NTNU – Trondheim
Norwegian University of
Science and Technology

Risk analysis methods within offshore wind energy

Lian Uk Van

Reliability, Availability, Maintainability and Safety (RAMS)
Submission date: June 2012
Supervisor: Jørn Vatn, IPK

Norwegian University of Science and Technology
Department of Production and Quality Engineering

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MASTER THESIS
2012
for
stud. techn. Lian Uk Van

RISK ANALYSIS METHODS WITHIN OFFSHORE WIND ENERGY UTLIZATION
(Risikoanalysemetoder ved utnyttelse av offshore vindenergi)

Background

In order to increase utilization of renewable energy offshore wind technology is believed to be implemented in large scale the coming decades. Offshore wind turbines will be operated in harsh weather condition, and both installation, operation and maintenance of these turbines is challenging from an HSE point of view. The starting point for the work is the results achieved during a specialization project conducted in the autumn 2011.

In the master thesis the candidate shall particular address the following:

1. Based on earlier work by SINTEF and in the specialization work select three or more safety challenges.
2. Propose a complete set of risk analysis techniques to apply for each of these safety challenges. This may need to be supported by further literature review.
3. Demonstrate the techniques for the selected safety challenges. This will include preliminary assessment of data such as human error probabilities, weather data, operational limits related to, e.g., wave height etc.
4. Propose risk reducing measures and procedures to reduce risk.

Within three weeks after the date of the task handout, a pre-study report shall be prepared. The report shall cover the following:

- An analysis of the work task's content with specific emphasis of the areas where new knowledge has to be gained.
- A description of the work packages that shall be performed. This description shall lead to a clear definition of the scope and extent of the total task to be performed.
- A time schedule for the project. The plan shall comprise a Gantt diagram with specification of the individual work packages, their scheduled start and end dates and a specification of project milestones.

The pre-study report is a part of the total task reporting. It shall be included in the final report. Progress reports made during the project period shall also be included in the final report.

The report should be edited as a research report with a summary, table of contents, conclusion, list of reference, list of literature etc. The text should be clear and concise, and include the necessary references to figures, tables, and diagrams. It is also important that exact references are given to any external source used in the text.

Equipment and software developed during the project is a part of the fulfilment of the task. Unless outside parties have exclusive property rights or the equipment is physically non-moveable, it should be handed in along with the final report. Suitable documentation for the correct use of such material is also required as part of the final report.

The student must cover travel expenses, telecommunication, and copying unless otherwise agreed.

If the candidate encounters unforeseen difficulties in the work, and if these difficulties warrant a reformation of the task, these problems should immediately be addressed to the Department.

The assignment text shall be enclosed and be placed immediately after the title page.

Deadline: June 11th 2012.

Two bound copies of the final report and one electronic (pdf-format) version are required.

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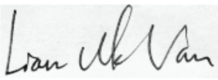
Per Schjølberg
Associate Professor/Head of Department

Jørn Vatn
Responsible Supervisor

Preface

This is a Master thesis in RAMS as part of the study program and was carried out during the spring semester of 2012. The thesis is a required project by department of production and quality engineering at NTNU. This was performed as an assignment and the title of the thesis is **risk analysis methods within offshore wind energy utilization**. The project was performed by stud.techn. Lian Uk Van with the help of responsible supervisor Jørn Vatn at Production and Quality Engineering at NTNU and second supervisor Erik Albrechtsen at SINTEF Safety Research.

Trondheim, 2012-06-11



Lian Uk Van

Acknowledgment

I would like to thank the following persons for their great help during this thesis assignment. First of all, I am thankful to Professor Jørn Vatn, whose patient guidance and consistent support throughout the project which enabled me to develop an understanding of the subject. This semester project would not have been possible without his guidance and support. I am also grateful to my other supervisor Eirik Albrechtsen. I really appreciate for his concern and help as he has made available his support in a number of ways for the possibility of this work.

O.N.

Lian Uk Van

Summary and Conclusions

This report starts discussing a number of possible risk analysis methods related to five challenges identified by SINTEF within offshore renewable wind energy industry, and it ends up with case studies on two challenges by testing SPAR-H method and proposing risk reducing measures.

I answer to all the questions, which are defined in the thesis assignment, by first selecting all the five safety challenges. I consider different risk analysis techniques and suggest a few of them for each individual challenges in a tabular fashion. I describe the proposed risk analysis techniques with their strengths and limitation and discuss, to a considerable extent, how they can be related to the challenges. The risk analysis techniques I suggested includes both technical and human error related methods. The technical related methods are based on some available risk analysis methods which are broadly acceptable in different applications. The human error analysis techniques, which have been practiced in nuclear industry, are the main focus in this report as it is believed that the techniques are applicable in the offshore wind firm industry.

Among the different challenges in HSE offshore wind farm operation, two challenges: collision (between the vessel and the wind turbine) and *Access or egress* from/to the offshore installation are presented as the main important part in the report. Because accident is most likely to happen when personnel transfer is required. Possible human errors and probability of accident due to those errors are broadly discussed. Possible risk-reducing measures to reduce the identified human errors and recommendation which may prevent the potential accident are discussed at the end of the project. More detail could be found at the end part of the report.

Contents

Contents for figures

Contents for tables

Acronym

AEMA	Action Error Mode Analysis
ASEP	Accident Sequence Evaluation Programme
ATHEANA	A Technique for Human Event Analysis
CREAM	Cognitive Reliability Error Analysis Method
ETA	Event Tree Analysis
FMECA	Failure Mode Effects and Criticality Analysis
FTA	Fault Tree Analysis
HEA	Human Error Analysis
HEART	Human Error Assessment and Reduction Technique
HEI	Human Error Identification
HEP	Human Error Probability
HEQ	Human Error Quantification
HER	Human Error Reduction
HRA	Human Reliability Analysis
HRMS	Human Reliability Management System
HTA	Hierarchical Task Analysis
NPP	Nuclear Power Plan
PRA	Probabilistic Risk Analysis
SHARP	Systematic Human Action Reliability Procedure
SPAR-H	Simplified Plant Analysis Risk Human Reliability Assessment
SWIFT	Structured What-If Technique
OSD	Operation Sequence Diagram
OTS	Offshore Transfer System
THERP	Technique for Human Error Rate Prediction
TTA	Tabular Task Analysis

1 INTRODUCTION

1.1 Background

This report is carried out as part of my master thesis during the spring semester of 2012. This is a required master thesis by department of production and quality engineering, University of NTNU. The title of this thesis is **risk analysis methods within offshore wind energy utilization.**

Due to an increase in energy consumption, rising fuel costs and concern about global climate change, it is believed that utilization of renewable energy offshore wind will provide a better solution in the coming future. To increase the utilization of renewable energy offshore wind, technology is believed to be implemented on a large scale in the coming decades. Future offshore wind turbines are huge and will be operated in a harsh weather. The problem is that unlike the other operations such as oil and gas industries, the offshore renewable energy industry is immature and information needed on the point of HSE is hardly available. Since the offshore wind farms have only started since the past few decades, safety related factors have not been properly analyzed. Only few HSE data have been collected from some offshore wind firms for safety culture and the risks associated with wind farm have not been properly identified. Thus, it is of great important that risk analysis is properly done from the early state of wind energy project development to avoid harm to human, environment and material values.

There are different challenges such as falling objects during installation, accident during transport due to the size of the wind turbine components or their heavy weight, accident during maintenance due to unstable weather conditions (e.g. wave, wind or current), ship collision between wind turbine and ship etc.. Most of these challenges are new and considerably different from other marine activities, so it is of great important that several new measures for offshore wind energy operations in different scenarios are taken into account in necessary risk analysis.

SINTEF report (Tveiten et al. 2011) has identified five important HSE challenges: (1) Falling objects during lifting operations, (2) Ship collisions within the wind farm, (3) Man overboard related to access to, and egress from wind turbines, (4) Occupational accidents related to working at height and (5) Challenges related to emergency handling. These challenges are only recognized in the report without concrete analysis or discussion, thus digging deeper into these safety challenges still remain.

1.2 Objective

The main objectives of the thesis work is to figure out relevant risk analysis techniques for the five challenges identified by SINTEF (Tveiten et al. 2011) and provide some suggestions for further risk assessment in one or two challenges. To achieve that, I need to:

1. Select three or more safety challenges based on earlier work by SINFEF report.
2. Propose relevant risk analysis techniques for these challenges.
3. Propose a complete set of risk analysis techniques to apply for each of these safety challenges.
4. Demonstrate the techniques for the selected safety challenges which include preliminary assessment data such as human error probabilities, weather data, operational limits related to, e.g., wave height etc.
5. Propose risk reducing measures and procedures to reduce risk.

Expected sub-objectives are:

1. To get familiar with different methods or tools to systematically identify human erroneous actions.
2. To understand a HRA method or more as the main tool to apply for the selected challenges.
3. To apply the methods on a case or more in order to get experience with the methods.
4. To investigate strengths and weaknesses of the HRA method.

1.3 Research approach

In order to achieve the main objectives the first step will be to perform literature studies on different risk analysis techniques and find out how they may be related to the challenges identified by SINTEF. Since the main focus in this report is considered to be human reliability analysis by both the supervisor and the report writer, the second step is to study some specific available methods or tools within human reliability analysis so that it would be possible to systematically identify human errors.

In order to identify possible human errors, I should consider a task or source related to the selected challenge where I can retrieve human errors which than can be used for input in a HRA method. Hierarchical Task Analysis (HTA) and Operation Sequence Diagram (OSD) will first be studied and used as a starting point because these will provide the source where human errors can be identified.

By going through a case study or more, I will try to collect all the possible human errors and find out the probability of accident (or incident) resulted from the identified human errors. After that I will study and test at least one HRA method into more detail in order to learn the method and to find out possible accidents due to the identified human errors.

By which way I will be able to highlight a risk picture for the selected challenges from a point of human reliability analysis. In addition, I will be able to investigate strengths and weaknesses of the chosen HRA method. Finally, risk reducing measures will be presented according to what have been found from the performed HRA risk analysis.

1.4 Limitations

Although, the report has reached its aims, there were some unavoidable limitations. Initially, the work was to begin with all the five challenges which SINFET report has stated, but due to the time limit, only two of the challenges (ship collision when approaching wind turbine and access or egress when personnel transfer is required) are focused in the report from the aspect of HRA method. Unfortunately, equipment and mechanical related factors are not part of the report. This study should also have involved applying different risk analysis methods for the different challenges. The student’s lack of previous knowledge about HRA method, to some extent, may affect the result of the report. A more considerable time should be available to get familiar with HRA methods. Available literatures or relevant sources related to HRA methods are also too limited. The paper selects only the SPAR-H method so no comparison between the different HRA methods could be part of the report.

2 Theory

To define the words of “risk analysis” has been considered to be a problem. Some alternative definitions are: “*Risk is an expression of the combination of probability for and consequence of an unwanted event (Norsk Standard 5814:2008), Risk is the combination of the probability of occurrence of harm and the severity of the harm (NORSOK Z-013/ISO-IEC Guide 51), and Risk is the potential for realization of unwanted, adverse consequences to human life, health, property, or the environment: estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event given that it has occurred (Society of Risk Analysis Glossary)”* (Haugen 2010).

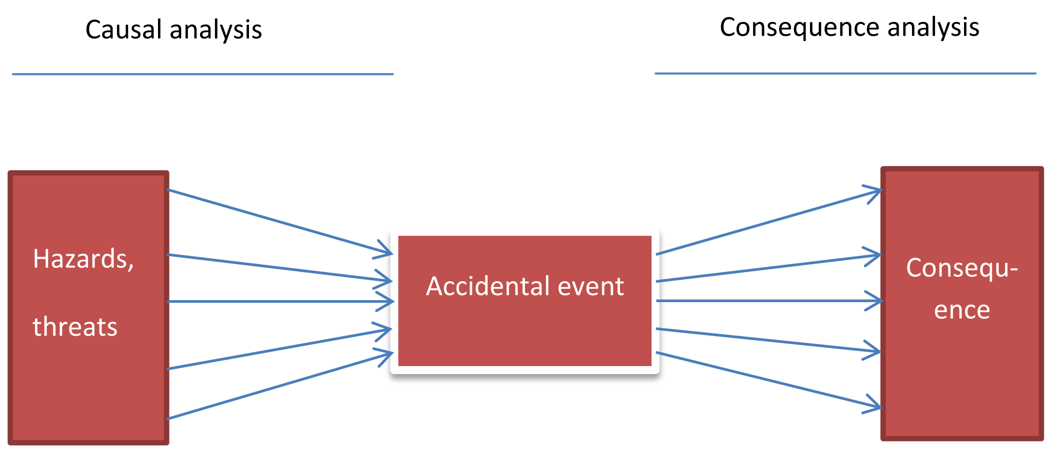


Figure 1: A simple bow-tie model.

As we could see from Figure 1, a bow-tie model may be useful for illustrating risk analysis. Risk analysis can be quantitative or qualitative and may be applied in various sectors such as nuclear power, offshore, process, aerospace, aviation, railway, marine, etc.

Some of the important standards are:

- NS5814:2008: Requirements for Risk Assessment
    - General risk analysis standard
- NORSOK Z-013: Risk and Emergency Preparedness Analysis, Rev 2, 1.9.2001
    - Specifically for use within the offshore industry
- ISO-IEC Guide 51: Safety aspects – Guidelines for their inclusion in standards
    - Terminology

- ISO 31010:2009: Risk Management – Risk Assessment Techniques

Although there is still no unified terminology or standard framework, numerous laws and regulations are required for carrying out risk assessments (Rausand 2011). A risk analysis requires several steps depending on type of the technique and the application area. Figure 2 explains the main process of a risk analysis in a four step process. The same process reflects in human reliability analysis (HRA) which will be coming at the end of this chapter.

