conditions and violent storm the standby vessels from nearby installations could not reach the site of disaster for evacuation of the crew. Rescue teams were not even able to save the personnel on the life boat due to extremely difficult conditions and harsh sea state. All 84 members of the crew lost their lives in this disaster. The rig capsized and was lost.

2.1.5 Glomar Java Sea Drillship Disaster, South China Sea

In October, 1983, South China Sea saw another disaster which resulted in loss of life of all 81 people onboard a drillship. In this wistful event The Glomar Java Sea Drillship, which was being operated by ARCO China on a contract, met a tragic end to its service by capsizing and eventually sinking in the sea, south-west of Hainan Island, China. The location of the accident can be seen in Figure 8.

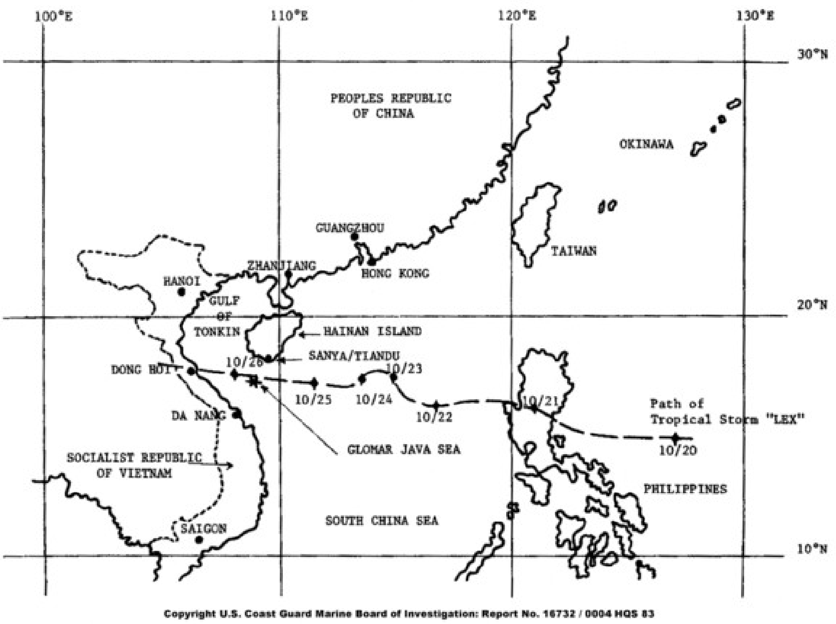

Figure 8: Location of the Glomar Java Sea Drillship and Path of the Typhoon Lex (USCG 1985)

The details of the accidents from (Kable 2014) inform that the drillship was hit by the tropical Storm Lex when it was at the drilling site. The operations were stopped before the arrival of the storm. Global Marine's office in Houston, Texas reported that winds of the scale of 138.9km/h were generated due to the storm and wrecked the drill-ship. Rescue and search team did not find any survivors and located the inverted drillship at a distance of 1,600ft south-west of its original position before the storm struck.

2.1.6 Bohai 2 Oil Rig Disaster, China

The Bohai 2 jack-up rig is one of the most fatal oil rig disaster which took place offshore. This disaster is also attributed to severe weather event which led to capsizing and toppling of the oil rig into the sea.

Unlike other accidents detailed in previous sections, this accident took place when the jack-up rig was being towed and was not in a moored condition. Accident information from (Kable 2014) suggests that severe storm struck the location of marine operation which led to generation of strong winds. Winds were so strong that they broke the ventilator pump located on the platform which resulted in a punctured deck. This caused flooding of the rig which lost stability because the rig was not jacked-up on its legs as it was being towed when the incident took place.

The investigations performed after the disaster suggest that the equipment on the deck was not secured properly and standard procedures for towing in bad weather conditions were not followed by the operators.

The tow boat was not able to rescue the crew members on the rig. 72 people lost their lives in this accident out of 76 people who were present on the rig when the accident took place.

2.1.7 Mumbai High North Disaster, Indian Ocean

This disaster took place in July, 2005 in one of the production platforms operated by Oil and Natural Gas Corporation, India. The platform Mumbai High North was located in the Mumbai High field in the Arabian Sea, at a distance of 160km from the coast. Samudra Suraksha, a multipurpose support vessel, was present near the platform before the incident. This disaster was initiated by severe sea state which played the major role in creating havoc on the production platform.

According to (Kable 2014) the accident was initiated when strong swells started to move the multipurpose support vessel towards the platform. The vessel ultimately collided with the platform with its rear part. This collision resulted in the damage to the gas export risers connected to the platform. The risers were ruptured and gas leaking from them ignited. The platform was set on fire and the heat damaged the platform, the vessel and another jack-up drilling rig under operation near the production platform.

The accident resulted in a production loss of about 120,000 barrels of oil and about 4.4 million m^3 of gas a day. A huge quantity of oil was spilled and caused environmental hazard. Figure 9 and Figure 10 show the big flames generated by the fire and provide a measure of the devastation caused due to this accident.

Figure 9: The Mumbai High North Platform on Fire After the Accident (Versatel 2005)

Figure 10: Samudra Suraksha Vessel on Fire After the Accident (Versatel 2005)

2.1.8 Usumacinta Jack-up Disaster, Gulf of Mexico

In October, 2007, 22 people lost their lives in an offshore disaster caused due to severe weather conditions. This incident happened in the Gulf of Mexico, in which the Usumacinta Jack-up collided with a platform.

According to the details presented in (Kable 2014), the jack-up was positioned near the platform Kab-101 and was being used for executing drilling operations. The jack-up was set up in oscillatory motion sue to a storm which resulted in its cantilever deck hitting the production tree valve. The storm was characterized with a wind speed of 130 km/h and a wave height of 8 m. The damaged valve caused the leakage of oil and gas, which ultimately got ignited and set the platform on fire.

22 people died in the accident and an approximate loss of 5,000 barrels of oil was reported in the process of controlling the blowout.

Figure 11: First Fire in Kab Well (Versatel 2007)

Figure 12: Usumacinta Jack-up Leaning Against Kab-101 Platform (Versatel 2007)

Figure 11 shows the fire on the Kab-well and Figure 12 shows the leaning jack-up rig against the platform.

2.2 Weather Conditions: A Potential Hazard

Extreme weather events are generally associated with increased risk and have a high potential to be associated with a disaster. Furthermore, non-extreme weather events may also lead to disasters depending on the status of the region of interest. Status of the region incorporates the physical conditions that exist and the operations which are under execution in that specific period of time.

These events are labeled extreme based on the values of statistical data of the parameters which characterize the potential of damage of the weather event. From details of majority of the accidents, it may appear that the hazard is mainly posed by the extreme weather events. But, many disasters may be attributed to the events which are not termed extreme according to the statistical methods used for the analysis of weather data.

Events which have taken place in the past show that even if similar extreme weather events take place, their consequences are different. These consequences are dependent on many factors, like geographical location, climate zone, environmental conditions which prevail during the event, preparedness of the system to avoid damage, etc.

The occurrence of weather events depends on the geographical location of the system under consideration. As offshore installations are located in different climate zones around the globe, also the vessels which are involved in marine operations are exposed to a variety of different climatic conditions, it is an important initial task to determine the hazards which the weather can pose in the specific area of operation. Apart from the incidents detailed in the previous section there are some more examples of the variety of weather phenomenon which may take place and pose potential hazard.

Starting with the US where hurricanes pose a great hazard to offshore wind farms and other offshore installations. Gulf of Mexico enjoys a lot of offshore activity which is mainly related to the oil and gas industry and tourism. Other locations in USA near the coasts also have a substantial amount of offshore installations and are exposed to hurricane risk. Region near North Carolina, Bahamas and Florida are most affected by the hurricanes and at high risk. According to (The Weather Company 2016), the 2005 hurricane season was the most damaging season recorded till date. US department of Energy reported that a number of facilities, which were located in the path of the hurricanes generated that year, had to be shut down and the personnel had to be evacuated. Hurricanes Katrina and Rita forced a number of refineries to be shut down which led to 29% of the total refining capacity of the United States. These storms together were responsible for destruction of 115 platforms and caused damage to another 52 platforms. According to the government reports no loss of life was reported due to these extreme weather events, but it did cause loss of asset and significant financial losses.

A number of offshore development projects have been executed in the Arctic regions. According to U.S. Geological Survey (USGS), Arctic regions have a huge scope of development in future as 30% of the undiscovered natural gas and 13% of the undiscovered oil on the planet is in these regions. The increase in activity in the Arctic also brings with itself the challenges of performing marine operations in the hostile weather conditions which are frequent and of various nature. Marine icing and polar low pressures are the major hazards which can be directly attributed to weather conditions.