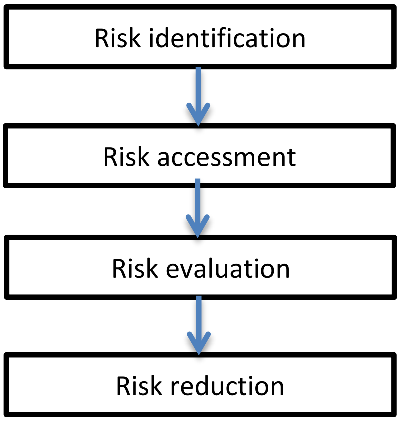


Figure 2: A risk analysis process

2.1 State of the ark and brief literature review in marine operation

There is no significant volume of literature which covers risk analysis methods in marine operation in spite of several attempts during this report period. A few sources such as ship collision estimation models for offshore operation and wind farm operations are identified. As these are commercial and software based models, no further information is available. A number of collisions between offshore platform and ship have been experienced in the past, and many relevant risk assessments have obviously been performed to a considerable extend. Risk assessment methods from oil industry, if available, are believed to be easily transferred to offshore wind farm industry.

Various organizations have developed their own model to estimate the probability of ship collision. Some of the models are considered to be appropriate for offshore wind farms. Appendix 4 illustrates all the available software models including references and the company/organization that develop the models.

The software COLLIDE and SOCRA have been used for risk analysis within offshore wind farms (Joanne Ellis 2008). (MARIN) claims that their software SAMSON has been used for different calculations such as calculation of the probability and expected number of fatalities (human safety), estimation of the risk of a collision of passing ships with the offshore wind farm, rerouting shipping traffic alongside the offshore wind farms, etc.

There exist other marine related risk analysis techniques which are developed to estimate collision and grounding risk, but they are not mentioned in Appendix 4. These are GRACAT (Grounding and Collision Analysis Toolbox), BaSSy Tool (A successor of the GRACAT software) and IWRAP MAK II (IALA Waterway Risk Assessment Program), SHIPCOF and MARTRAM (Marine Traffic Risk Assessment Model) (Nyman 2008).

These models are also presented in (Karin af Geijerstam 2008) stating: "*The models are in general pretty similar and the common approach is to estimate the number of possible collisions and multiply this with an estimated fraction of when a collision occurs. The causation factor considers the probability that a collision will not be detected and avoided. The models are based on the assumption that the collision frequency is proportional to the quantity of ships passing an offshore installation.*" (Karin af Geijerstam 2008)provides a bit more discussion about COLLIDE and CRASH which seem to be the most frequent used models within offshore continental Shelf. The model used in COLLIDE is quite similar to CRASH. (Kleissen 2006) describes SAMSON model with basic model inputs, assumptions and parameters used in the calculation, but any description about the program itself and risk calculations by the program are not included. The model MARCS could be found in (Christensen 2007) which briefly explains the most important assumptions and input parameters to the model and collision due to human failure and technical failure is shortly presented.

2.2 Suggested risk analysis techniques

This section contains 2 parts: Part I includes FMECA, FTA, ETA, CHECKLIST METHOD and SWIFT. Part II is only Human Error related risk analysis techniques. In both parts, all the suggested risk analysis techniques are collected in tabular form. The main purpose is to show how each method is considered and how they may be suitable to individual safety challenges by the SINTEF report. Since human error usually plays a significant role in the contribution of accident occurrence, it would be reasonable to recommend that human related risk assessment be given priority.

FTA, ETA and Checklist method are commonly used applications. FMECA refers mainly to analyze components in a technical system, but still the technique is considered appropriate e.g. for falling object during lifting operation in the report. Checklist method is considered for every challenge including emergency preparedness.

The HRA presented in Part II may be qualitative or quantitative and all of them are considered to be relevant for all the 5 challenges. Many of the identified HRA techniques from the literature study are for nuclear industry and there is no clear signal to transfer their applicability to wind farm industry. But it is strongly believed that some of them could be applicable for risk assessment within offshore wind farm industry.

In fact, selecting the most appropriate risk analysis technique is often difficult. In some organizations, risk evaluation team has to choose the most appropriate method. For an inexperienced analyst it can be very challenging to figure out the best techniques for a specific application. (Bridges 2004) states: *"The thought process behind hazard evaluation techniques is complex, and a variety of factors can influence that decision-making process."* Several factors are to consider before choosing an appropriate technique depending on type of results needed, resource availability, type of information available, etc.

Appendix 6 provides a good example which could be helpful to choose the most appropriate technique depending on the complexity of the task, application area, process type etc. It provides for both quantitative and quantitative risk assessments. It may be many possible risk analysis techniques which could be selected for offshore wind farm operation.

2.2.1 Part I

The proposed risk analysis techniques in part I are selectively chosen, for the different challenges, based on some available risk analysis methods which are broadly acceptable in different applications. This includes FMECA, FTA, ETA, CHECKLIST METHOD and SWIFT. FTA, ETA and CHECKLIST METHOD are commonly used techniques. FMECA refers mainly to analyze components in a technical system, but the technique is still considered appropriate for falling object during lifting operation. Checklist method is considered for every challenge including emergency preparedness.

Table 1: Risk analysis techniques considered appropriate for safety challenges in offshore wind farm

Challenges / Risk analysis techniques	Falling objects during lifting operations	Ship collisions within the wind farm	Man overboard related to access to, and egress from wind turbines	Occupational accidents related to working at height	Challenges related to emergency handling
1. FMECA	X				
Description	*"Crane operation is an inherent part of offshore oil and gas operations, lifting a multitude of supplies and materials to and from offshore facilities. Injuries and dangerous occurrences arising from lifting operations account for about 20% of the total of those occurring offshore. Actions that should be taken, including undertaking a failure mode effects and criticality analysis (FMECA) study to identify safety critical parts of the crane." (HSE).* **Strengths and weaknesses** (Mohr 1994)**:** *"Strengths:* • *Frequently, human errors and hostile environments are overlooked.* • *Because the technique examines individual faults of system elements taken singly, the combined effects of coexisting failures are not considered.* • *If the system is at all complex and if the analysis extends to the*				

	assembly level or lower, the process can be extraordinarily tedious and time consuming. • *Failure probabilities can be hard to obtain; obtaining, interpreting, and applying those data to unique or high-stress systems introduces uncertainty which itself may be hard to evaluate* *Weaknesses:* *• Discovers potential single-point failures.* *• Assesses risk (FMECA) for potential, single-element failures for each identified target, within each mission phase.* *• Knowing these things helps to:* • *Optimize reliability, hence mission accomplishment.* • *Guide design evaluation and improvement.* • *Guide design of system to "fail safe" or crash softly.* • *Guide design of system to operate satisfactorily using equipment of "low" reliability.* • *Guide component/manufacturer selection.* *• High-risk hazards found in a PHA can be analyzed to the piece-part level using FMEA.* *• Hazards caused by failures identified in the FMEA can be added to the PHA, if they haven't already been logged there.* *• FMEA complements Fault Tree Analysis and other techniques."* Falling objects may occur in any of the three different phases: installation, operation and maintenance. Accident that may happen from any phases can cause serious injuries, material losses and such. Since FMECA analysis mainly refers to component failures, the tool could be appropriated to analyze component failures of lifting machine such as crane or helicopter to minimize the risk of falling object. Hydraulic system, thruster, winch etc. could be the root causes in case of falling objects. In general the components of an offshore wind turbine are designed and produced separately before installing as a whole at the final location on the sea. These heavy components are lifted by enormous cranes to set up a complete installation at the site. Engineers should ensure that the wind turbine components during lifting operation do not fall down due to mechanical failure. FMECA may be conducted to analyze

	major failures which may result from lifting equipment.				
	Falling objects	Ship collisions	Man overboard	Working at height	Emergency handling
2. FTA	X	X	X	X	
Description	A Fault Tree Analysis (FTA) may be used for qualitative and quantitative risk analysis or both depending on depending on the scope of the analysis. The method is commonly used for risk and reliability studies and has been used within the nuclear, chemical and aerospace industries. This analysis has traditionally been applied to mechanical and electromechanical, but may also be applied to any type of system (Rausand 2011). FTA is regarded very often to be one of applicable tools in marine risk assessment. FTA could be used for researching factors and causes contributing to accident within offshore wind farm operation. The method can focus on critical events such as loss of power, collision between ship and wind farm (Joanne Ellis 2005)**.** Danaher states that Fault tree analysis is the most commonly used technique in both reliability engineering and system safety engineering in almost every engineering study and it has one or more purposes: 1. *"Estimation of the likelihood of the occurrence of a particular incident.* 2. *Determination of the combinations of equipment failures, operating conditions, and human errors that contribute to an incident.* 3. *Identification of remedial measures and their impact."* 4. **Strengths and weaknesses** (Danaher) *"Strengths:* • *Systematic.* • *Probabilities of undesirable outcomes can be calculated.* • *The analysis could be widely used for qualitative or quantitative.* *Weaknesses:* • *It requires a complete understanding.* • *It requires sometimes a very large Tree which needs to be developed*				

	depending on the system. • *A great deal of effort is usually required to develop the fault tree.* • *There is a potential for error if failure or causation paths are omitted.* • *There is no unique Tree."* The strengths and the weaknesses are further discussed in more detail in (Rausand 2011). It could be determined that FTA can be used to examine possible events for falling object during lifting operation, ship collision, personnel falling from the wind turbine or occupational accidents related to working at height. There is also questionable if the tool is appropriate for emergency handling, but any supported materials were not yet found from the literature search.

	Falling objects	Ship collisions	Man overboard	Working at height	Emergency handling
ETA	X	X	X	X	
Description	Event tree analysis (ETA) can be used to analyze all types of technical systems, with or without operators. It can be both qualitative, quantitative, or both, depending on the objective of the analysis and the availability of relevant data. Event tree analysis is also commonly used for human reliability assessment and has been used successfully in the nuclear industry, the chemical process industry, and in several other application areas(Rausand 2011). **Strengths and Weaknesses** (Rausand 2011): *"Strengths:* • *It is widely used and well accepted.* • *Is well documented and simple to use.* • *Clearly presents the event sequences following a hazardous event and the consequence spectrum.* • *It provides a good basis for evaluating the need for new or improved barriers.*				

<table>
<tr><td></td><td colspan="5">• It can be used to justify allocation of resources for improvements.
• It can identify system weakness and single-point failures.
• It does not require that end events need to be foreseen.
Weaknesses:
• It has no accepted standard for the graphical layout of the event tree.
• It requires that sequence of pivotal events has to be foreseen.
• It requires that hazardous events must be analyzed one by one.
• It does not facilitate incorporation of partial successes or failures.
• It is not well suited for handling dependencies in the quantitative analysis.
• It does not show acts of omission.”

Even though there is no materials available in relation to the above four selected challenges, it can be considered that Event tree analysis is appropriate. It has also been discussed in other application areas of offshore operation, e.g., by (Vinnem) or (Spouge 1999).</td></tr>
<tr><td></td><td>Falling objects</td><td>Ship collisions</td><td>Man overboard</td><td>Working at height</td><td>Emergency handling</td></tr>
<tr><td>Checklist Method</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Description</td><td colspan="5">CHECKLIST approaches are used in a wide range of application areas and for many different purposes. CHECKLISTS have been used further to ensure that organizations are complying with standard practices. Hazard checklists may be useful as part of other and more detailed hazard identification methods (Rausand 2011).

Strengths and Weaknesses (Rausand 2011):
“Strengths:
• It can be used by non-system experts.
• It makes use of experience from previous risk assessment.
• It ensures that common and more obvious problems are not</td></tr>
</table>

	overlooked. • *It is valuable in the design process for revealing hazards otherwise overlooked.* • *It requires minimal information about the installation, and so is suitable for concept design.* *Weaknesses:* • *It is limited to previous experience, and thus may not anticipate hazards in novel designs or novel accidents form existing designs.* • *It can miss hazards that have not been seen previously.* • *It does not encourage intuitive/brainstorming thinking, and gives limited insight into the nature of the hazards related to the study object."* CHECKLIST METHOD is one of hazard identification methods, and since it is useful for most risk assessments it could be assumed that this method is appropriate for any of all the challenges in offshore wind farms.				
	Falling objects	Ship collisions	Man overboard	Working at height	Emergency handling
SWIFT	X	X	X	X	X
Description	A SWIFT analysis is most often carried out after a preliminary hazard analysis. The analysis may be applied to work procedures and is usually based on a task analysis (Rausand 2011). **Strengths and Weaknesses**(Rausand 2011): *"Strengths:* • *It is very flexible, and applicable to any type of installation, operation, or process, at any stage of the life cycle.* • *It creates a detailed and auditable record of the hazard identification process.* • *It uses experience of operating personnel as part of the team.* • *It is quick, because it avoids repetitive considerations of deviations.*				

	• *It is less time-consuming than other systematic techniques.* *Weaknesses:* • *It is not inherently thorough and foolproof.* • *It works at the system level, such that lower-level hazards may be omitted.* • *It is difficult to audit.* • *It is highly dependent on checklists prepared in advance.* • *It is heavily dependent on the experience of the leader and the knowledge of the team."* What-if analysis maybe carried out both to identify existing hazards and continuous improvement. It appears that analysis is flexible and applicable to any equipment or system of interest at any stage of the lifecycle (Maguire 2006).

2.2.2 Part II

The HRA presented in Part II may be qualitative or quantitative and all of them are considered to be relevant for all the 5 challenges. Many of the identified HRA techniques from the literature study are for nuclear industry and there is no clear signal to transfer their applicability to wind farm industry. But it is strongly believed that some of them could be applicable for risk assessment within offshore wind farm industry.

Many HRA methods are available and it has become obvious that some of them have been developed and used in risk assessment. A few of them are chosen and rewritten from (Holroyd 2009) to demonstrate their origins, brief description of the tools, pros and cons and their possible applicability in other domains. Although they are mainly designed for nuclear industry, they may be applicable as well to other sectors. It is also believed that a few methods of HRA could be transferred to risk assessment in offshore wind farm. Some of the techniques are publicly available, but it is still challenging to find out how they may be applied in other industries, for example, in wind farm industry.

Table 2 HEA considered appropriate for safety challenges in offshore wind farm

Challenges / Risk analysis techniques	Falling objects during lifting operations	Ship collisions within the wind farm	Man overboard related to access to, and egress from wind turbines	Occupational accidents related to working at height	Challenges related to emergency handling
1. THERP	X	X	X	X	X
Description	*"Technique for Human Error Rate Prediction (THERP) was developed by Swain and Guttman (1983) and it was prepared for the US Nuclear Regulatory Commission. The theory presents methods, models and estimated human error probabilities (HEPs) to enable qualified analysis to make quantitative or qualitative assessment of occurrences of human errors in nuclear power plants (NPPs). THERP is a total methodology for assessing*				

<table>
<tr><td></td><td colspan="5">human reliability that deals with task analyses, error identification and representation, as well as the quantification of HEPs. THERP is often referred to as a ‘decomposition’ approach in that its descriptions of task have a higher degree of resolution than many other techniques. It is also a logical approach and one that puts a larger degree of emphasis on error recovery than most other techniques. Essentially, the THERP handbook presents tabled entries of HEPs that can be modified by the effects of plant specific Performance Shaping Factors (PSFs), using other tables. THERP was designed for nuclear industry application but is a generic tool that can be applied in other sectors (Holroyd 2009).”

Pros and cons (Kirwin 1994):
“Pros:
• THERP is well used in practice
• It has a powerful methodology that can be audited
• It is founded on a database of information that is included in the THERP handbook.
Cons:
• THERP can be resource intensive and time consuming.
• It does not offer enough guidance on modeling scenarios and the impact of PSFs on performance.
• The level of detail that is included in THERP may be excessive for many assessments.”</td></tr>
<tr><td></td><td>Falling objects</td><td>Ship collisions</td><td>Man overboard</td><td>Working at height</td><td>Emergency handling</td></tr>
<tr><td>2. HEART</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
</table>

Description	*"*Human Error Assessment and Reduction Technique *(HEART) is designed to be a quick and simple method for quantifying the risk of human error. It is a general method that is applicable to any situation or industry where human reliability is important.* *The HEART assessment can shed light on the key points of task vulnerability and suggest areas for improvement. The method includes error reduction strategies or remedial measures linked to the error producing conditions (Holroyd 2009).* *The method is based on a number of premises.* *1. Basic human reliability is dependent upon the generic nature of the task to be performed.* *2. In 'perfect' conditions, this level of reliability will tend to be achieved consistently with a given nominal likelihood within probabilistic limits.* *3. Given that these perfect conditions do not exist in all circumstances, the human reliability predicted may degrade as a function of the extent to which identified Error Producing Conditions (EPCs) might apply.* *There are 9 Generic Task Types (GTTs) described in HEART, each with an associated nominal human error potential (HEP), and 38 Error Producing Conditions (EPCs) that may affect task reliability, each with a maximum amount by which the nominal HEP can be multiplied. The key elements of the HEART method are: Classify the task for analysis into one of the 9 Generic Task Types and assign the nominal HEP to the task. Decide which EPCs may affect task reliability and then consider the assessed proportion of affect (APOA) for each EPC. Then calculate the task HEP (Holroyd 2009)."* An example HEART calculation is as the following which is taken from (Mohr 1994) :

	GTT classified as Task F (restore or shift a system to original or new state following procedures, with some checking). Nominal HEP = 0.003 (5th & 95th percentile bounds 00008-0.009) Total HEART **EPCs** — Affect — APOA — Assessed Affect Inexperience — x 3 — 0.4 — (3-1) x 0.4 + 1 = 1.8 Opposite Technique — x 6 — 1 — (6-1) X 1.0 + 1 = 6.0 Risk Misperception — x 4 — 0.8 — (4-1) X 0.8 + 1 = 3.4 Assessed nominal likelihood of failure 0.003 x 1.8 x 6 x 3.4 = 0.11 Similar calculations may be performed to calculate the predicted 5th and 95th percentile bounds, which in this case would be 0.07 – 0.58. HEART has been extensively used in the UK nuclear industry, and also in most other industries (chemical, aviation, rail, medical etc.). The underlying HEART model has subsequently been used to inform the development of some other tools in the area of HRA (Holroyd 2009). **Pros and cons** (Holroyd 2009)**:** *“Pros:* • *A versatile, quick and simple human-reliability-calculation method, which also gives the user (whether engineer or ergonomist) suggestions on error reduction.* • *Requires relatively limited resources to complete an assessment.* *Cons:*

	• *Error dependency modeling is not included.* • *Requires greater clarity of description to assist users when discriminating between generic tasks and their associated EPCs; there is potential for two assessors to calculate very different HEPS for the same task.* • *Lack of information about the extent to which tasks should be decomposed for analysis.* • *Potential for double counting (some elements of EPCs are implicit in the task description)* • *Subjective nature of determining the assessed proportion of affects*."				
	Falling objects	Ship collisions	Man overboard	Working at height	Emergency handling
3. CREAM	X	X	X	X	X
Description	*"CREAM was developed by Erik Hollnagel (1993) and the method is still under development. Hollnagel describes CREAM as fully bidirectional i.e. the same principles can be applied for retrospective analysis as well as performance prediction. The model is based on a fundamental distinction between competence and control. A classification scheme clearly separates genotypes (causes) and phenotypes (manifestations), and furthermore proposes a non-hierarchical organization of categories linked by means of the sub-categories called antecedents and consequents.* *This basic CREAM method can be used as a screening process to decide whether or not to continue with a HRA. The next stage of extended analysis requires a cognitive demands profile to be built. This involves describing each cognitive activity in terms of observation, interpretation, planning and execution (i.e. COCOM functions) and plotting this in graphical form. Based on the phenotype genotype classification, it is possible to create a complete list of cognitive function failures; however for practical purposes a subset of the list would be produced. For a defined subset each of the cognitive*				

	functions (observation errors, interpretation errors, planning errors and execution errors) would have identifiable potential cognitive function failures, the distribution of which would once again be graphically represented and a Cognitive Failure Probability (CFP) would be calculated for each. Finally, a weighting factor is applied to the CFP scores depending on whether contextual influences (CPCs) are determined to be weak, medium or strong. ***Pros and cons*** *(Holroyd 2009)**:*** *Very few references were available that provided any level of critical review. The only comments that were identified are 10 years old and are as follows:* *In discussing Cognitive psychological approaches such as CREAM, Kirwan (1998) notes that "these approaches are potentially of most interest to psychologists and others who want to predict the more sophisticated error forms associated with misconceptions, misdiagnosis, etc. They attempt to explore the error forms arising from 'higher-level' cognitive behaviours".* *Kirwan (1998) also states that, "more development is clearly needed in this category, and could be linked to cognitive task analysis approaches". He also reports that the development of such approaches "…is limited, and new approaches are required, whether building on systems such as GEMS, or more novel hybrids such as the prototype CREAM technique which is still under development".* *CREAM was developed for use in the nuclear industry, however the underlying method is generic and, therefore, it is suitable for use in other major hazard sectors.***				
	Falling objects	Ship collisions	Man overboard	Working at height	Emergency handling
4. ASEP	X	X	X	X	X
Description	*"ASEP was developed by Swain for the US Nuclear Regulatory Commission. P. ASEP comprises pre- accident screening with nominal human reliability*				

	analysis, and post-accident screening and nominal human reliability analysis facilities. ASEP provides a shorter route to human reliability analysis than THERP by requiring less training to use the tool, less expertise for screening estimates, and less time to complete the analysis." The four procedures that comprise the ASEP HRA procedure are described as follows: 1. *Pre-accident tasks: those tasks which, if performed incorrectly, could result in the unavailability of necessary systems or components in a complex plant such as a nuclear power plant (NPP) to respond appropriately to an accident.* 2. *Post-accident tasks: those tasks, which are intended to assist the plant to cope successfully with an abnormal event that is to return the plant's systems to a safe condition.* 3. *Screening HRAs: Screening probabilities and response times are assigned to each human task as an initial type of sensitivity analysis. If a screening value does not have a material effect in the systems analysis, it may be dropped from further consideration. Screening reduces the amount of detailed analyses to be performed. HRAs at this stage deliberately use conservative estimates of HEPs, response times, dependence levels, and other human performance characteristics.* 4. *Nominal HRAs: The regular probabilistic risk assessment carried out on tasks identified during the screening process. These use what the HRA team judges to be more realistic values, but still somewhat conservative (i.e. pessimistic) to allow for the team's inability to consider all possible sources of error and all possible behavioral interactions."* **Pros and cons** (Holroyd 2009): *"Very little information was identified about the relative pros and cons of ASEP. Kirwan (1994) noted that ASEP is quicker to carry out than THERP and can be computerized. It tends to be used as a screening approach to identify*

	those tasks that require a more detailed analysis using THERP. ASEP is a nuclear specific tool and, therefore, not suitable for other major hazard sectors."				
	Falling objects	Ship collisions	Man overboard	Working at height	Emergency handling
5. SPAR-H	X	X	X	X	X
Description	*"SPAR-H was developed for the US Nuclear Research Commission, Office of Regulatory Research. The method was used in the development of nuclear power plan (NPP) models and, based on experience gained in field-testing, was updated in 1999 and re-named SPAR-H. It was mentioned that SPAR-H does the following:* • *Decomposes probability into contributions from diagnosis failures and action failures;* • *Accounts for the context associated with human failure events (HFEs) by using performance shaping factors (PSFs), and dependency assignment to adjust a base-case HEP;* • *Uses pre-defined base-case HEPs and PSFs, together with guidance on how to assign the appropriate value of the PSF;* • *Employs a beta distribution for uncertainty analysis, which can mimic normal and log normal distributions, but it has the advantage that probabilities calculated with this approach range from 0 to 1; and* • *Uses designated worksheets to ensure analyst consistency.* *The SPAR-H method assigns human activity to one of two general task categories: action or diagnosis.* • *Action tasks – carrying out one or more activities indicated by diagnosis, operating rules or written procedures. For example, operating equipment, performing line-ups, starting pumps, conducting calibration or testing, carrying out actions in response to alarms, and other activities performed during the course of following*				

	plant procedures or work orders. (Generic error rate of 0.001) • *Diagnosis tasks – reliance on knowledge and experience to understand existing conditions, planning and prioritizing activities, and determining appropriate courses of action. (Generic error rate 0.01)* *Eight PSFs were identified as being capable of influencing human performance and are accounted for in the SPAR-H quantification process. The potential beneficial influence, as well as the detrimental influence, of these factors is included in the method.* *PSFs are:* • *Available time* • *Stress and stressors* • *Experience and training* • *Complexity* • *Ergonomics (& Human Machine Interface)* • *Procedures* • *Fitness for duty* • *Work processes* *When developing the basic SPAR H model, only three of the eight PSFs are evaluated: time available, stress and stressors, and complexity. The remaining five PSFs are generally considered to be event, plant or personnel specific and would be evaluated when a plant specific model is being developed.* *A major component of the SPAR H method is the SPAR H worksheet, which simplifies the estimation procedure. The process for using the worksheet differs slightly, depending on whether the analyst is using the method to build SPAR models, perform event analysis, or perform a more detailed HRA analysis."*

	Pros and Cons (Holroyd 2009): *"Pros:* • *A simple underlying model makes SPAR-H relatively easy to use and results are traceable.* • *The eight PSFs included cover many situations where more detailed analysis is not required.* • *The THERP-like dependence model can be used to address both subtask and event sequence dependence.* *Cons :* • *The degree of resolution of the PSFs may be inadequate for detailed analysis.* • *No explicit guidance is provided for addressing a wider range of PSFs when needed, but analysts are encouraged to use more recent context developing methods if more detail is needed for their application, particularly as related to diagnosis errors.* • *Although the authors checked the SPAH-H underlying data for consistency with other methods, the basis for selection of final values was not always clear.* • *The method may not be appropriate where more realistic, detailed analysis of diagnosis errors is needed.* *SPAR-H is based on the Heart approach and uses data from CREAM, THERP and ASEP."* The method is believed to be applicable to other sectors, but no evidence was found of being used except nuclear plan (Mohr 1994)."

2.3 The process of Human Reliability Analysis

This section presents a process for Human Reliability Analysis (HRA) that should be followed with a few basic steps. These different steps in the HRA analysis are presented in this section and discussed how they fit together. This is an introduction for the case studies coming in the next chapter. All the steps presented in the section reflect in two case studies in sections 3 and 4.

Human reliability analysis is executed in a process which consists of four mainly different steps. Figure 3 illustrates how a HRA may be performed with a systematic approach. Appendix 3 illustrates a more comprehensive process of HRA and the inclusion of it in the bow-tie risk analysis model.

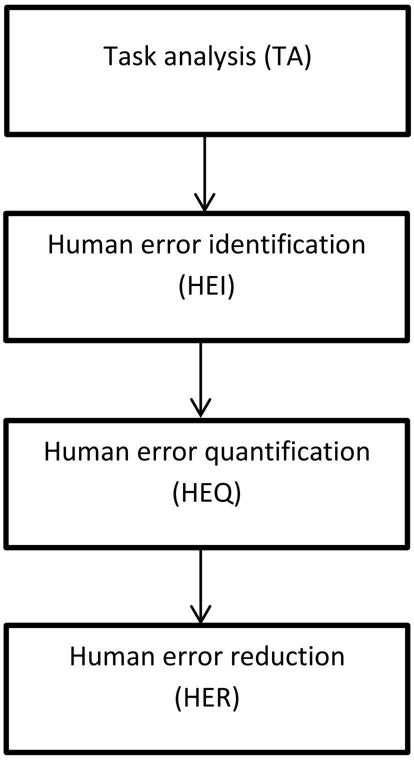


Figure 3: The process of Human Reliability Analysis (HRA)

There may be different systems or steps designed to reduce probability of making errors. The first typical step needed to do may be a task analysis. The method may be similar to job safe analysis or procedure HAZOP. Below are further explanations for every step of the HRA process in Figure 3.

2.3.1 Task analysis

"*In order to identify human error modes, we must first understand the tasks that are being carried out. If we do not fully understand the tasks that people will perform, and the manner in which they are to be carried out, we cannot comprehensively identify where errors may originate. The tasks are studied most effectively by a task analysis*." (Rausand 2011)

Task analysis is an initial step which gives systematic method for describing an operation from where human error can be identified. The task analysis is presented in the beginning and further detail analysis is extended from it step by step when HRA is needed to perform.