Coming to Asia, where offshore installations and deep-water operations are increasing in number every year. Asian region experiences two main weather periods which are quite distinct in nature. One is the wet season and another is the dry weather season. Extreme weather events can be encountered in both these phases and during any time of the season. According to (Raj 2016), the weather phenomenon which causes maximum damage to life and assets in the south

Asian region is, typhoon. Typhoons generally occur in the period extending from July to October. Other major hazards which exist in the South East Asian offshore climatic zone are burst of strong winds and the swells caused due to the cold surges from the continent in the winter season. The current and tides in some of the basins of South East Asia also have a complex nature and my pose a hazard for marine operations performed in these regions. Another hazard in this region is the atmospheric haze which poses a problem for the marine operations and more specifically when there is a need of aviation activities, e.g., evacuation procedures by helicopters and emergency supplies.

From the examples of regions described above it can be appreciated that they have different climatology, hence, hazards associated with them are of different nature. When risk associated with weather events is to be evaluated, the difference must be reflected in selection of hazards, calculation of vulnerability, selection of risk indicators and at other important steps where the parameters are dependent on the local effects.

3 Chapter Three: Offshore Marine Operations

3.1 Regulations for Assessing the Environmental Conditions

Weather is the main factor which influences the environmental conditions. The environmental conditions are important from the point of view of structural loads and have a potential to pose limitations or complete restriction to the operations required to be performed in the offshore conditions. These conditions are the result of the natural phenomenon which take place in the region where the operations are performed. According to (Det Norske Veritas 2011) phenomenon which carry the main importance are;

- Wind
- Waves / Swell
- Currents
- Tide

Other phenomenon of importance are;

- Ice and snow
- Temperature
- Visibility / Fog
- Heavy rain

Furthermore, (Det Norske Veritas 2011) suggests that some of the environmental phenomena are not reflected properly in the statistical data obtained. Hence, more investigation must be performed to include all the possible hazards to make the analysis holistic. The phenomenon which come under this category are;

- Local tide variations
- Local swell or wave conditions (e.g. Due to current against the waves)
- Local wind variations / Conditions
- Strong winds due to squalls and polar lows
- Current variations
- Tsunami

The characterization of the environmental phenomena is generally accomplished by using the physical variables, which can be evaluated using statistical methods. The characteristic environmental conditions are the physical conditions of the environment for which a probability of being exceeded during a specific period of time is defined. (Det Norske Veritas 2011) suggests that the characteristic values of the parameters, which are used for describing the environmental conditions, should be determined with the help of statistical data as the most preferable source of information. It should also be assured that the statistical data can be processed to obtain the extreme conditions together with the variations in both long-term and short-term. Thus, the statistical data used for determining the characteristic environmental criteria shall be obtained for a long time period and it should be sufficient to obtain the above mentioned information with confidence.

3.2 Regulations for Marine Operations

There are some operational requirements which are required to be fulfilled for any marine operation to be executed successfully and with safety. Some of these requirements suggested in (Det Norske Veritas 2011) are;

- Design criteria for environmental conditions should not be exceeded during the operation
- Proper manning and organization of the operation is executed.
- Surveys are performed (before the commencement and during the operation) to provide sufficient information.
- Proper documentation of the marine operation is ensured.

3.2.1 Design Criteria

Marine operations are classified into different categories by (Det Norske Veritas 2011). This categorization is based on the way in which the environmental loads which effect the operations are selected. Generally, they are divided into two categories;

- Weather restricted marine operations
- Unrestricted marine operations

For these operations, an operation reference period is calculated which is compared to the weather window available for performing it safely. The reference period (T_R) is obtained by adding contingency time (T_C) to planned operation period (T_{POP}).

Weather restricted operations are the marine operations for which the reference period is calculated to be less than 96 hours and the planned operation period is less than 72 hours. If the conditions (climate or location) are such that the uncertainty associated with the information provided by the weather forecast is not acceptable, then (Det Norske Veritas 2011) suggests that shorter limiting values of reference period shall be used.

Figure 13 shows the operation periods and the points when a weather forecast shall be used to update the operation progress.

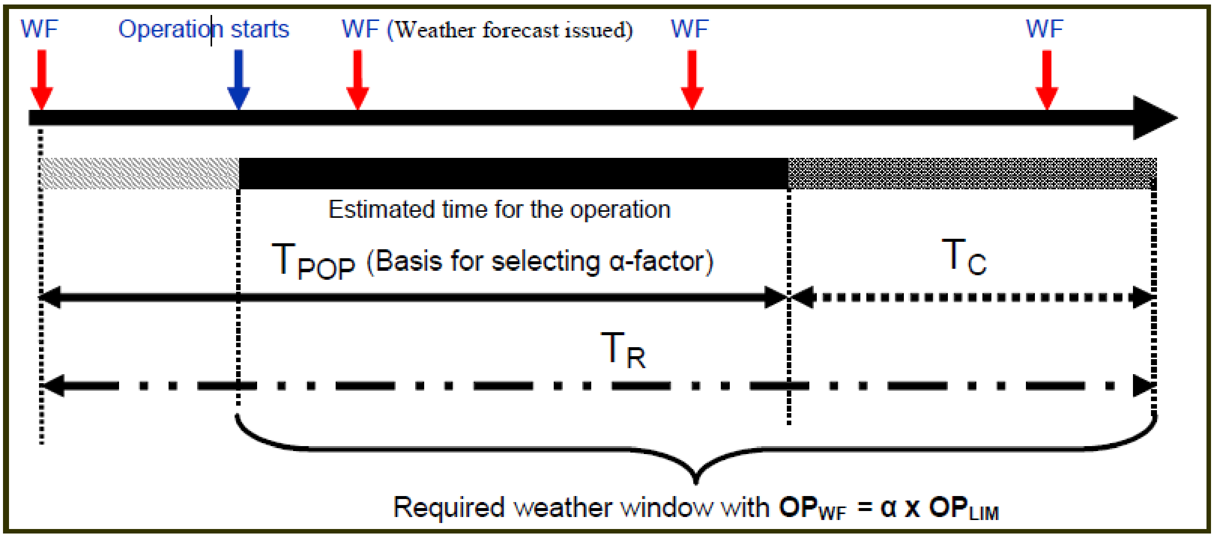

Figure 13: Operation Periods (Det Norske Veritas 2011)

Unrestricted marine operations are those operations which take longer time than the restricted marine operations. Extreme value statistics is used for determining the limiting environmental conditions for these operations.

3.2.2 Weather Forecasts and Monitoring of Design parameters

Weather forecasts are very important for safe execution of marine operations and are required to be made available at frequent time intervals throughout the life cycle of the operation. They are vital for decision making support during the planning and design phases of the marine operation. Also, during the marine operations, forecasts provide the current status of the risk level due to the weather conditions.

Specialized weather forecasts are used, which focus specifically on the location where the operation is performed and the route which is required to be followed during the marine operation.

Weather forecasts are categorized into different levels in (Det Norske Veritas 2011). The basis for the categorization is sensitivity of the operations to the weather conditions and the reference period of the marine operation. Three categories, level A, B and C, are defined as follows;
Weather forecast which are categorized in level A focuses on major marine operations which are sensitive to the environmental conditions. Main operations which fall in this category are;

- Mating operations
- Offshore float over
- Multi barge towing
- GBS tow out operations
- Offshore installation operations
- Jack-up rig moves

Level B weather forecast deal with the marine operations which are sensitive to environmental changes and involve heavy damage to the asset. Due to serious unwanted consequences, large monetary loss is possible in these marine operations. Some typical examples of such operations are;

- Float-out operations
- Offshore lifting
- Subsea installation
- Sensitive barge towing

Weather forecast of level C are applied to the marine operations which are not so sensitive to the weather conditions. These operations are frequently performed and are not very critical from the perspective of harsh consequences of bad weather conditions;

- Onshore / inshore lifting
- Loadout operations
- Tows in sheltered waters / harbour tows
- Standard barge tow without wave restrictions

On the basis of the weather forecast level required for the marine operation to be performed, the procedures for forecasting are decided on the basis of Table 1.

Table 1: Weather Forecast Levels

Weather Forecast Level	*Meteorologist required on site?*	*Independent WF sources*	*Maximum WF interval*
A	Yes[1)]	2[2)]	12 hours[3)]
B	No[4)]	2[5)]	12 hours
C	No	1	12 hours

Monitoring of the environmental conditions is also a very important aid for making decisions regarding the execution of marine operations. Monitoring of the parameters can be done for both;

- Environmental conditions
- Response of the environmental phenomenon

Monitoring is specially recommended for waves, swells, currents and tides. Special monitoring procedures must be dedicated for these environmental conditions before the commencement of the operations and also during the operations as these conditions change rapidly and can cause severe damage if appropriate measures are not taken to provide safety to the exposed personnel and asset. Continuous monitoring provides expected values for the environmental conditions which have significant effect on the overall risk involved in the operations.

4 Chapter Four: Risk Picture

4.1 Theory of Risk

The main objective of determining risk involved in an activity is to provide safe environment for successful execution of the activity. Activities which are expected to expose human life, assets, environment or economic resources to any kind of harm must be analyzed for their potential of causing damage to any of these vital resources.