In task analysis methods, the first three steps:

1. Hierarchical Task Analysis (HTA)
2. Operation Sequence Diagram (OSD)
3. Tabular Task Analysis (TTA)

The starting point is the HTA from the first step above and goes into the next OSD and TTA into more and more detail level.

2.3.1.1 Hierarchical Task Analysis (HTA)

Hierarchical task analysis is part of the steps of Human Error Analysis (HEA) and is widely used in human reliability analysis. This is the first step of HEA. The application can be applied in all types of areas. It has been successfully applied in process control, military applications, aviation, power generation, and so on (Rausand 2011).

(Rausand 2011) also states its advantages and limitations as follows:

"*Advantages of HTA:*

- *Well documented and the most commonly used task analysis method.*
- *Easy to learn, easy to implement, and requires minimal training.*
- *Generic and can be applied to a variety of tasks.*
- *Flexible such that tasks can be analyzed to any required level of detail.*

Limitations of HTA:

- *Is descriptive rather than analytical.*
- *Can be time-consuming for complex and large tasks.*
- *Does not easily provide any scenario description.*
- *Provides little information regarding collaboration.*
- *Does not identify the participants involved in the task and the roles they play.”*

2.*3.1.2* Operation Sequence Diagram (OSD)

Related work tasks can be described in the operational Sequence Diagram sequentially. This is the next step in the task analysis which is further developed, and different actors could be involved. This OSD shows how the different actors are interrelated between each other during an operation.

2.3.1.3 Tabular Task Analysis (TTA)

Tabular Task Analysis is the next step where it is necessary to go even more detail in analyzing each step which has been identified in OSD. Each action performed by different actors has become an input for further investigation. In tabular task analysis cues and feedbacks are the main concern. By applying cues and feedbacks, it becomes obvious how the task is flowing step by step in connection with the actors involved in the work sequence. When a feedback for each task is performed, it is possible to identify if something go wrong: in other words, in case of an ongoing failure, it can be identified before it is too late as the feedback is performed on that particular task. In addition, possible errors can be identified by including extra colon in the table if it is needed.

“Two main concepts of a TTA, according to (Rausand 2011), are:

- *“Cues. The cues indicate to the operator that an action can/should be initiated. (What is the next thing I should do?)*
- *Feedback. The feedback informs the operator about the effects of carrying out the action. (What was the last thing I did?)”*

The application is used inn all type of areas and has been shown to be useful in the following contexts (Rausand 2011):

- *“Design or evaluation of human-machine interfaces.*
- *Preparation for, or as part of a detailed HRA.*

- *Preparation of operational procedures.*

Advantages of TTA:

- *Is a flexible technique that allows any factor associated with the task to be analyzed.*
- *Has the potential to provide a very comprehensive analysis of a particular task.*
- *Is entirely generic and can be used in any domain.*
- *Provides a much more detailed description of tasks than HTA.*
- *Is potentially very exhaustive if the correct categories are used.*

Limitations of TTA:

- *May be a very time-consuming technique to apply.*
- *Requires information that is often not available to the study team."*

2.3.2 Human error identification (HEI)

After the three steps in a task analysis, check lists can be performed for each task which has been simply identified in every action. However it could be hard to identify all possible human errors. Swain and Guttmann (1983) state; "*To identify all possible errors is usually impossible. Even the best analyst cannot identify all possible modes of human response. No one can predict unlikely extraneous acts by plant personnel. Still, given sufficient time, a skilled analyst can identify most of the important tasks to be performed in a system and most of the ways in which errors are likely to be committed.*"
(Rausand 2011) also states: it is necessary to use one or more structured approaches to be able to identify as many of the critical human error modes as possible.

In order to identify human errors a method of Action Error Mode Analysis (AEMA) worksheet can be used. This method is applied to systematically identify any possible way of making human error including the consequences from making those errors.

The next thing after the check list of AEMA is summing up for possible human errors in a tabular form. These possible human errors are needed for the inputs in further risk analysis in form of qualitative and quantitative screening. Possible human error may also be directly identified tabularly without following all the above steps, but their occurrences and consequences cannot be visualized in more detail as it is seen in the AEMA work sheet.

2.3.3 Human error quantification (HEQ)

HEQ is a technique to estimate the human errors which is also illustrated in HRA process. Some of the techniques are illustrated in Table 2 and are proposed to be relevant risk analysis techniques for the safety challenges. Many human reliability analysis techniques are available now and SPARE-H is chosen to be tested in section 4.

2.3.4 Human error reduction (HER)

There are no separate HER methods found in the literature to reduce human errors. Although a HRA method is performed quantitatively, risk reduction may still be proposed qualitatively. In addition, necessary adjustment in the HEQ tool may be performed in order to reduce risk, for example, the SPAR-H method is tested at a later part of the report and risk reducing measure can be traced by making some adjustment in the method itself.

3 Case study I

Access and egress would be considered to be taken into account in the following case analysis study. Ship collision between the access vessel and the wind turbine would also be part of the study. Human factors would be the main focus. Other factors which might appear during this operation are not taken into account, for example, adverse weather condition, thruster failure, and signal loss from Satellites to keep the vessel in position and so on.

As it has been described previously in the process of HRA, a case study could be executed system by system. Firstly, a task analysis would be performed to provide the operation picture for access and egress. The task analysis would then provide a source where possible human errors can be considered to retrieve systematically. Then secondly, a suitable HEI method would be used to identify possible human errors and their possible consequences. This case study 1 provides only half of HRA process, the rest of it will be continued in section 4.

3.1 Hierarchical Task Analysis (HTA)

HTA is the first step applied in the task analysis to provide the operation picture for access and egress. Figure 4 shows how the task is considered when access and egress is required. The task is broken down in four levels where I initially start in plan 1 by checking weather condition and end up with the walk-way connection in plan 4.

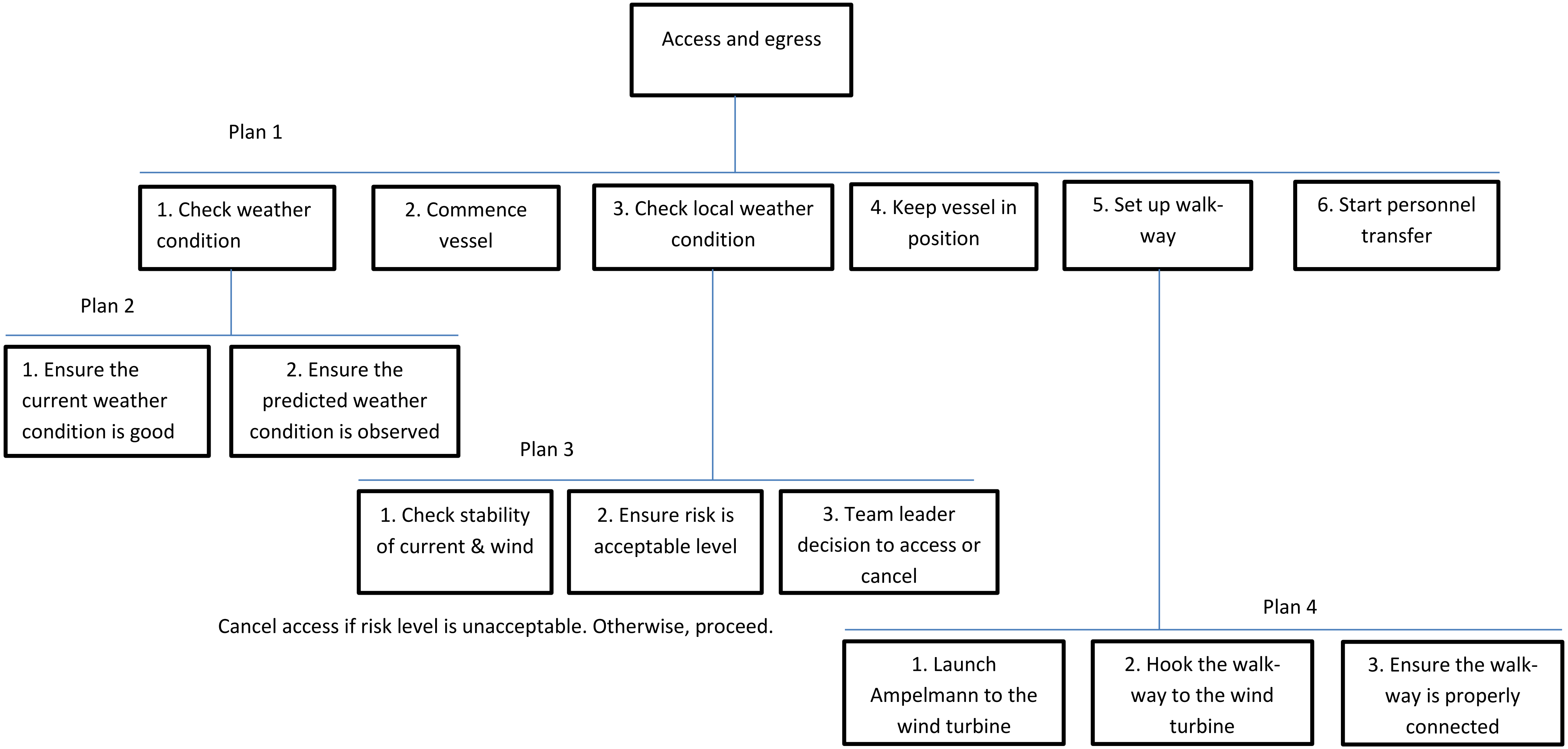


Figure 4: Hierarchical Task Analysis (HTA)

3.1.1 Operational Sequence Diagram (OSD)

The diagram is based on the previous HTA but only part the whole task which may be depicted from step 4 and 5 in plan 1 and all the steps in plan 4. Figure 5 shows the OSD for access to the wind turbine. In OSD, It is assumed that access or egress is carried out by using OTS (Offshore transfer system) or Amplemann between vessel and wind turbine. Communication has to take place among the vessel operator, machine operator (Walk-way machine operator) and team leader (or personnel). The operation must be carried out in the correct sequence in order to perform safe access to the installation. This is a sequential description during the operation of access and egress. According to the task performed in this case, 4 different actors are identified. They are forming different parts of the work tasks and are also working together to perform this specific operation.

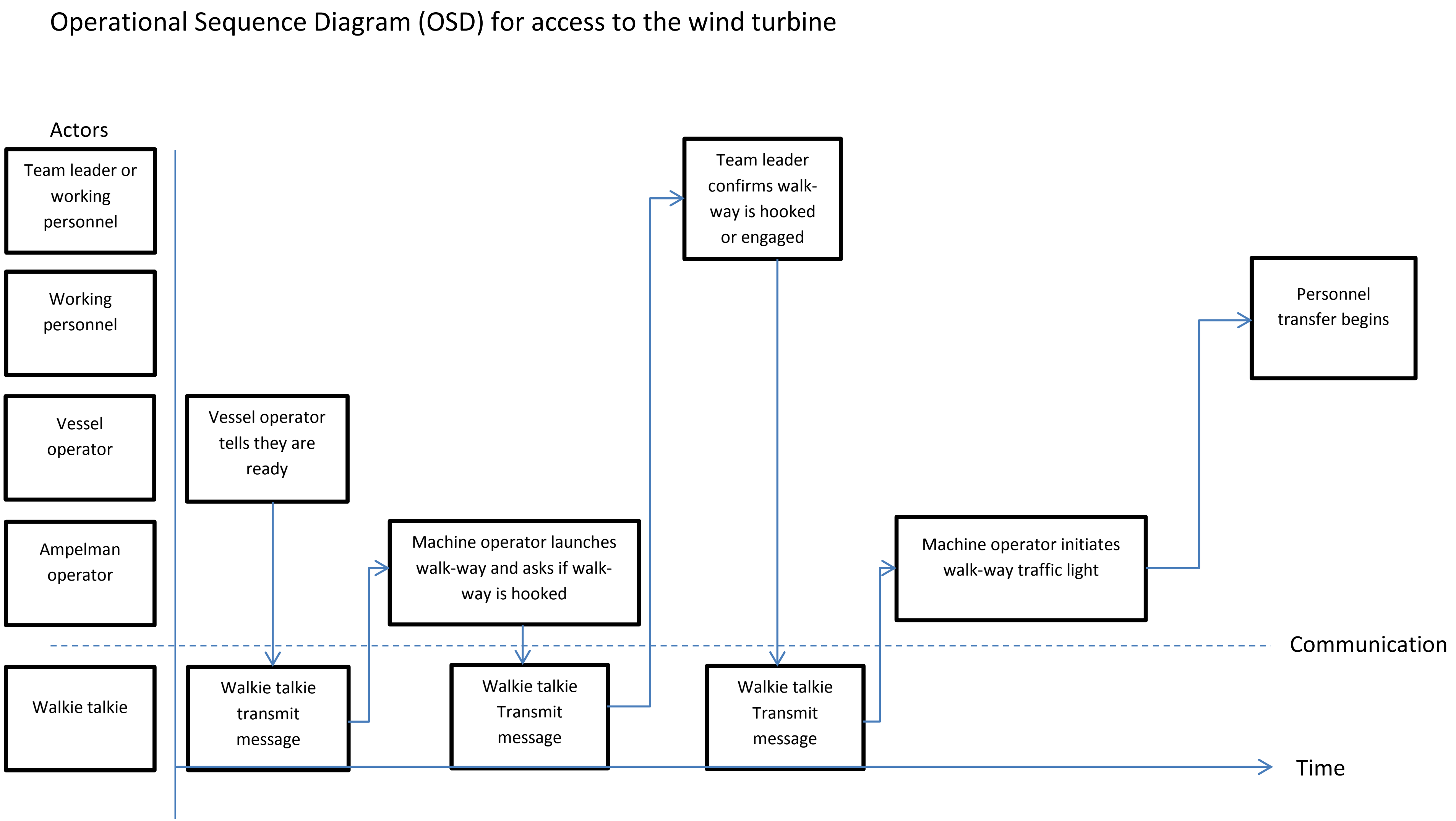


Figure 5: Operational Sequence Diagram (OSD)

3.1.2 Tabular Task Analysis (TTA)

Tabular Task Analysis is the next step where it is necessary to go even more detail in analyzing each step which has been identified in OSD. Each action performed by different actors has become an input for further investigation. In tabular task analysis cues and feedbacks are the main concern. By applying cues and feedbacks, it becomes obvious how the task is flowing step by step according to the actors involved in the work sequence. When a feedback for each task is performed, it is possible to identify if something go wrong: in other words, in case of an ongoing failure, it can be identified before it is too late as the feedback is performed on that particular task. In addition, possible errors can be identified by including one more colon in the table if it is needed. Table 3 shows the identified cues and feedbacks which may occur when access to the wind turbine is required.