An important question which arises here is how can the risk be appreciated and the information obtained from the study be presented such that it is put to its best use. It is essential to obtain an informative risk picture which describes risk such that the decision making for safety critical issues can be done with confidence. For the specific activity, this can be achieved by including all the building blocks of the risk picture in the analysis. According to (Aven 2015), important building blocks for obtaining a comprehensively descriptive risk picture encompass the following;

- Initiating events (The hazards, the threats or the opportunities)
- Causes
- Probability reducing barriers (Preventive barriers)
- Consequences
- Consequence reducing barriers

A detailed research of the above mentioned components, collectively provides the true risk picture. These components are generally represented in the form of a bow-tie diagram for a better understanding of their interrelation.

There is no single definition of risk on which agreement of the experts from different fields of applications can be achieved. One definition of risk, presented by (Aven and Renn 2009), which clearly takes the concepts mentioned above into consideration is;

"Risk is uncertainty about severity of the consequences of an activity, with respect to something that human beings value".

According to this definition and (Aven 2014), risk can be described as a combination of (A, C and U).

$$\text{Risk description (R)} = (RS, A , C , Q , K)$$

We begin with the source of risk, RS. A is an activity or an event which is the central issue of the analysis and helps in defining the scope. This activity or the system is required to produce some outputs and has specific functions to perform to achieve those outputs. During the process of performing the required functions a number of events may take place which have a potential of producing some unwanted consequences. The consequences may be of various degree of severity. The events or the situations which may develop are indicated as A in the definition. Categorization of these sources is done into three groups by (Aven 2007). These groups are;

i. Threats (Used in the sense of security)
ii. Hazards (Used in the sense of safety)
iii. Opportunities (Used in the sense of economic context)

The term ‘threat’ is related to intentional activities, e.g. terrorism threat, and are used in the context of security. ‘Hazard’ is used for the events which are more related to safety of the system or activity from the accidents. Whereas, the term ‘opportunity’ is relevant for the economic context (Aven 2007).

In the definition C denotes the future consequences which can develop due to the occurrence of the event A. These consequences can be translated to a set of quantities of interest denoted by C’. C’ can be identified from consequences (C) and characterize their severity, typically by quantitative measures.

Q is the description of uncertainty associated with the occurrence of the consequences represented by C. A tool which can be used for quantifying Q is probability, P. (Aven 2015) suggests use of the knowledge based probability or the subjective probability for this purpose. Uncertainty is an important part of the overall description of risk as it is a vital factor which determines the overall severity of the consequences of the activity. At the time point when risk is defined, it is not known if one or more of the events would take place at any specific time in future. Also, if they occur, then there is no certainty about the consequences which would develop for the specific activity/system under consideration.

4.2 Vulnerability

Concept of vulnerability can be defined in simple words as the susceptibility of the system to get affected acutely. Vulnerability in the context of disaster risk covers the state of the system and the people involved in the operations. According to (Wisner 2004) all the attributes of the system and the people, which in turn influence their ability to get prepared and foresee the adverse effects, endure them, resist their extreme consequences and finally recover from the damage caused by these events.

A simple example is presented in Figure 14 which presents the concept of vulnerability for an FPSO. The FPSO is connected to the riser and production is under way. If harsh weather conditions develop, the FPSO becomes vulnerable and is exposed to risk of oil spill or fuel ignition. The connection of the riser to the FPSO may get damaged and may cause oil spill or lead to fuel ignition. Also, vulnerability present in this case is more than an FPSO which is not connected to the riser. Presence of the riser makes it difficult to perform preventive measures and move the FPSO away from the location of harsh weather region. This weakness in the system to respond makes it vulnerable.

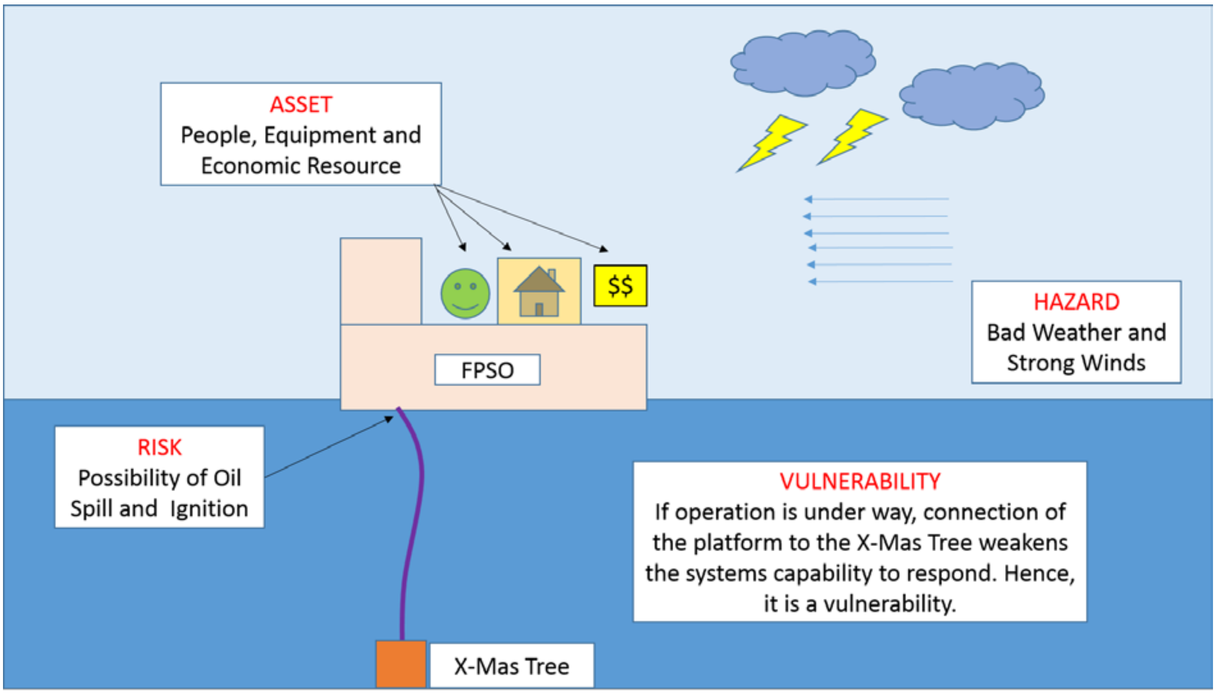

Figure 14: Example of Vulnerability

Vulnerability is the risk conditional on the fact that an event has already happened. If an event has taken place then the characteristics of the system under consideration can provide information regarding the likelihood of the consequences. For example, if a man is running on the stairs and he accidently slips, he is more vulnerable as he can fall down and get severely injured. But, if the same man is climbing the stairs at a normal pace, he has a better chance of trying to maintain his balance or avoiding injuries. Thus, state of a system is very important for determining its vulnerability.

Definition of vulnerability proposed by (Aven 2007) is;

"The combination of possible consequences and associated uncertainties given a source"

From this definition and taking into consideration the definition of risk, it can be concluded that risk can be defined as a combination of the sources (events) and the vulnerabilities. It has to be noted that the uncertainties associated with the sources must also be taken into consideration (Aven 2007).

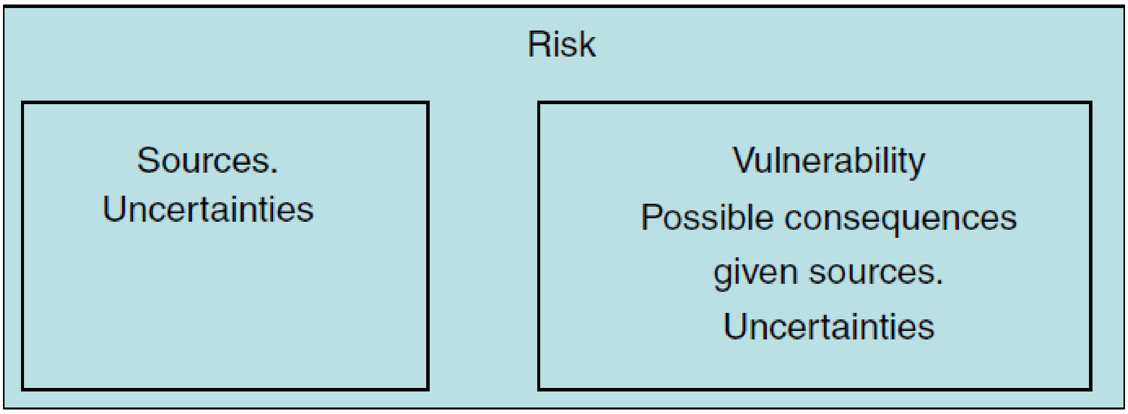

Figure 15: Risk as a Combination of Sources and Vulnerability (Aven 2007)

Thus the general form of the description of risk suggested by (Aven 2014) is (C', Q, K | RS/A), given that event A has taken place or RS is known. The concept of vulnerability is of importance when focus is laid on the consequences of the event which has already taken place.

4.3 Risk Picture for Weather Events in Offshore Conditions

Severe weather events can take different forms and cause damage to the assets, environment and pose a hazard for human life. In offshore scenario the initiating event can be strong damaging winds, huge waves, storms, low temperature, typhoons and cyclones. Tropical cyclones and typhoons are frequently encountered in the South East Asia, Australia and regions near Pacific Ocean.

As this scenario is related to environmental phenomenon and is not in control of human beings, the events which take place are accidents and do not come under the scope of intentional activities. Thus, weather events fall under the category of 'hazards'.

In offshore conditions, risk due to severe weather can be described by;

$$\text{Risk description (R)} = (RS, A', C', Q, K)$$

Here, A' are some specified severe weather events. Typically, A' will include the events of damaging wind, huge waves, cyclones, storms, typhoons, etc. Inclusion of all the potential initiating events is of foremost importance to obtain an exhaustive analysis. If any critical event is missed, then the true risk involved in the activity will not be discovered. Events which constitute A' will differ from one region to another over the globe as different weather systems are active in different parts of the earth.

A few studies have been undertaken to explore the effects of extreme weather events on the society ((Vajda A, Tuomenvirta T et al. 2011), (Makkonen 2006), (Meehl GA, Zwiers F et al. 2000)) but very few of the studies give a picture of how the consequences (C) of the extreme weather events can be related to associated probabilities (P) or the uncertainties (U). This has been attempted by (Wagner 1999), who worked on relating events of extreme hot weather with the consequences of heat on the health of human beings exposed to it. (Blennow and Olofsson 2008) conducted a research, in which the effect of climate change was studied for obtaining information about the likelihood of the damage caused to the forests. Another study was undertaken by (Mansour and Preston 1995), which dealt with the development of methods to determine the probability of encountering severe storm by a ship. Development of this method was based on storm probabilities, wave statistics, and the operation profile of the ship. In another study by (Virta H, Rosqvist T et al. 2011), flood events were assessed on the basis of their consequences. Consequences of flood events were assessed for different scenarios dealing with failure of critical infrastructure. Failure of water distribution systems, electricity grids, telecommunications grids, etc. were considered for this study.

4.4 Vulnerability in Weather Events in Offshore Conditions

Various studies and projects were conducted in the past to relate consequences of the extreme weather events to probabilities, but a convincing result was not obtained. Concept of vulnerability has been used for a lot events in the last decade.
Risk associated with extreme weather events can be described as a function of hazard (H) and vulnerability (V). This can be expressed by the following definition suggested by (Villagra´n de Leo´n JC 2006);

$$R = f(H, V)$$

As already explained in the previous section, hazards are considered to have unwanted consequences (C') only if hazardous event (A) has taken place. Then the system, which is exposed to the hazard, is vulnerable.

This definition is in alignment with the definition of risk and vulnerability proposed by (Aven 2007).

Total risk (TR) related to natural disasters is defined by (Alexander 2000), as a combination of elements which are at risk, the natural hazards to which the elements are exposed and the vulnerability of the object under consideration. The following equation expresses this definition;

$$\text{Total Risk (TR)} = (\sum \text{Elements at risk}) \times \text{Hazard} \times \text{Vulnerability}$$

Here, elements at risk for offshore facility or vessels could be the personnel, machinery, rigs and the associated economic activities.

Vulnerability is expressed as a function of the concepts like exposure, susceptibility and coping capacity by the Disaster Reduction Institute (DRI). These concepts are directly related to the definition of risk and provide additional clarity to the risk picture. DRI expresses Vulnerability by the following equation;

$$\text{Vulnerability} = \frac{\text{Exposure} \times \text{Susceptibility}}{\text{Coping capacity}}$$

Exposure in the above equation refers to the personnel working in the offshore locations, equipment installed offshore, vessels, and any other asset in the region of interest. All these elements are present in the hazard zone and are exposed to potential damage due to bad weather conditions.

Susceptibility of these elements is their behavior towards the effects of bad weather. It deals with the reaction of these elements when they are exposed to bad / severe weather conditions and their capability of receiving, admitting, undergoing, or being affected by them.

Coping capacity is the ability of personnel and the systems to deal with the unwanted situations which could affect or damage them severely. The ability can be the skill or equipment present with the personnel which can be used in adverse weather conditions, safety equipment present in the offshore facility, safety features present in the machinery in use, other special disaster management protocols and equipment, etc. Overall measure of all the abilities to deal with harsh weather and adverse climatic conditions and hence reduce or eliminate chance of loss is given by the coping capacity of the system or the organization.

4.5 Risk Indicators

Risk is related to future events and their consequences (Aven 2008). We can't predict with certainty if the events will take place in future or not, or when will they take place in case they occur. Also, we can't be certain about the consequences if the events take place in future. Thus, an uncertainty is always involved with both the occurrence of the events and their consequences and literature of (Aven 2008) supports this argument. The offshore industry associated with oil and gas production and marine industry mainly operates away from the land. Hence, risk involved with these activities is high. Risk is involved in all the phases of the operations, from the beginning of the operation till the end. High safety level is required to be maintained, under all circumstances, to prevent any undesirable outcome. The risk level from the activities performed has to be updated on a regular basis to obtain details of change in the level. Uncertainty about the harmful consequence of the activities undertaken during the activities is an important element which affects the assessment. There are a lot of consequences which are not known until it is too late and problem becomes difficult to tackle.

It is a firm belief of the writer and (Aven 2008) that risk is more than historical observations and probability values. Yet, it is considered to be an essential data to start with. Historical data should have certain qualities to get qualified for being fit for use in the evaluations. The data which can be used must be chosen with great care, keeping in mind other aspects of risk it has to present. To perform this systematically, risk indicators are required to be developed. The indicators can be divided into different categories and provide different outputs depending on its type and how it is interpreted. These indicators must address all the essential requirements related to risk perception of the specific scenario under consideration. Thus, indicators can be developed for different scenarios to collect the relevant data and they provide a basis of assessing the risk.

The crucial task for risk assessment is to determine the safety level and how it changes over time for the activities performed under the scope of work of the operation. This would allow us to develop an understanding of the risk and provide a basis for selection and implementation of risk reducing measures (Kvaløy and Aven 2005).

The methodology of assessment of safety level, according to (Aven 2008), is directly related to the definition of risk (RS, A , C , Q , K). We are uncertain about the occurrence and consequences of the accidents and we need to get more knowledge about the activities and accidents to assess the uncertainties involved.

If we consider large scale accidents leading to fatalities as an example, the preliminary phase of improving knowledge includes collection of historical data. The data collected should be objective. Apart from this data we also need to include other aspects of risk perception to assess the safety level (Aven 2012).

Expressing the actual risk levels and status of HES levels can be done by the use of indicators. But, it is a common misconception that choosing the correct indicator which is most relevant for the scenario is enough for determining these levels. (Aven 2008) says that there is no fully objective way of expressing the actual HSE levels by the use of single indicator.

Technique which is recommended and adopted in the risk level project suggests triangulation. A number of indicators must be used to determine the true risk levels which provide different approaches through different paths and in combination present the full picture. (Aven and Vinnem 2007) suggest that different statistical, engineering and social science methods can be used in different combinations to obtain relevant information about the severity and scope of the problem.

Indicators are associated with the hazards, challenges or any other unwanted incidents. There can be a number of indicators associated with a specific incident. For example, areas of concern for offshore installations are (Aven and Vinnem 2007);

- Major hazards on the installations
- Major hazards during transportation of personnel by helicopter
- Incidents posing challenge in emergency preparedness levels
- Incidents of occupational injuries
- Incidents of exposure to hazards having potential of causing occupational illness

All these incidents have indicators associated with them. If we only consider major hazards associated with offshore installations, only the first two points are relevant for the discussion.

Indicators which are used for major hazard risk according to (Vinnem, Aven et al. 2006) are;

- Indicators based on occurrence of incidents with emergency preparedness challenge.
- Indicators based on occurrence of occupational injuries.
- Indicators based on exposure of employees to selected hazards with occupational illness potential.

The indicators are used in many ways, which are significantly different, by different field of studies and industries. Indicators which are used by different industries differ in their characteristics. One way of categorizing the indicators is by distinguishing them on the fact that they are leading indicators or lagging indicators. According to (Vinnem 2010) there is not a clear rule of thumb to distinguish between the leading and lagging indicators.

Definition of a leading indicator by (Kjellén 2009) is: “A leading safety performance indicator is, in this interpretation, an indicator that changes before the actual risk level has changed.” According to (Kjellén 2009) this definition is suitable for economics, but not suitable for use in the scenarios of safety studies and researchers in safety studies use a different approach (Vinnem 2010).

This definition was accepted as it was found to be suitable for the sake of the discussion in this thesis. According to (Vinnem 2010) if the indicator which we are using changes before the actual risk level has changed qualifies as a leading indicator. These indicators are very important for the major hazards as they are very useful in preventing the escalation of the precursor events to major accidents. As these indicators must change before the change in actual risk level, precursor events can't be counted as leading indicators.