Table 3: Tabular Task Analysis

No.	Action (Description)	Cues	Feedback	Possible errors	Comments
1	The vessel operator approaches the wind turbine	The vessel operator positioned the vessel	Observe the vessel is being stationary, e.g. visual or GPS on the operating screen on the vessel	1.The vessel is unstable or moving, e.g. due wrong maneuvering and directional control 2. Too close or too far	Weather condition such as wind and current direction are considered to have been observed before this operation
2	The vessel operator informs that the vessel is ready	Message given to the Ampelmann operator	Confirmation of receiving message given back to the vessel operator	Communication error	The vessel operator will require confirmation from the Ampelmann operator
3	Machine operator launches the walk-way after he was informed that the vessel is in position.	Request if the walk-way is properly engaged to the wind turbine	Receive confirmation that the walk-way is hooked	The walk-way is not connected properly to the wind turbine. (Hook wrongly)	Communication. Visual check Double confirmation
4	Team leader observes if the walk-way is engaged and informs the machine operator	Tell the machine operator (Ampelmann)	Check that machine operator receives the message	Communication error e.g. due to environmental stress	Give visual signal in addition to verbal communication
5	Start personnel transfer	Initiate the green light for personnel	Observe that the green light is on	Walk on the gang way too soon before it is	Personnel transfer may be only one at a

		transfer		ready	time to reduce risk in case of mechanical failure or sudden change of weather

3.1.3 Human Error Identification

All possible human errors related to a particulate task within access and egress are considered and systematically identified. The worksheet in Figure 6 describes how human errors are systematically identified with their possible consequences which may result. The next summary Table 4 further extends the level of risk and risk reducing measures for each identified error. Only one worksheet and a summary table are presented here to demonstrate how it is performed. The rest of all the other worksheets within this operation are attached in the Appendix 1.

Ref: 1	**Action** The vessel operator approaches the wind turbine	**Cue** The vessel operator positioned the vessel	**Feedback** Observe the vessel is being stationary	**Comments**

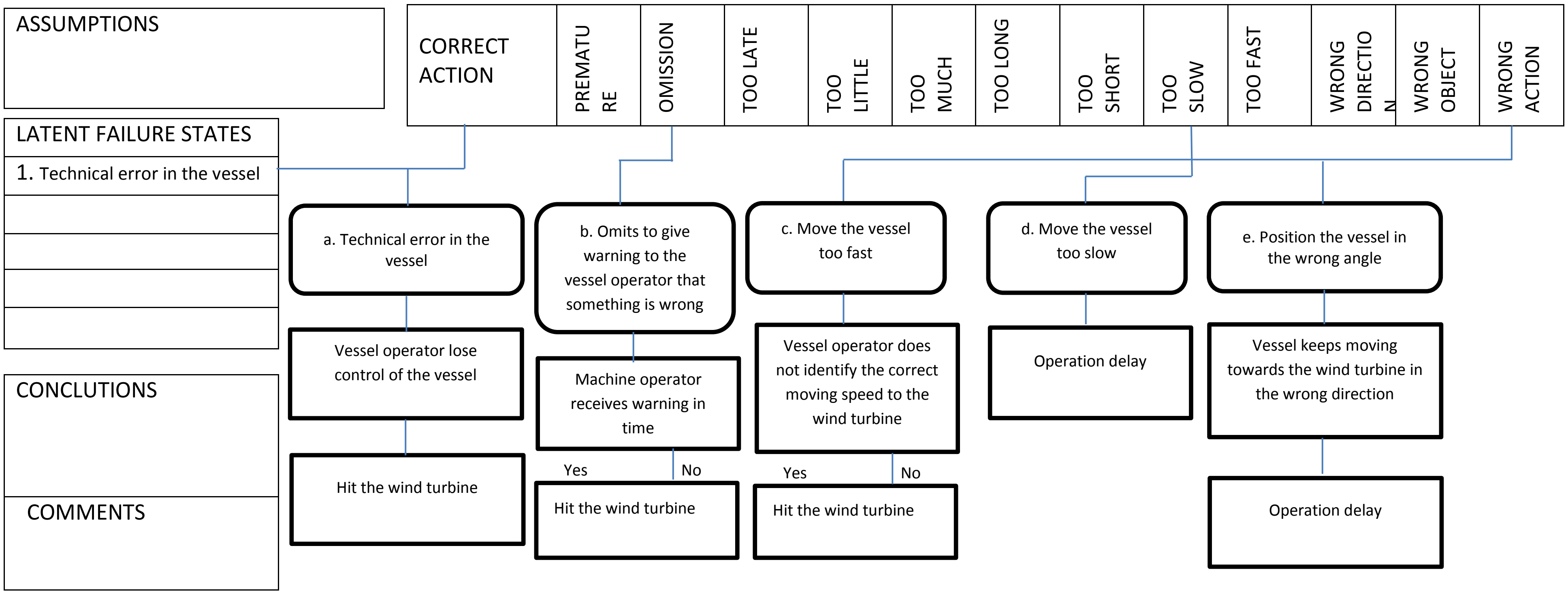


Figure 6: Action Error Mode Analysis work sheet (AEMA)

Table 4: Human Error Mode Analysis (AEMA) worksheet

No.	Action (Description)	Action error mode	Action error cause	Action error consequences	Risk	Risk reducing measure	Comments
1.	The vessel operator approaches the wind turbine	- Wrong maneuvering - Move too fast	- Procedure error - Slip	Collision with the wind turbine	H	Adequate training	
1.	Keep the vessel into position for access	Move away from the right position (The vessel may be too far or too close)	- Procedure error - Communication error - Slip - Lapse	May lead to material loss or/and injuries to working personnel	H	Adequate training to the vessel operator	
2.	The vessel operator informs that the vessel is ready	The vessel is positioned but the dynamic positioning system has not been activated. Or the current and the wind direction were not considered for the right position of the vessel.	- Procedure error - Mistake - Slip	May lead to material loss or/and injuries to working personnel	H	Having a simple working procedure / Adequate training to the vessel operator	

3.	Machine operator launches the walk-way after he was informed that the vessel is in position	Hit the wind turbine	- Procedure error - Mistake - Slip	May lead to material loss or/and injuries to working personnel	H	Adequate training to the vessel operator	
4.	Hook the walk-way to the wind turbine for access	Not properly hook to the wind turbine	- Procedure error - Communication error - Slip - Lapse	Walking personnel may fall	M	Visual check should be carried out if the walk-way is engaged properly before personnel transfer	
5.	Initiate personnel transfer	1. Give green light signal too early 2. Disengage the walk-way too early	- Procedure error - Communication error - Slip	Walking personnel may fall	M	Machine operator observes the transfer process visually	

4 Case study 2

This study presents a HRA method by using the SPAR-H worksheet for estimating the human error probabilities which may occur during access and egress. This method is assumed to be an adequate HRA tool in performing risk analyses for this challenge. In this study only possible human errors are included when testing SPAR-H model. Other contributing factors are neglected in the analysis. And the analysis is performed according to the steps and procedures in the report by (D. Gertman 2004).

The SPAR-H method is tested here and its worksheet provides a pre-defined base-case HEPs where detail information is unavailable when assigning the appropriate values of the PSF levels. Therefor the analysis is performed with a lot of assumptions. Based on some reasonable information which can be considered most relevant to access and egress, assumptions are made to fill out the HRA worksheet. If this HRA worksheet is applied in a practical situation, without having too many assumptions made, where detailed information about each PSF level is available, then it can be assumed that the more accurate HEP, which is closer to the reality, will be achieved from the calculation.

After finishing the worksheet a more detailed analysis of ETA is also presented as part of this section. The ETA consists of the evaluated human errors which have been modified on the worksheets. The ETA model used to evaluate this case includes both action and diagnosis (or a combination of both) depending on the tasks found in the event sequence. Different possible human errors and reasonable situations are considered for filling out PSF levels in the worksheet to go through a thorough investigation of how the SPAR-H model works for this challenge. All the calculated HEPs are included in the section and in Appendix 2 for detailed analysis.

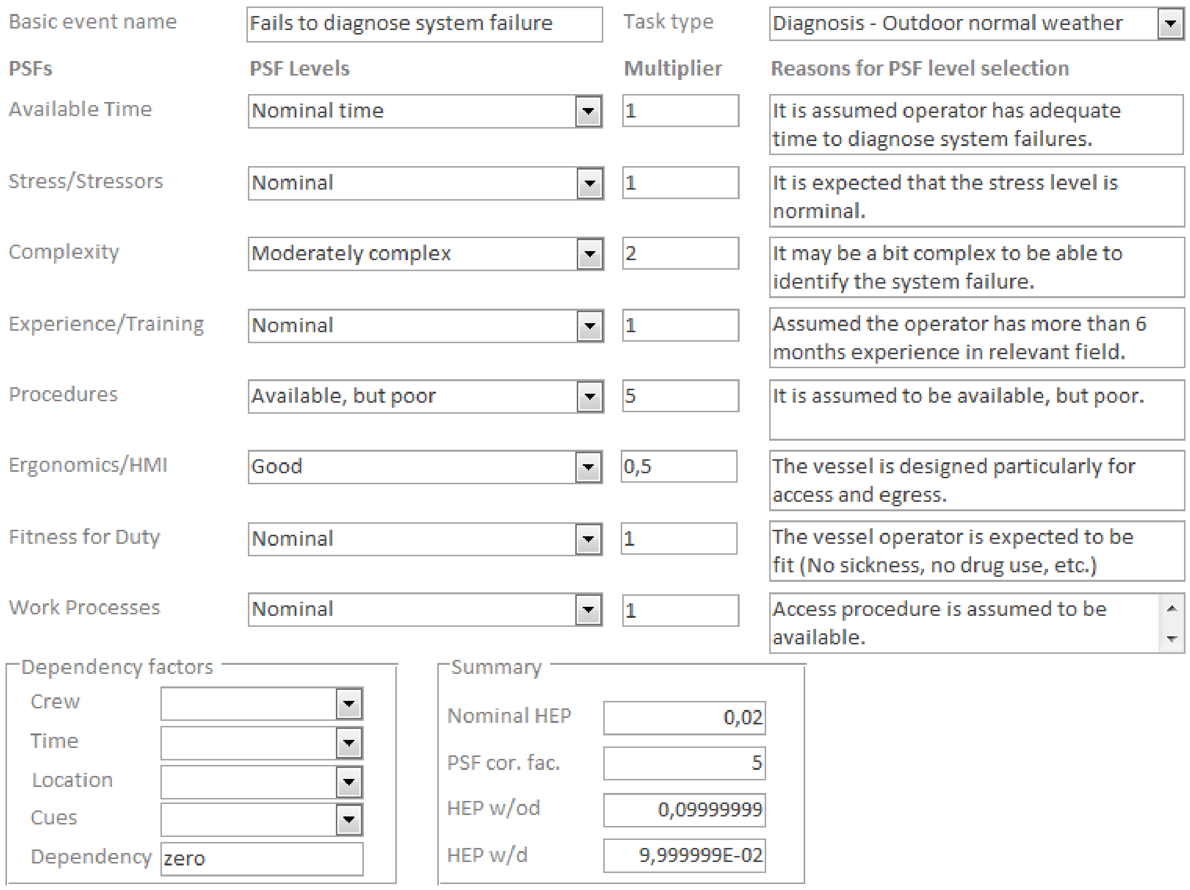
4.1 Case study analysis for approaching the wind turbine for access and egress

The following case analysis is related to a vessel approach to a wind turbine when access is required. The event is assumed to be loss of control of the vessel due to malfunction of the system and human errors. A number of human errors are identified within this operation. These include failing to: diagnose system failure in the vessel, perform a correct action when manual operation is needed to control the vessel, control the vessel in time, etc.

To make a possible case, some assumptions considered to be most relevant are first made as follows:

- The weather condition is predicted and reasonably fine for access and egress.
- The local weather condition is also good when the vessel is out there.
- Approaching the wind farm is considered to be critical, therefor the vessel is equipped with GPS to detect speed and distance, alarm system when the vessel is too close and dynamic braking system (system to reverse propeller for backward motion). Unfortunately these are malfunctioning and do not provide the correct information indicating that the vessel operator can proceed further operation. But in fact, the vessel operator has to control the vessel manually now.
- Human error probabilities which apply in this case: (1) probability of vessel operator failing to diagnose the system failures in the vessel, (2) probability of operator failing to detect the speed and distance, (3) probability of operator failing to take correct action after being detected the system failure and (4) probability of failure that operator cannot control the vessel in time which can result collision.
- If the crew has no available time to respond in any of the above 4 incidents, then there is no doubt that the probability of colliding the vessel with the wind turbine is too high. Each time a human error occurs in the above case, it is assumed that there is enough time to respond. For example, even if the dynamic braking system of the vessel fails, it is still considered that the operator has enough time to recover the situation to void collision.
- The distance is about 100-200 meters.
- If the vessel speed is too high, it will lose control; in the worst case collision will occur.

Here, the basic event is assumed to be the operator's failure to detect the vessel system failure while approaching the wind turbine at a considerable speed. This is the first task selected to perform in the SPAR-H worksheet without formal dependence. The basic event involves only a diagnosis.



Basic event name	Fails to diagnose system failure	Task type	Diagnosis - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed operator has adequate time to diagnose system failures.
Stress/Stressors	Nominal	1	It is expected that the stress level is norminal.
Complexity	Moderately complex	2	It may be a bit complex to be able to identify the system failure.
Experience/Training	Nominal	1	Assumed the operator has more than 6 months experience in relevant field.
Procedures	Available, but poor	5	It is assumed to be available, but poor.
Ergonomics/HMI	Good	0,5	The vessel is designed particularly for access and egress.
Fitness for Duty	Nominal	1	The vessel operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Nominal	1	Access procedure is assumed to be available.

Dependency factors	
Crew	
Time	
Location	
Cues	
Dependency	zero

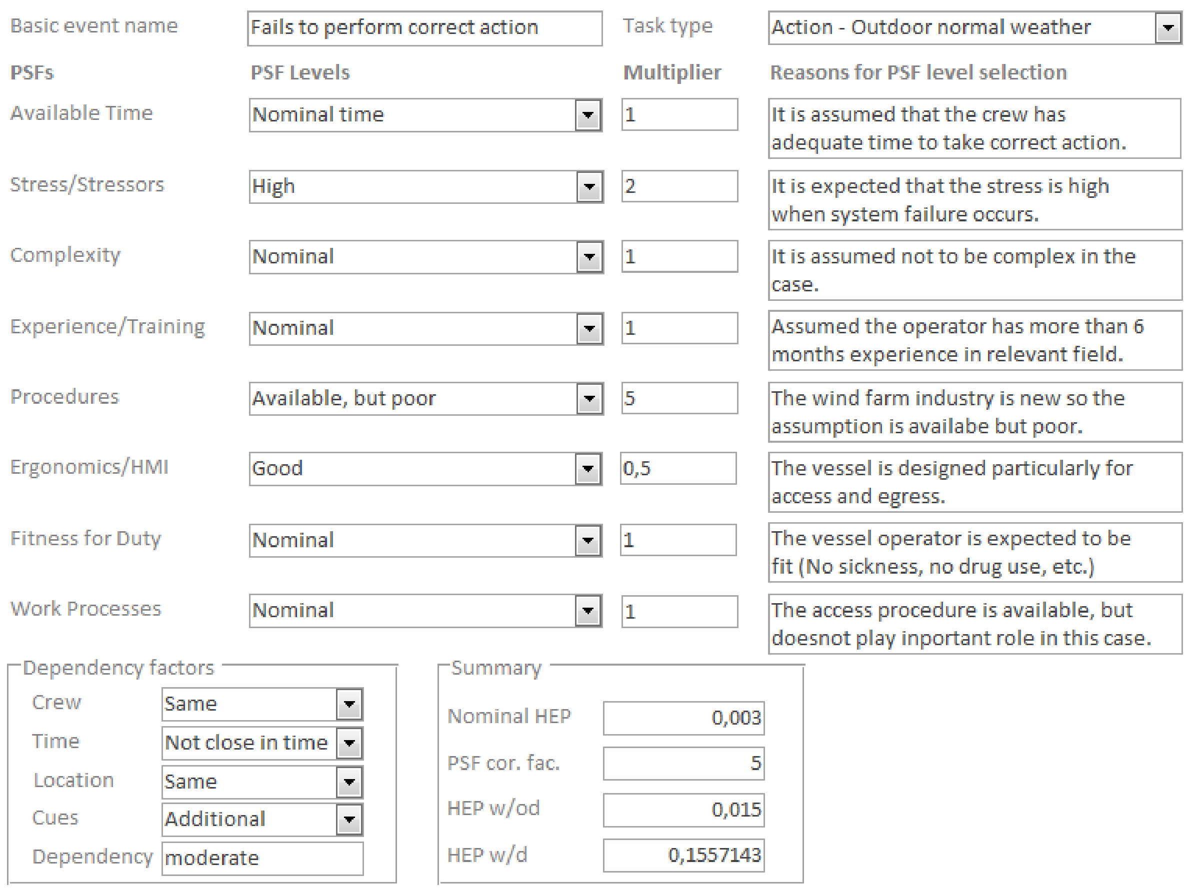
Summary	
Nominal HEP	0,02
PSF cor. fac.	5
HEP w/od	0,09999999
HEP w/d	9,999999E-02

Figure 7: SPAR-H worksheet for a diagnosis error to identify system failure

Only 2 negative PSF influences are present according to the above evaluation so that the final diagnosis HEP is accepted without needing to make an adjustment factor. So it is possible to say that the probability of being unable for the operator to detect the system failure is 9 %.

If, for example, the available time to diagnose the system failure is assumed to be barely an adequate time, then the HEP increases up to 50 %. On the other hand, if the procedure is changed to be nominal in this case assuming that the procedure is available on the vessel which enables to detect system failure, and then the HEP decreases to 20 %. The PSF for the procedure is set up as "available, but poor", but in the real situation a procedure may not necessarily be available to identify such system failure. And if this is the case, the HEP increases up to 100 % which seems really unreasonable. The calculation of the SPAR-H worksheet shows that a single contributing factor can play a significant role for the final HEP. The difference between the normal weather and the bad weather condition or dependency factors also show a significant change of the final result.

If considering a second possible human failure in the event sequence, it can be that the system failure has been detected but the operator fails to perform correct action to control the vessel.



Basic event name	Fails to perform correct action	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that the crew has adequate time to take correct action.
Stress/Stressors	High	2	It is expected that the stress is high when system failure occurs.
Complexity	Nominal	1	It is assumed not to be complex in the case.
Experience/Training	Nominal	1	Assumed the operator has more than 6 months experience in relevant field.
Procedures	Available, but poor	5	The wind farm industry is new so the assumption is availabe but poor.
Ergonomics/HMI	Good	0,5	The vessel is designed particularly for access and egress.
Fitness for Duty	Nominal	1	The vessel operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Nominal	1	The access procedure is available, but doesnot play inportant role in this case.

Dependency factors	
Crew	Same
Time	Not close in time
Location	Same
Cues	Additional
Dependency	moderate

Summary	
Nominal HEP	0,003
PSF cor. fac.	5
HEP w/od	0,015
HEP w/d	0,1557143

Figure 8: SPAR-H worksheet for an action error to perform correct action

The above is no longer a diagnosis analysis, but action. The worksheet calculation shows that action analysis gives usually lower HEP when comparing to diagnosis analysis. Here, the calculated HEP is only 1,5 %, if this is in case diagnosis analysis it turns up to be 9 % which obviously means that the chance of human failure to diagnosis is higher than to take action. As the previous example, only two negative influencing factors are found that no adjustment is applied according to the worksheet procedure. But dependency factors now are included here which finally results that the human error probability to take correct action is around 16 %.

The final possible event considered in this sequence is that the operator fails to control the speed in time to avoid collision which may happen after the system failure has been detected and correct action has been performed. Here, the dynamic position system is assumed to be functioning, but this may not play an important role to control the vessel.

Basic event name	Fails to control the speed in time	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Time available is approx. the time	10	It is assumed that time is approximately available, not too much.
Stress/Stressors	Nominal	1	It is expected that stress is norminal in this situation.
Complexity	Nominal	1	The situation here is assumed to be nominal in this case.
Experience/Training	Nominal	1	Assumed the operator has more than 6 months experience in relevant field.
Procedures	Available, but poor	5	It is assumed procedure is available, but poor as the industry is new.
Ergonomics/HMI	Good	0,5	The vessel is designed particularly for access and egress.
Fitness for Duty	Nominal	1	The vessel operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Good	0,5	Access procedure is assumed to be available.

Dependency factors	
Crew	Same
Time	Not close in time
Location	Same
Cues	Additional
Dependency	moderate

Summary	
Nominal HEP	0,003
PSF cor. fac.	12,5
HEP w/od	0,0375
HEP w/d	0,175

Figure 9: SPAR-H worksheet for an action error to control the vessel's speed in time

No adjustment factor applied due to only two negative influencing factor as the previous two evaluation and the final action HEP is 17, 5 %.

Not any of the above evaluations is a combination of diagnosis and action HEP. Each of them is separately analyzed in the worksheet, but at a later part of this section more evaluation involving both diagnosis and action HEP is discussed.

The following ETA is presented to perform a more detailed analysis. The intention is to find out the probabilities of possible collision between vessel and wind turbine due to human errors. All the HEPs from the calculation of the SPAR-H worksheet above are applied in the model.

The logical sequence of the operation can be described as below. Possible technical failures are not considered in the analysis of this report.

Fails to diagnose the vessel system failure	Fails to perform a correct action to control the vessel	Fails to control the speed in time	Probability

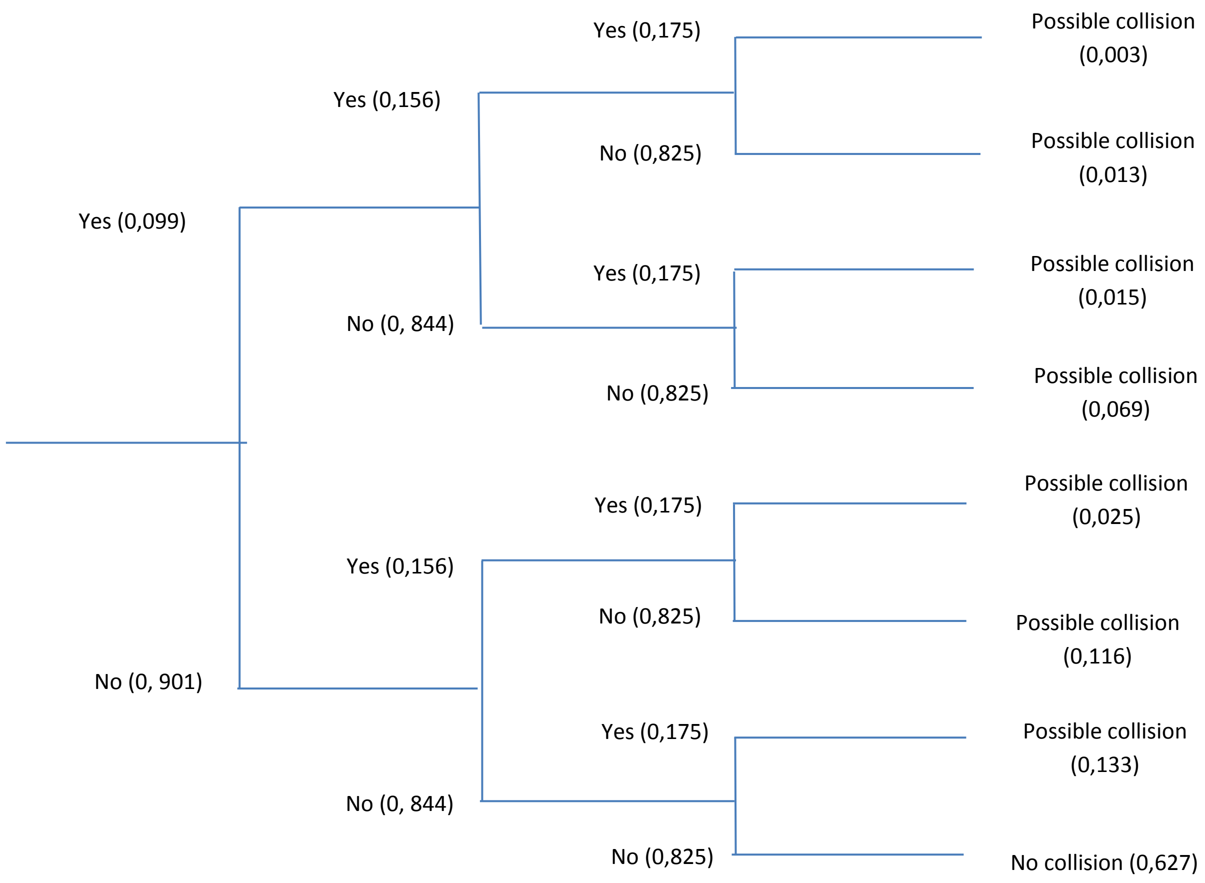
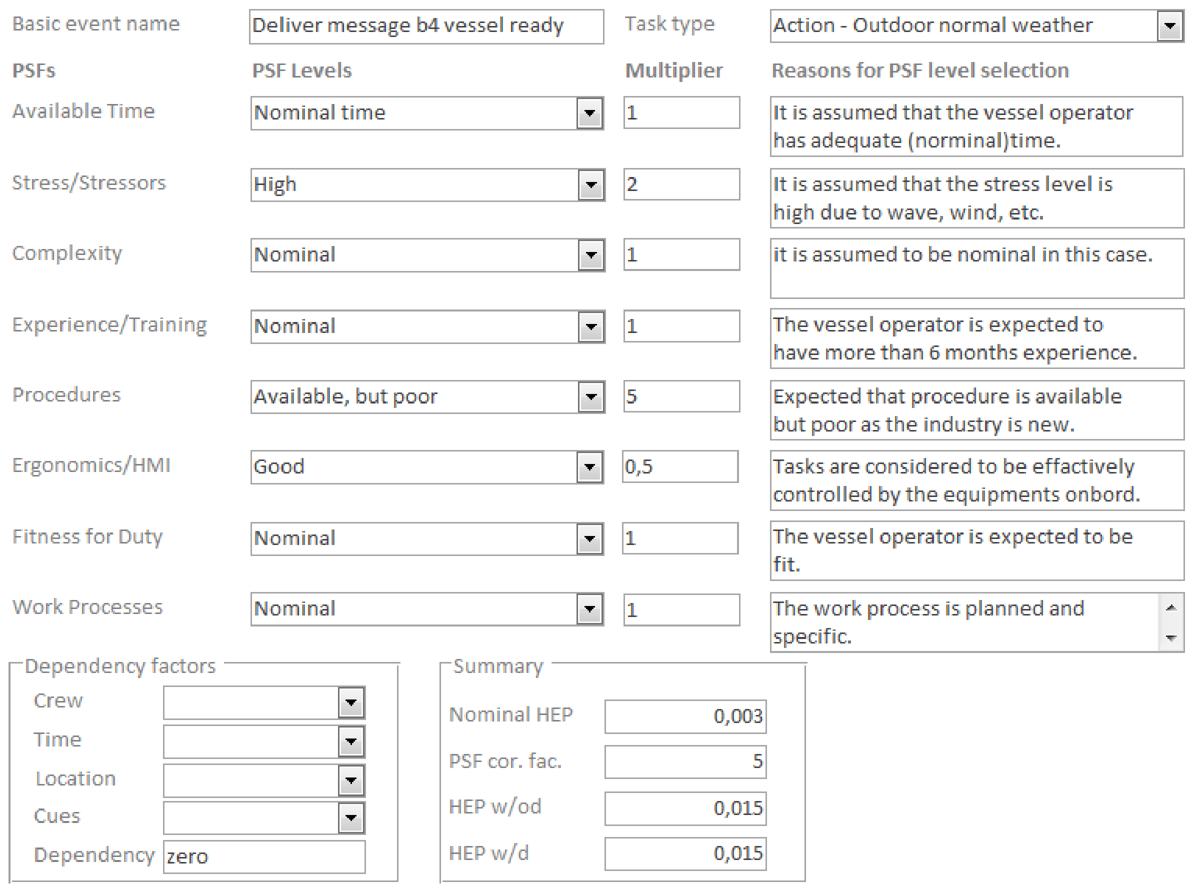


Figure 10: HRA event tree structure for a detailed analysis of collision between vessel and wind turbine

4.2 Case study analysis for personnel transfer from the vessel to the wind turbine

The following case study analysis is also a SPAR-H application followed by the ETA model as it was done in the previous analysis. The operation includes positioning the vessel near the wind turbine, launching the walk-way (OTS or Amplemann) to wind turbine, engaging the walk-way to the landing station built on the wind turbine, and transferring personnel to the installation. Three different actors now involve in the analysis.