The analysis is not very easy when a number of indicators are used. Complexity increases with the increase in the number of indicators and they effect the overall risk in different measures. According to (Aven and Vinnem 2007) all the indicators must be assigned a weight corresponding to the extent to which they effect the overall risk. Then, a composite indicator is obtained by using the data from the indicator and the weight assigned to the indicator.

5 Chapter Five: Discussion

5.1 Characteristics of Weather Events in Offshore Conditions

Severe weather events can be attributed to be one of the most unpredictable hazards to which human beings are exposed. Bad weather is even more dangerous in offshore conditions, as a system is more vulnerable when it is in the sea and has limited options to choose as a response in case of an emergency. It can be observed from the accidents detailed in Chapter 2 that weather can cause devastation in a variety of ways and there is no single method of preventing the damage.

In the COSL accident in the North Sea, damage was caused by the forces of weather and nothing much could be done to prevent the loss of assets in this case. Fatalities could have been avoided by following the correct safety measures and keeping updated knowledge about the weather conditions through forecasts. In such accidents it is also important that the evacuation is started before it is too late to perform the procedure safely. During the COSL incident, it was very difficult task for the rescue services to evacuate people safely. This difficulty was posed due to harsh weather which prevented the helicopters from landing on the rig. People were lifted from the rig, which exposed them to additional risk generated during lifting.

In three other accidents discussed in chapter two, weather events resulted in setting the facility on fire due to different reasons. Ardrossan Wind Farm fire resulted from strong winds which was above the design limit of the equipment. The failure of the mechanical components to prevent the disaster also has a significant role in the accident. This accident could have been prevented if the machinery was well prepared for such extreme events. Fire on Mumbai High North platform and in the Usumacinta Jack-up accident were caused due to collision. Here, the weather forces did not result in equipment damage by their own, but provided destruction force to the vessel and the jack-up. The vessel in Mumbai High North accident was not secured properly to take such loads. Whereas, the Usumacinta Jack-up was not expected to behave like it did during the weather loading. Therefore, when dealing with risk related to weather conditions it is not sufficient to only take into consideration the load which the severe weather can apply as environmental loads on the component of interest. All the assets and equipment which is present in the surroundings and can be instigated by the bad weather to transform into potential source of damage must be taken into consideration. Proper safety measures and regulations must be strictly followed for general cases and also scenario specific analysis must be undertaken.

In weather disasters like Ocean Ranger oil rig disaster and Glomar Java Sea Drillship disaster, damage or loss of asset could not be prevented but the loss of lives can be avoided if adequate safety measures are taken. Improved and quick access to weather related information is also critical for quick decision making and executing the evacuation procedures. In both these accidents large number of people lost their lives as they were not evacuated in time. Glomar Java Sea Drillship disaster is an example of the quick nature of weather incidents. Whereas, Ocean Ranger disaster is an example where the severe character of weather was unforeseen and timely evacuation was not performed.

Bohai 2 jack-up rig disaster was a different type of accident where the marine operation being performed has some shortcomings in the procedures followed. No doubt the bad weather, which existed during the towing operation was the initiating event, was the main cause of the accident. But, the accident could have been prevented if adequate safety measures were taken during the transportation of the jack-up. This shows that safe procedures and resistance to environmental loads are important not only for the installed condition of the facility or the equipment, but also for the complete period when it is exposed to offshore weather conditions.

The important characteristics of extreme weather events on the basis of the accidents discussed above can be summarized in the following points;

- The events take place were quickly giving very less time to react.
- The events are capable of heavy damage and must not be underestimated.
- Harsh weather can critically hamper the rescue operations.
- In some cases these events can be predicted in advance.
- These events can take place during any phase of the project or operation.
- Devastation effect of the weather loads can significantly increase in later stages, if the initial damage caused leads to unstable conditions on a facility or a vessel.

The measures which can be taken to avoid loss of life and minimize damage to assets are;

- Knowledge about the weather phenomenon existing in the region and the forecast must be updated regularly.
- Multiple layers of safety features must be designed into critical components which are expected to be exposed to harsh weather.
- Rescue operations must be planned keeping in mind the conditions which may exist and pose hurdle.
- Procedures must be defined and strictly followed in all phases of the operations, including transportation of the components.
- All the surrounding objects and facilities must be taken into consideration when the load cases are considered, as they can act as the damaging object under the influence of environmental loads. Securing the loose components in the sea and on the facility is important.
- Decision making is very tough in this period, so region specific guidelines must be laid down and regular training must be conducted for quick decision making.

These lists does not cover all the scenarios and it can be increased with study of more historical accident reports and other possible scenarios.

5.2 Evaluation of Risk Indicators for Weather Events in Offshore Conditions

Knowledge about the indicators presented in Chapter Four is used to develop an approach which includes leading indicators for hazards developed due to harsh weather.

To proceed in a systematic way, the methods used in a research by (Molarius, Könönen et al. 2014) will be used as a reference. This research focuses on risk due to extreme weather phenomenon for transportation system. Risk related to offshore marine operations can also be determined on the similar lines with suitable changes in the methodology followed. This will be discussed in the following paragraphs.

As risk has been described in the previous chapters as a function of the hazards and vulnerability. Hence, risk indicators must be developed which can capture these concepts as far as possible. A detailed stepwise methodology can be followed which would result in determining the overall risk associated with a specific scenario.

The main steps of this methodology are to determine the indicators for hazard, vulnerability and finally risk. The historical data and knowledge about the phenomenon can be used to determine the hazard indicators, vulnerability indicators and risk indicators by following these steps;

i. The first step is determining and defining the hazard indicators. The possible consequences of the weather events can be selected and the probability of their occurrence must be evaluated. As a number of paths may lead to similar consequences, all the possible chain of events must be taken into consideration to find out the exact values of the likelihood of the consequence taking effect. Also, the probability of all the paths leading to the same consequence are different.
ii. The second step is to determine the vulnerability indicators. These indicators will dependent on the specific features of the climate of the region, the asset and professionals present on the facility, the preparedness of the system to resist or absorb damage due to unwanted weather events. Hence, vulnerability indicators will be different for every installation and it is essential that they all the factors which can affect the vulnerability are taken into consideration when their calculations are done.
iii. The final step is to determine the risk indicator for the facility taking all the weather events into consideration.

To determine the hazards of interest, historical data from reliable sources is required to be collected. This data should be of the extreme weather events which have taken place in the region of concern. The actual consequences which have taken place in those incidents together with those consequences which could have taken place must be studied together to generate an exhaustive list of the most devastating weather events. Additional knowledge from the incidents which gives a clear picture of the causes which lead to these consequences is also required to determine the probability of their occurrence. For this purpose, information from accident databases and meteorological databases is of greatest use. As a chain of events leads to the consequences, then individual probabilities of occurrence of all the different events of the chain must be evaluated. As this information is not readily available in most of the cases, advice from experts is required to study the scenarios and decide the probability values.

5.2.1 Probability Based Hazard Indicator

Developing hazard indicators for extreme weather events can be achieved by using causal diagrams. As the consequences of the incidents caused due to weather events can have multiple causes this choice is justified. Also, between an extreme weather phenomenon and a specific consequence multiple paths are possible. Probabilities of these paths are obviously different as the events which take place in different paths have different likelihood of taking place in reality. Causal diagrams provide the flexibility of analyzing the different paths which lead to a particular consequence. Following stepwise procedure is required to be performed to obtain the desired hazard indicators;

i. To start with the analysis, the initiating weather phenomenon can be selected and is assessed for all the possible steps it proceeds along to reach a consequence. This should be repeated for all the hazardous phenomenon determined to be important for the offshore scenario. The consequences must cover all the aspects including loss to personnel safety, asset loss or economic loss.
ii. In the next step the paths which are critical, i.e., which have a high probability of occurrence or may lead to high consequences, are identified from the cause map.
iii. Then probabilities are assigned to each step of all the paths. Assigning of probabilities can be done on the basis of historical information or subjective probabilities may be assigned by the experts. When all the probabilities are assigned, the branches of the cause tree can be translated to a matrix of assigned probabilities having same structure as the causal diagram.
iv. Next step is to determine the most probable path from each consequence to a weather phenomenon. As multiple weather phenomenon may lead to same consequences in this method, each consequence can be related to a number of weather phenomenon. The main task of this step is to determine the most probable path which reaches a consequence from all the associated weather phenomenon. This is performed with the use of the probability matrices and causal diagrams generated in the pervious steps. Finally, the probabilities of the most probable chain of events are used for making the hazard indicators.

5.2.2 Vulnerability Indicator

Indicator for vulnerability can be calculated by the use of data which is representative of its constituent concepts. These concepts are exposure, susceptibility and coping capacity. Vulnerability is directly proportional to exposure and susceptibility. Thus, vulnerability of an offshore installations increases with increase in exposure, e.g. due to increased number of personnel on a rig the exposure is increased which in turn increases the vulnerability of the whole system. Similar increase in vulnerability can be seen with increase in susceptibility. Susceptibility is high if the system or organization in the offshore condition is not of competent quality and this in turn makes the system more vulnerable. Coping capacity on the other hand has an inverse relation with vulnerability. An increase in the capacity of the offshore facility or vessel, in overcoming the disaster caused by bad weather at any intermediate stage, makes the overall system less vulnerable.