The first one is the SPAR-H worksheet analysis for the task of getting ready for access after the vessel is being positioned near the wind turbine. The potential error modeled is giving message too early by the vessel operator to the machine operator. The vessel has approached the wind turbine; the operator activates the DPS and then gives message to the machine operator that access can now be initiated.



Basic event name	Deliver message b4 vessel ready	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that the vessel operator has adequate (norminal)time.
Stress/Stressors	High	2	It is assumed that the stress level is high due to wave, wind, etc.
Complexity	Nominal	1	it is assumed to be nominal in this case.
Experience/Training	Nominal	1	The vessel operator is expected to have more than 6 months experience.
Procedures	Available, but poor	5	Expected that procedure is available but poor as the industry is new.
Ergonomics/HMI	Good	0,5	Tasks are considered to be effactively controlled by the equipments onbord.
Fitness for Duty	Nominal	1	The vessel operator is expected to be fit.
Work Processes	Nominal	1	The work process is planned and specific.

Dependency factors		Summary	
Crew		Nominal HEP	0,003
Time		PSF cor. fac.	5
Location		HEP w/od	0,015
Cues		HEP w/d	0,015
Dependency	zero		

Figure 11: SPAR-H worksheet for an action error to deliver message too soon before the vessel is ready

The second one is an analysis for the task of launching the walk-way by the machine operator to the wind turbine. The activity takes place after the vessel has been properly positioned. The machine operator launches the walk-way and engages it to the landing station on the wind turbine. The potential error modeled is failing to properly engage the walk-way to the landing station on the turbine. This is considered that both action and diagnosis are included in this mode.

Part 1, evaluate each PSF for diagnosis

Evaluate PSFs for the diagnosis portion of the task

Basic event name	fails to properly engage walk-way	Task type	Diagnosis - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that there is adequate time.
Stress/Stressors	High	2	It is assumed that stress is higher than normal due to wind, wave, etc.
Complexity	Nominal	1	It is assumed that the complexity is nominal.
Experience/Training	Nominal	1	It is assumed that the operator has more than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Nominal	1	It is assumed to be norminal in this case.
Fitness for Duty	Nominal	1	The Amp. Operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Nominal	1	The access procedure assumed to be available.

Dependency factors	
Crew	Different
Time	Not close in time
Location	Same
Cues	Additional
Dependency	low

Summary	
Nominal HEP	0,02
PSF cor. fac.	10
HEP w/od	0,2
HEP w/d	0,24

Figure 12: SPAR-H worksheet for improper engagement of the walk-way (diagnosis portion)

Part 2, evaluate each PSF for action

Evaluate PSFs for the action portion of the task

Basic event name	fails to properly engage walk-way	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that there is adequate time.
Stress/Stressors	High	2	It is assumed that stress is higher than normal due to wind, wave, etc.
Complexity	Nominal	1	It is assumed that the complexity is nominal.
Experience/Training	Nominal	1	It is assumed that the operator has more than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Nominal	1	It is assumed to be norminal in this case.
Fitness for Duty	Nominal	1	The Amp. Operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Nominal	1	The access procedure assumed to be available.

Dependency factors	
Crew	Different
Time	Not close in time
Location	Same
Cues	Additional
Dependency	low

Summary	
Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,0785

Figure 13: SPAR-H worksheet for improper engagement of the walk-way (action portion)

The third one is the SPAR-H worksheet analysis for the working personnel crossing the walk-way before the machine is ready. This activity should only take place after the walk-way is engaged properly to the installation.

Basic event name	Cross the walk-way before ready	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It's assumed that adequate time is available
Stress/Stressors	High	2	It is assumed that stress will be higher than normal.
Complexity	Obvious diagnosis	0,1	It is assumed that personnel can easily identify when to cross the walk-way.
Experience/Training	High	0,5	It is assumed that personnel are familier with relevant field. E.g. Trafic.
Procedures	Nominal	1	The procedure is available and this is assummed to be norminal
Ergonomics/HMI	Good	0,5	Personnel er expected to understand well about the light is green or red.
Fitness for Duty	Nominal	1	Personnel are expected to be fit.
Work Processes	Nominal	1	The access procedure is assumed to be available.

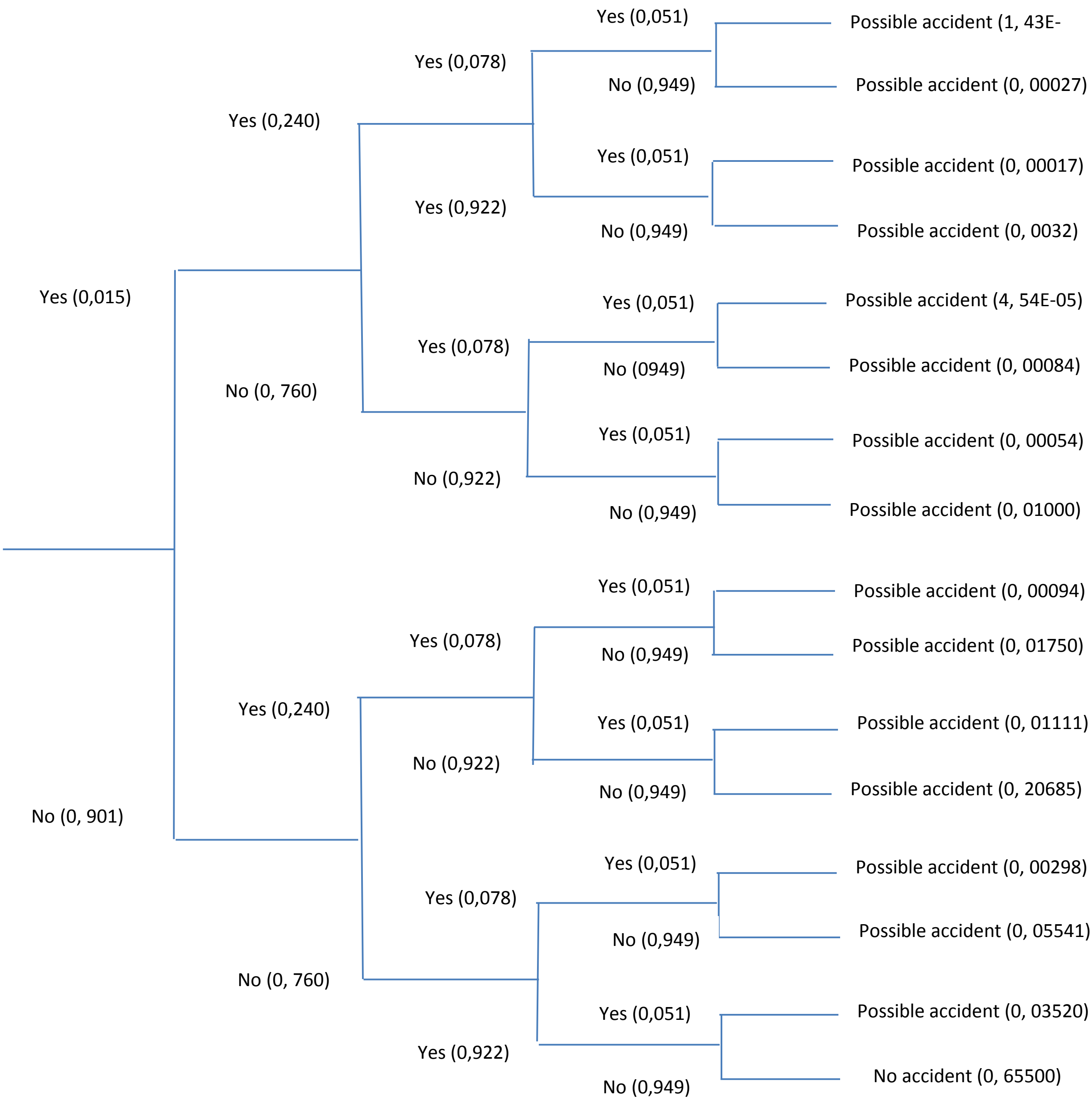
Dependency factors	
Crew	Different
Time	Not close in time
Location	Different
Cues	Additional
Dependency	low

Summary	
Nominal HEP	0,003
PSF cor. fac.	0,05
HEP w/od	0,00015
HEP w/d	0,05095

Figure 14: SPAR-H worksheet for an action error to cross the walk-way

The logical sequence of the operation can be described as below.

Deliver message before vessel ready	Fail to properly engage the walk-way (Diagnosis)	Fail to properly engage the walk-way (Action)	Cross the walk-way before ready	Probability of hazardous event (e.g. personnel injured or fall)



Note: Only possible human errors are considered in the ETA analysis.

Figure 15: HRA event tress structure for a detailed analysis of personnel transfer to wind turbine

5 Risk reducing measures for HEP and Recommendation

The SPAR-H method produces a simple estimation of HEP for risk models. The eight PSFs contained in its work-sheet have interrelationship which effect on the estimated HEP. By focusing on each PSF, possible risk reducing measures can be proposed.

1. Time is the most influencing factor that plays important role when it is needed to reduce risk. In every task performed on the case studies, it shows that the estimation of HEP can be reduced considerably by having more available time. For example, in case study analysis 1, it was assumed that a system failure had to be identified in order that the probability of the vessel collision would be reduced. The time applied in the worksheet is nominal which results the calculated HEP with 0.0999. When changing the time available from nominal to expensive time, the calculated HEP reduces from 0,0999 to 0,000999. If a failure exists in the system of the vessel, it should be identified as early as possible before the vessel is out there on the sea for access or egress. Regular maintenance both for the vessel and the access machine should be performed. It could be too late to avoid unwanted event if system or equipment failures are identified when they are required.

   Time-press should be avoided. If possible, there should always be more available time for the operator or working personnel to carry out every action. In the event where it is assumed that the operator fails to perform a correct action, it is assigned as nominal, but when the time available increases to an extra amount of time the reduction results from 0,156 to 0,143. In the event where it is assumed that the operator fails to control the speed in time is assigned to be approximately available (not too much) this results the HEP with 0,175, but if the time available increases to an extra amount of time, the estimated HEP ends up with 0,143.

   When the three reduction values above are further assigned in the following ETA, it results that the probability of no collision between the vessel and the turbine has increased to 0,734 which was earlier 0,627.

2. Environmental factors such as strong wind, heavy current, mist or rain should be avoided if possible because these can affect the operator's mental or physical

performance. These factors can increase stress which is one of PSFs in the SPAR-H worksheet.

3. All the tasks should be made clear before they are executed, if possible, they should be performed by only those who have skill.
4. Proper training and sufficient information should be provided to the people involved.
5. Communication is also vital part in the operation; therefor clear communication should be in place during access and egress. Simple procedures should be established regarding the communication for the work tasks between the vessel operator, machine operator and the team leader. This may reduce the possibility of communication errors. An example may be to require verification of critical messages where the receiver repeats the message.
6. Use the safest way for access or egress; for example, use OTS (Offshore Transfer System) instead of a direct helicopter landing, crane or rope transfers. It is claimed that over 7000 successful connections with 100,000 personnel transfers with no LTIs has been completed since early 2006 (B.V. 2011).
7. Ensure that weather condition and the sea stage is good before entering the wind farm.
8. Visual check should be carried out wherever it is necessary. For example, when the walk-way is engaged to the wind turbine, it should be ensured by visual check that it is properly connected before personnel transfer is initiated.
9. All the involved people should work as a team and should be able communicate what is expected and what actually happens before and during access and egress, as well as providing feedback once the operation is complete

6 Summary and recommendation

In this final chapter, I would sum up what it has been done in the report and which result I have got. I would also propose some suggestion for improvement. Advantages and disadvantages of the SPAR-H method found from the case studies would be covered as well. I would end my report by including recommendation for further work.

6.1 Summary and conclusion

The report begins by suggesting possible risk analysis methods which may be most relevant within the five challenges identified in the report by SINFEF, 2011. Different risk analysis techniques both quantitative and qualitative are proposed with focus on all the five challenges. The first part of the report suggests possible risk analysis methods which could be applicable for equipment and system failures, and the rest of the report mainly discusses risk analysis techniques related to human reliability analysis.