To calculate the vulnerability indicator for a facility in offshore environment, the information required is described in the following points;

i. Exposure can be indicated by a number of statistics. The data should be able to quantify the asset / people / capitol / brand name which is at risk in the region.

ii. Susceptibility can be evaluated by the information collected about the current condition and the quality of the infrastructure of the offshore facility or vessel being used for performing marine operations. Experience from the experts is required to evaluate the values of the parameters which can define the robustness of the facility, machinery or the procedures used for marine operations.

iii. Coping capacity can be indicated by evaluating the features of the system which have a potential to avoid or mitigate the damage caused by the extreme weather events.

All the three indicators, chosen for the three constituents (exposure, susceptibility and coping capacity) can be classified into four levels (quartiles) for ease of analysis. The scheme shown in Table 2 can be used to quantify the chosen indicators by classifying them into different levels based on quantitative or qualitative information. This classification is helpful in the cases where normalization of data from different offshore locations is difficult. But, the process also requires expert guidance from all the available sources and careful approach so that any important aspect is not missed in the evaluation.

Table 2: Quartile Scheme

Quartile	Value
First quartile (Best)	0.25
Second quartile	0.50
Third quartile	0.75
Fourth quartile (Worst)	1.00

This scheme can be used for all three constituents of vulnerability. Where minimum exposure, minimum susceptibility and maximum coping capacity is expressed by the first quantile value, i.e. 0.25. Here, high coping capacity is expressed as lower value of quantile so that the final calculation of vulnerability becomes easy because only multiplication of the values of the constituent indicators is required to quantify vulnerability.

5.2.3 Risk Indicator for Weather Events in Offshore Conditions

The risk indicator for extreme weather events is developed on the basis of the suitable definition of risk for weather events. As it has been explained in previous chapters that risk picture for weather events is clearly explained by the definition proposed by (Villagra´n de Leo´n JC 2006);

$$R = f(H, V)$$

A function of hazard and vulnerability gives the estimate of risk. For this thesis a simple function will be used with a multiplication operator between the two variables as shown below;

$$R = H \times V$$

5.3 Knowledge from Marine Operations for Evaluating the Indicators

Marine operations are performed in a variety of different climatic zones and are exposed to many different hazards. Figure 16 presents the causal diagram which is developed for marine operations using the important phenomenon from (Det Norske Veritas 2011) , which are already discussed in Chapter Three. This causal diagram is general with basic information, but, a similar diagram is required to be developed for the system under consideration. Location specific information must be used to select the phenomenon prevalent in the region of information and the effects and consequences it can lead to in future.

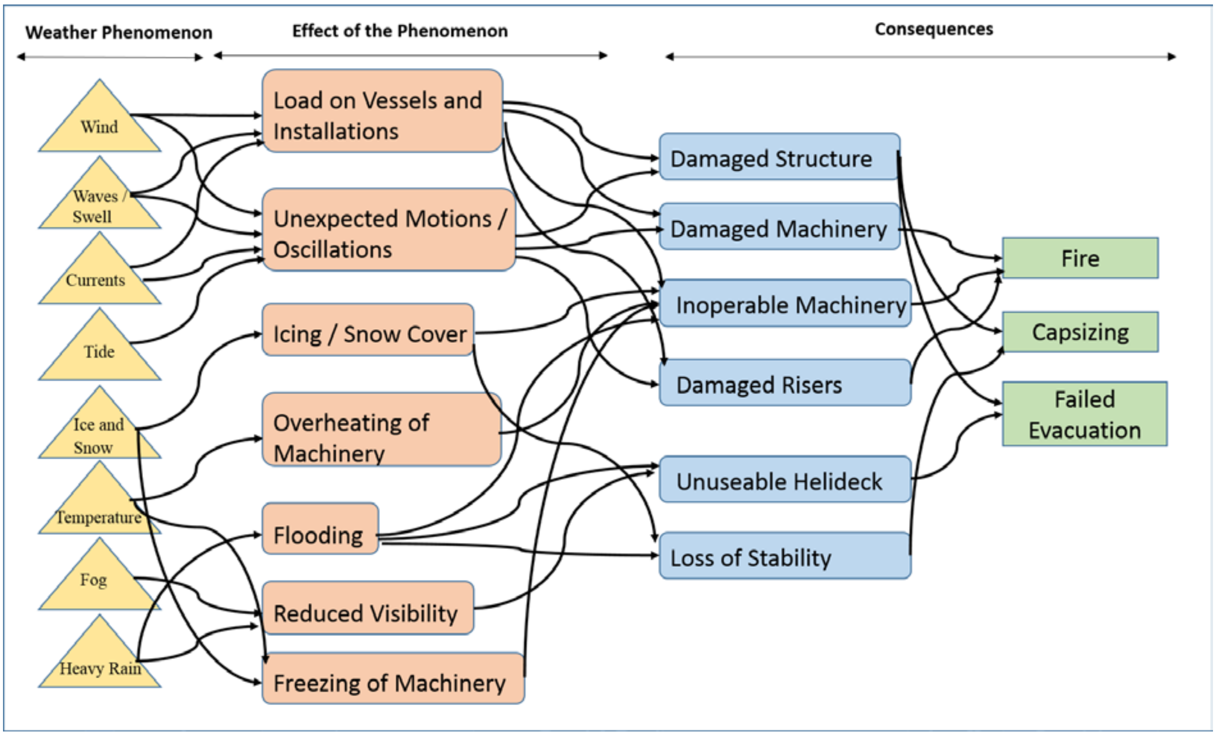

Figure 16: Example of Consequence Tree for Marine Operations

For example, if marine operations are performed in an Arctic oil field, hazardous weather phenomenon are marine icing, polar low pressure, fog, wind, breaking waves, snow and low temperature. Effect of these phenomenon will depend on the type of vessel or installation being used. If an artificial island is used, icing and snow loads are not of serious concern as they can be easily dealt with in this structure. Alternatively, if a drillship or a semisubmersible is used for operations, marine icing and snow loads can cause loss of stability. It is important to obtain the detailed information about the following items before making the causal diagram;

- Climatology of the location
- Marine operations to be performed
- Type of Facility to be used
- Size of Facility to be used
- Distance from safe location

- Ease of access / evacuation

After the causal diagram is generated with all the possible phenomenon and their consequences listed, the next step is to determine the most probable (critical) paths for each hazard. This can be done by the use of the following;

- Historical data of the accidents in the region
- Weather hind-cast data of the region
- Weather fore-cast data of the region
- Facility specific drawbacks
- Marine operation specific drawbacks

Vulnerability has already been defined in previous chapters and has exposure, susceptibility and coping capacity as its constituents. For a marine operation all these parameters can be calculated by the use of available codes, industry best practices and knowledge from the experts.

In the context of vulnerability, exposure is the measure of the operations done by the system in hazardous situations or under the possibility of hazardous conditions. Exposure in offshore locations with weather hazard probability can be indicated by any of the following data;

- Number of installations present in a particular region
- Number of personnel involved in activities on the offshore facilities
- Number of unrestricted marine operations performed in the region

Generally, only one indicator can be used for quantifying the exposure. For example, if two different oil fields, Field A and Field B. Field A has four rigs and Field B has three rigs. Field A has 100 crew members on each rig and Field B has 200 crew members on each rig.

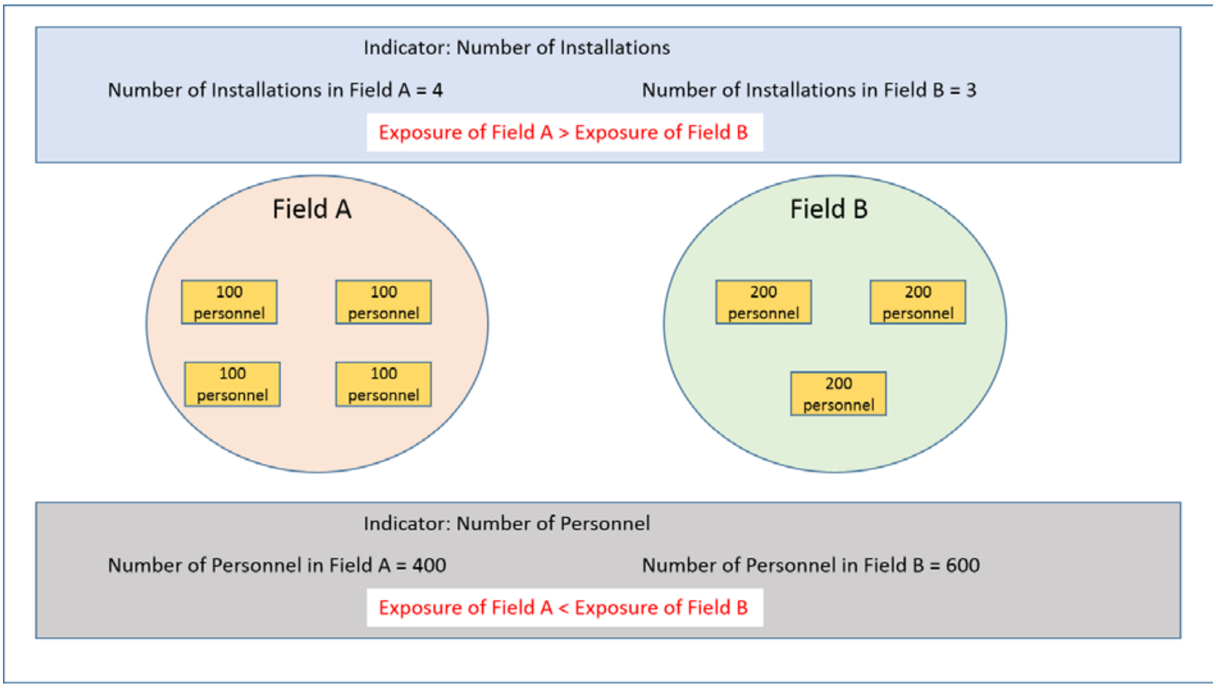

Figure 17: Example of Indicators

There are two main problems with this approach. Firstly, the hazard calculated in this setting with the use of different indicators will give different results, this is evident from the results shown in Figure 17. Second problem is related to normalization of the resultant values so that they can be logically used in future steps of the analysis for mathematical operations with other indicators.

One solution of the problem is a use of multiple indicators to evaluate the hazard indicator. If all the three datasets (installations, personnel, operations) are included in a common exposure indicator, the result will be more logical and holistic. But, this makes the calculation trickier and still the second problem related to normalization exists. It can be explained on the basis of the example presented in previous paragraphs, where the number of installations as indicator will give a single digit answer whereas number of personnel as indicator will give To tackle this problem, the indicator values must be classified into quartiles based on their characteristics. Same scheme of classification as detailed in Table 2 can be followed.

When this normalizing scheme is followed. If a big system with many subsystems is the scope of the analysis, the vulnerability analyses should be performed at the subsystem level and then the final indicator for the system can be derived from them. For example, if a single exposure indicator is calculated for the system having two subsystems, details of which are shown in Table 3 Constant value of coping capacity is taken for this example.

Table 3: Calculation of Exposure Example I

System	Installations	Personnel	Exposure
Sub-system A	0.25	0.25	0.0625
Sub-system B	0.75	0.75	0.5625
Full System	0.50	0.50	0.25

If mean values of installations and personnel are taken before calculating the exposure, the answer is 0.25. When mean values are used, the high personnel value for sub-system B is divided into the whole system. Same happens with low personnel value of sub-system A, but the overall result obtained tends to produce a lower value of exposure as compared to the case where individual exposure analyses are performed at sub-system level and then mean of the those values is taken to produce the output.

Sub system level analysis gives a mean value of 0.3125. The subsystem level analysis gives a better picture as the neutralization of critical situations (e.g., sub-system B in the example) does not take place in the calculations.

Another important point to be kept in consideration is that use of mean values, whether in system level analysis or sub-system level analysis, does not give the actual picture of the risk. Using mean values teds to have a similar effect on results as performing system level or sub-system level analysis. More complex methods can be used, but for this stage of the analysis a simple solution to this problem is assigning weightage to each value of indicator for calculating the overall exposure. It is obvious the human life is given more weightage as compared to assets. For example if there is a system having two sub-systems, A and B. Sub-system A is the process area, where personnel are more at any given time period compared to subsystem B which has 2 installations but very few people. From Table 4, it can be seen that sub-system level analysis gives a mean value of 0.1875 which is much lower than the system level analysis which gives a value of 0.25. Clearly, sub-system A must be given weightage based on presence of large number of crew members present.

Table 4: Calculation of Exposure Example II

System	Installations	Personnel	Exposure
Sub-system A	0.25	0.75	0.1875
Sub-system B	0.75	0.25	0.1875
Full System	0.50	0.50	0.25

Thus, overall indicator for exposure (E) must be calculated as;

$$E = W_1 \times I_1 + W_2 \times I_2 + W_3 \times I_3 \ldots\ldots W_n \times I_n$$

Where,

W_i = Weightage of i^{th} component of exposure

I_i = Value of i^{th} component of exposure based on quantile scheme

n = Number of factors chosen for evaluating exposure

Thus, background knowledge is also taken in consideration in addition to statistical data which makes the analysis stronger. Same exposure indicator can be taken as same for all the hazards as the factors on which exposure is based are general and are applicable more or less for all the hazards.

Evaluation of susceptibility indicator requires more detailed analysis of the operations being performed and overall state of infrastructure of the facility. This indicator should be calculated individually for all the identified hazards. Scientific evaluation methods for specific weather phenomenon are detailed in (Det Norske Veritas 2011) but uncertainties exist in all the steps of such evaluation. Strength of background knowledge is very important factor to estimate the uncertainties in the results. All the factors which increase the background knowledge must be given due respect and included in the analysis. (Det Norske Veritas 2011) suggests measures to increase the knowledge about the phenomenon in various ways.

- Knowledge about local variations may be improved by using information from local harbour authorities, pilots etc.
- The code recommends a data collection spanning at least three to four years for meteorological and oceanographic parameters. Data collections needs to be exercised for longer periods when seasonal data is used (i.e. analysis is performed for a specific season under scope).
- Operating criteria can be determined with more accuracy and confidence if the knowledge about monitoring procedures is improved.
- Increase in knowledge about weather forecasts would also provide an improved picture of the uncertainty associated with the process and would provide a stronger approach to increase the confidence in the selection of the criteria.

- The environmental design conditions which should be met during the period of operation should be based on overall evaluation of the conditions. These conditions are based on statistical data, but the conditions can also be set without the use of statistical data.
- In case of unrestricted operations, the weather criteria determined on the basis of the extreme value statistics, can be relaxed if the strength of knowledge about the phenomenon is strong. If this relaxation is considered, then additional information from the long term weather forecast is required to provide support to the decision taken.
- Knowledge is required and uncertainties should be evaluated in its light to take a decision. If enough documented knowledge and evidence is available to convincingly state that the long term weather forecasts are sufficient for predicting the occurrence of extreme weather events during the period when the marine operation is required to be performed, then the relaxation in the environmental criteria can be done. This relaxation can also be availed in the situations of open sea transportation, where this decision is based on the information about the speed of the vessel. If the speed if the vessel is enough to avoid the harsh effects of the extreme weather events then uncertainty about the consequences is reduced and risk is lowered.
- Nature of the marine operation and the duration for which it is planned should be considered when weather forecasting procedures are chosen and followed. Forecast must also provide additional knowledge apart from the general weather situation. This includes the following;
    - ➢ Wind (speed and direction)
    - ➢ Waves and swell (significant and maximum height, mean or peak period and direction)
    - ➢ Rain, snow, lightning, ice
    - ➢ Tide variations and/or storm surge
    - ➢ Visibility
    - ➢ Temperature
    - ➢ Barometric pressure

Uncertainty is always associated with the data and both the steps, the methodology used for collecting the data and its processing have various steps and associated uncertainties.

Hence, the code suggests that the statistical data which is old should be validated in the view of the technicalities related to:

- Data collection methodology / technology
- Accuracy of the methods
- Sensitivity and usability of the available data in current practice
- Long term changes which have occurred in the environment during this period of time.

For deciding the operation criteria the steps which follow after the decision is made provide crucial basis. Monitoring of the environmental conditions as well as their forecasting are important processes which would be performed for determining the feasible time window for performing the marine operations. It is obvious that both these processes involve uncertainties of various forms.

Uncertainty is always associated with forecasted information and it is recommended that a specific forecasted operational criteria should be used for every new design case. To reduce the uncertainty further, monitoring of the environmental conditions should be performed at the beginning of the operation.

These uncertainties are taken into consideration and a forecasted operational criteria (OP_{WF}) is defined as;

$$OP_{WF} = \alpha \times OP_{LIM}$$

These alpha factors (α) act as safety factors when applied to operational limit and provide a more conservative operational criteria. Appropriate alpha factors are chosen for different operational criteria based on;

- The statistical data of the weather conditions which prevail in the location where the operation is required to be performed is used to determine the uncertainty which exists in the weather forecast.
- The operation schedule influences the uncertainty that exists in the weather forecast.
- Wave and vessel response system monitoring systems are additional measures which are taken into account to make a decision while choosing appropriate alpha factors.
- Weather forecast levels are also taken into account which represent the uncertainty associated with the forecasting methodology and inherent unpredictability of some events.

One drawback of these alpha factors is that they don't take into consideration the uncertain extreme weather events. To account for these events, set of weather forecasts for the region of marine operation could be collected, which in turn would provide the information about the estimate of how the weather conditions are spread. Information regarding the probability of occurrence of extreme weather events can also be obtained from the set of weather forecasts.
Uncertainties related to weather forecasts are expressed with the help of confidence levels which are required to be included in the written weather forecast documentation.

- To reduce the uncertainty further the content and the format of the weather forecast should be reviewed by meteorologists before the commencement of the marine operation.
- Uncertainty is reduced in the procedure of weather forecasting with the use of independent weather forecasting sources for the Level A and Level B forecasts. As the operations requiring weather forecasts of level C are not very critically affected from the perspective of harsh weather events.
- Uncertainties in the weather forecast can be reduced by continuous monitoring and following robust monitoring procedures. The weather forecast for a specific time point and the results of the monitoring performed for the same can be used as an indicator for determining the confidence in the forecasting procedures being followed. Calibration of the weather forecast for the remaining time, more specifically the time until the next monitoring results are available, can be done. Monitoring procedures must

accommodate analyses to compare such data and generate the required information to reduce the uncertainty and hence the risk level.

Keeping all the above factors into consideration, a general equation for evaluating the susceptibility indicator (S_j) for a specific hazard can be;

$$S_j = W_1 \times I_1 + W_2 \times I_2 + W_3 \times I_3 \ldots\ldots W_n \times I_n$$

Where,

W_i = Weightage of i^{th} component of susceptibility

I_i = Value of i^{th} component of susceptibility based on quantile scheme

n = Number of factors chosen for evaluating susceptibility

The factors chosen for calculating susceptibility in marine operations can be broadly divided into five different heads shown in Figure 18;

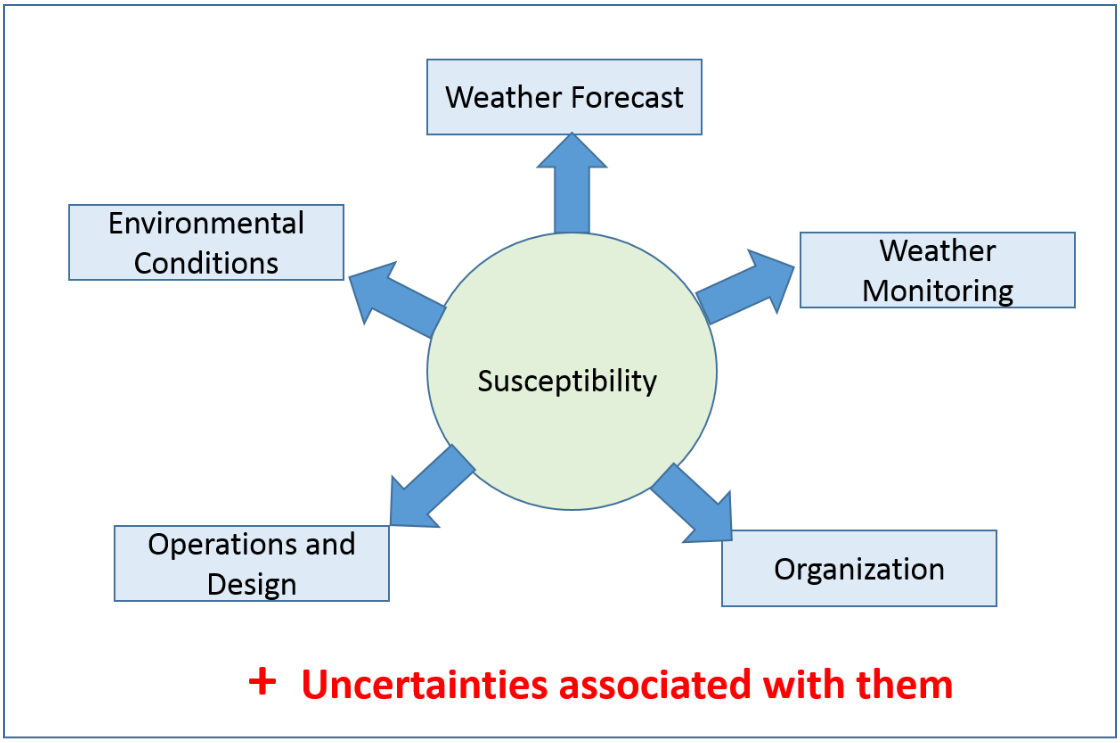

Figure 18: Components of Susceptibility

Next, the environmental conditions for a specific case can be further divided into four different sub-groups as shown in Figure 19.

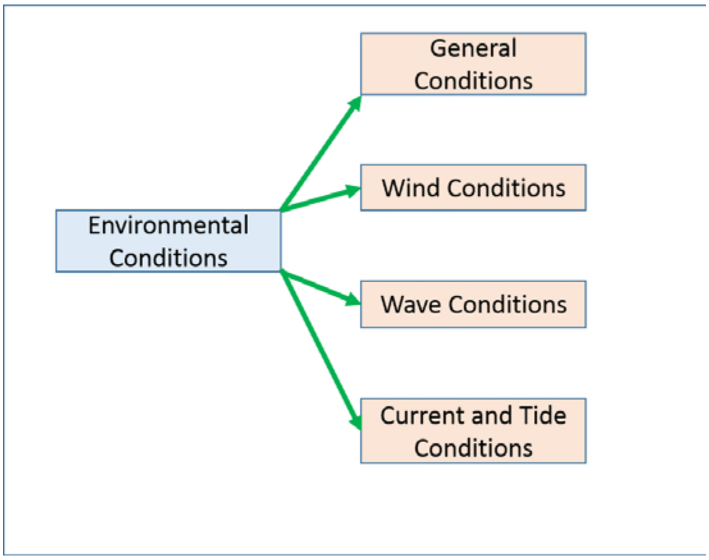

Figure 19: Components of Environmental Conditions

Similarly, other components of susceptibility can be divided into their sub-components and evaluation of appropriate indicators for each factor which comes under these heads must be evaluated keeping the involved uncertainties in consideration.

After the evaluation, the indicators must be normalized and must be presented as quartiles as explained for exposure indicator. Appropriate weightage must also be calculated for each factor based on the knowledge about the operation and geographical location. Finally, susceptibility can be evaluated using the equation presented.

Coping capacity for a system in harsh offshore weather conditions can be evaluated by using the following indicators;

- Capital available with the organization to spend in emergency caused due to undesired weather event.
- Preparedness measures available for evacuation of personnel during emergency.
- Procedure availability to safely stop the ongoing operation and secure all machinery and exposed parts of the facility from damage.

$$C = W_1 \times I_1 + W_2 \times I_2 + W_3 \times I_3 \ldots\ldots W_n \times I_n$$

Where,

W_i = Weightage of i^{th} component of coping capacity

I_i = Value of i^{th} component of coping capacity based on quantile scheme (High coping capacity must be represented by lower value of quantile)

n = Number of factors chosen for evaluating coping capacity

As in case of exposure, actual scenario cannot be modelled by only one indicator. Coping capacity also needs information from a number of indicators, some of which are detailed above. Also, coping capacity is affected by different measures in different ways and magnitude, so weightage factors are necessary for the components of coping capacity also. Coping capacity indicator like exposure can be taken as same for all the hazards.

Once values of E, S and C for a specific hazard are available, Vulnerability can be calculated using the formula;

$$V_j = E \times S_j \times C$$

Here, C is in numerator because high coping capacity was represented by lower value of quantile.

Risk indicator (R_j) can then be calculated by multiplying the hazard probability of a specific hazard (H_j) with vulnerability of the hazard (V_j).

The reason why individual risk for each hazard is suggested is that the occurrence of multiple phenomenon at the same time exposes the system to higher risk. Experience and judgement is required for choosing the combination of potential hazards applicable to the scenario and calculating the total risk.

6 Chapter Six: Conclusions and Recommendations

The literature presented in this thesis presents a basic framework for determining the important factors which can lead to an effect on overall risk due to weather conditions. From the arguments presented in this thesis, it can be concluded that weather conditions are;

- Change in a very short span of time
- Have a potential of causing great damage
- Highly uncertain

Another concept which is evident from the examples presented is, the risk analysis must not be based only on the probability values. The approach suggested for determining the risk associated with the marine operations takes into consideration all the factors associated with the design and operation, not only probability values.

Indicators are required to be developed to determine the risk. It is evident from the examples that one single indicator is not sufficient to describe the risk which marine operation is exposed to. It is required to take a step back and develop indicators for the component activities. Uncertainties can be hidden in any component activity, which may get reflected into overall values. Use of multiple indicators with appropriate weightage factors is suggested. Weightage factors are important as they useful when two different operations are affected differently by the risk in component steps.

The development of individual indicators provides a better decision making support for applying preventive and safety measures. Overall indicator of risk will be of little help if the root cause of the main risk generating issue is to be identified. Vulnerability of component steps of an operation provides a clear picture showing where the weakness lies in the system.

7 Chapter Seven: References

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