Since the contribution of human erroneous action is usually higher than equipment and mechanical failures when accidents occur, human reliability analysis are prioritized and taken into account when considering risk assessment methods and applications. Therefor it was decided that the thesis work deals mostly with HRA. The process of HRA and SPAR-H could be considered as an important part of this report. Among all the suggested risk analysis methods, SPAR-H method was chosen to put into a test in the report because the method is based on the HEART approach and uses data from CREAM, THERP and ASEP. It was therefore reasonable to believe that the SPAR-H method is the most appropriate method. A predefine SPAR-H worksheet was used for the explicit documentation of PSFs, and calculation of adjusted HEPs. The worksheet was provided by my supervisor and is discussed in (MARINA 2012) where some proposed modification to the nominal HEPs are given.

Off all the five challenges identified by SINTEF report, two of them are mainly discussed and taken into account in the two case studies: collision between vessel and wind turbine when approaching a wind turbine and access/egress when personnel transfer is required. In this scenario, an investigation from HRA point of view was performed explicitly in the two case studies and Appendix 2. Any possible human errors, potential hazardous events and the way how the hazardous event might happen are described in the case studies. HRA method is performed in a process by using different tools and techniques. The first part of the HRA process is a systematic approach to identify all possible human errors which become preliminary assessment of data needed in a HEQ method in the final risk analysis. SPAR-H technique was applied for quantitative risk analysis. The procedures provided for SPAR-H technique is followed according to the report by (D. Gertman et al. 2004). ETA was followed after the SPAR-H techniques for more detailed analysis. Possible risk reducing measures for HEP are finally suggested.

6.2 Result discussion

In the section I would clarify if the objectives of the report in section 1 are met. There may be some uncertainty but all the questions defined in the thesis assignment are answered. All the objectives are placed in Table 5 with the answers achieved from the report.

Table 5: Objectives and results of the report

Main objectives	1.	Select three or more safety challenges based on earlier work by SINFEF report	Yes. All the safety challenges are selected in a tabular form in section 2.
	2.	Propose relevant risk analysis techniques for these challenges.	Yes. All different risk analysis techniques are proposed for all the challenges in table 1 in section 2.
	3.	Propose a complete set of risk analysis techniques to apply for each of these safety challenges.	Yes. In this report, HRA is the main focus risk analysis technique. The process of HRA is presented. The limitation is that only two challenges are taken into account due to time limit.
	4.	Demonstrate the techniques for the selected safety challenges which include preliminary assessment data such as human error probabilities, weather data, operational limits related to, e.g., wave height etc.	The preliminary assessment data of Human error probabilities are achieved. But unfortunately, other data such as current, wave height, wind etc. are not taken into the report due to time limit during the report period.
	5.	Propose risk reducing measures and procedures to reduce risk.	Yes, risk reducing measures are proposed in section 5.
Sub -objectives	1	To get familiar with different methods or tools to systematically identify human erroneous actions.	Yes. HTA, OSD, TTA and HEI are presented.
	2	To understand a HRA method or more as the main tool to apply for the selected	Yes, SPAR-H method is used in this report.

		challenges.	
	3	To apply the methods on a case or more in order to get experience with the methods.	Yes. The SPAR-H method is applied on two cases: collision and access or egress.
	4	To investigate strengths and weaknesses of the HRA method.	Yes. The pre-defined strengths and weaknesses the SPAR-H method is presented. In addition, more limitations and weaknesses are discussed according to the results of the two case studies.

6.3 Strengths and weaknesses of the SPAR-H method

The pros and cons of the SPAR-H method are mentioned by Holroyd 2009 in Part II in section 2, but these are presented again in order that comparison may be possible in some cases.

Pros and Cons (Holroyd 2009):

"Pros:

- *A simple underlying model makes SPAR-H relatively easy to use and results are traceable.*
- *The eight PSFs included cover many situations where more detailed analysis is not required.*
- *The THERP-like dependence model can be used to address both subtask and event sequence dependence.*

Cons :

- *The degree of resolution of the PSFs may be inadequate for detailed analysis.*
- *No explicit guidance is provided for addressing a wider range of PSFs when needed, but analysts are encouraged to use more recent context developing methods if more detail is needed for their application, particularly as related to diagnosis errors.*
- *Although the authors checked the SPAH-H underlying data for consistency with other methods, the basis for selection of final values was not always clear.*
- *The method may not be appropriate where more realistic, detailed analysis of diagnosis errors is needed."*

According to the two cases studies performed, a number of strengths and weaknesses can also be further listed. Some of them are the same as the above pros and cons, but more information are available from the following findings as well.

Advantages:

1. The SPAR-H method is a simplified approach which can be used either qualitative or quantitative screening analysis.
2. Its work-sheet is easy to apply by just making relevant assumptions behind each PSF assignment which also reduces expert judgment as much as possible.

3. In the estimation of the HEP, the worksheet includes 8 PSFs which contribute negative effects on performance. For example, an estimated human error probability increases as a negative influence of a PSF grows. So the most contributing factors among the eight PSFs can be traceable.

Weaknesses:

1. The method itself does not mention the remedial measures. Remedial action has to be considered separately in the logic structure of fault tree models or event tree models.
2. The method does not provide guidance on how to develop a probabilistic risk analysis (PRA).
3. The gap between HEP with and without dependency factors is difficult to understand and not often traceable.

6.4 Recommendations for further work

SINFEF report has identified 5 challenges, but only two of the challenges are part of the report: collision between vessel and wind turbine and access or egress due to human errors. These two challenges are analyzed only from the HRA point of view. Other technical related risk analysis assessments, e.g. from the suggested techniques in table 1 in section 2, should also be performed. The other three challenges should also be taken into account for risk assessments by the suggested risk analysis techniques.

Although SPAR-H method is easy to use, there is some confusion when it comes to dependency factors. One should find out more about how these factors are considered in the SPAR-H worksheet.

Fault Tree Analysis and Event Tree Analysis are often mentioned in relation to SPAR-H method, but the relationship between the two model and SPAR-H are not explained in the report by (D. Gertman 2004). Further efforts should be attempt in order to find out the relationship and how they fit together.

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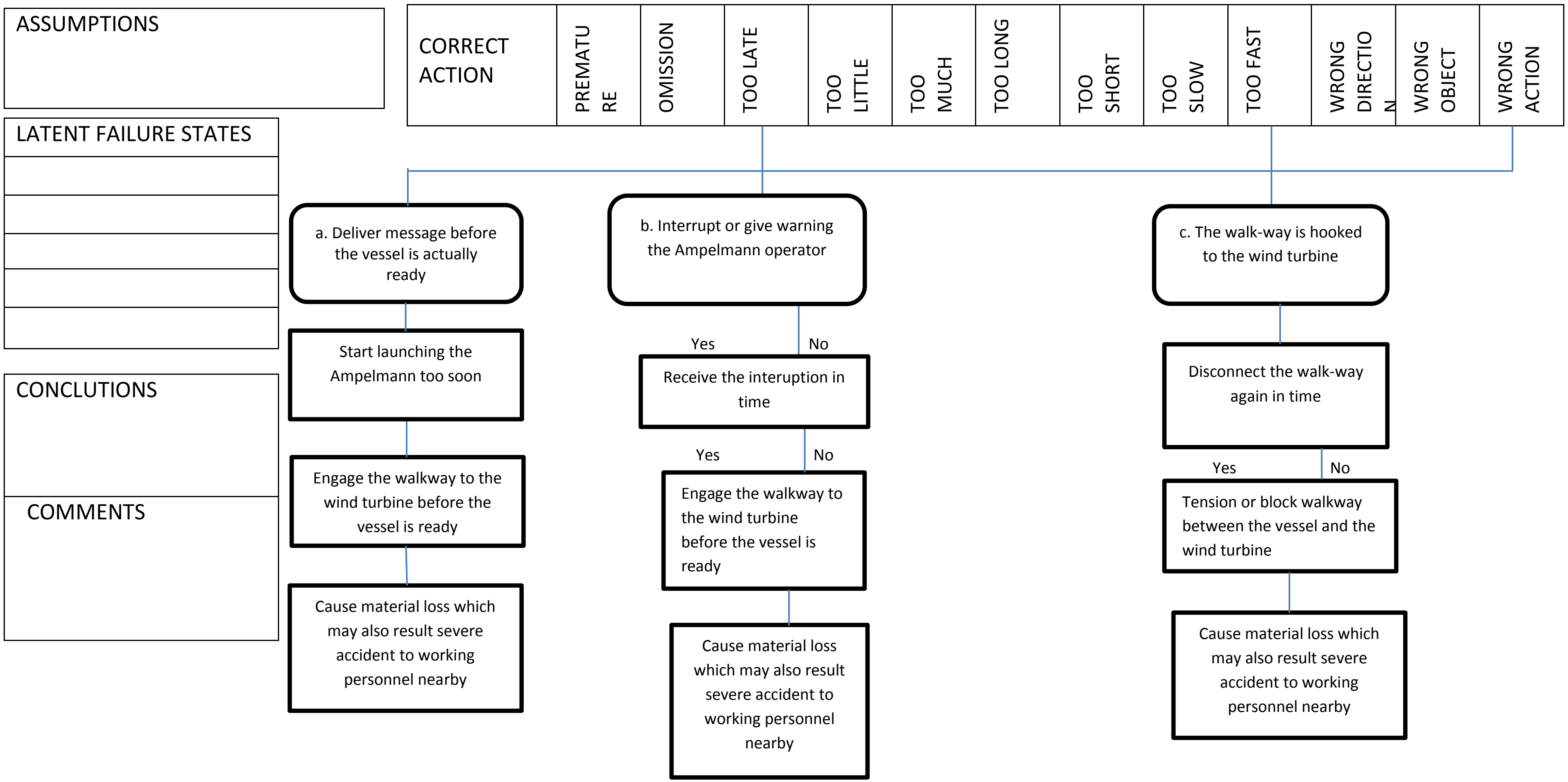
Appendix 1

Ref: 2	**Action** The vessel operator informs that the vessel is ready	**Cue** Message given to the Ampelmann operator	**Feedback** Confirmation of receiving message given back to the vessel operator	**Comments** The vessel operator will require confirmation from the Amplemann operator



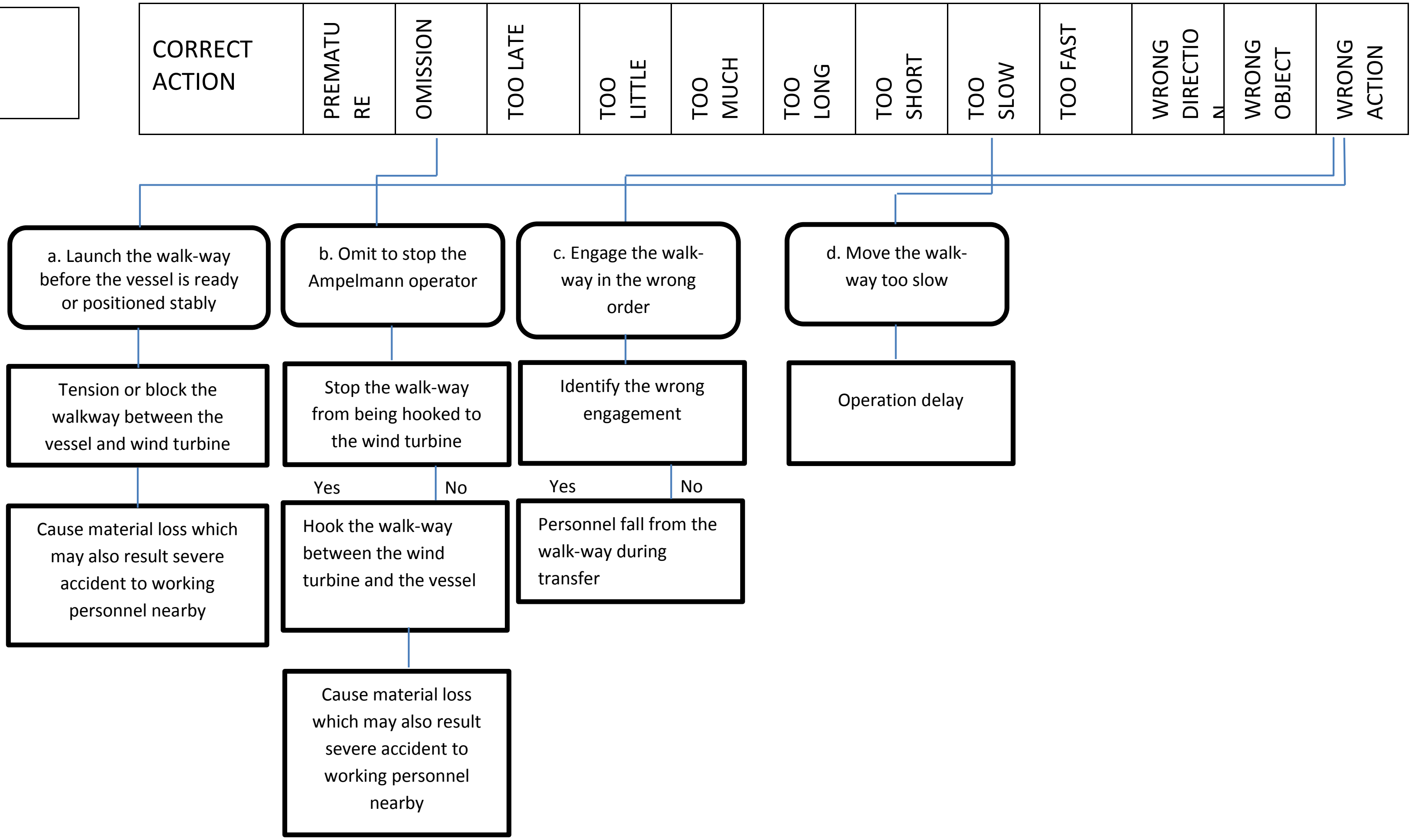
Ref: 3	**Action** Machine operator launches the walk-way after he was informed that the vessel is in position.	**Cue** Request if the walk-way is properly engaged to the wind turbine	**Feedback** Receive confirmation that the walk-way is hooked	**Comments** Communication between the Ampelmann and team leader

ASSUMPTIONS

LATENT FAILURE STATES

CONCLUTIONS

COMMENTS



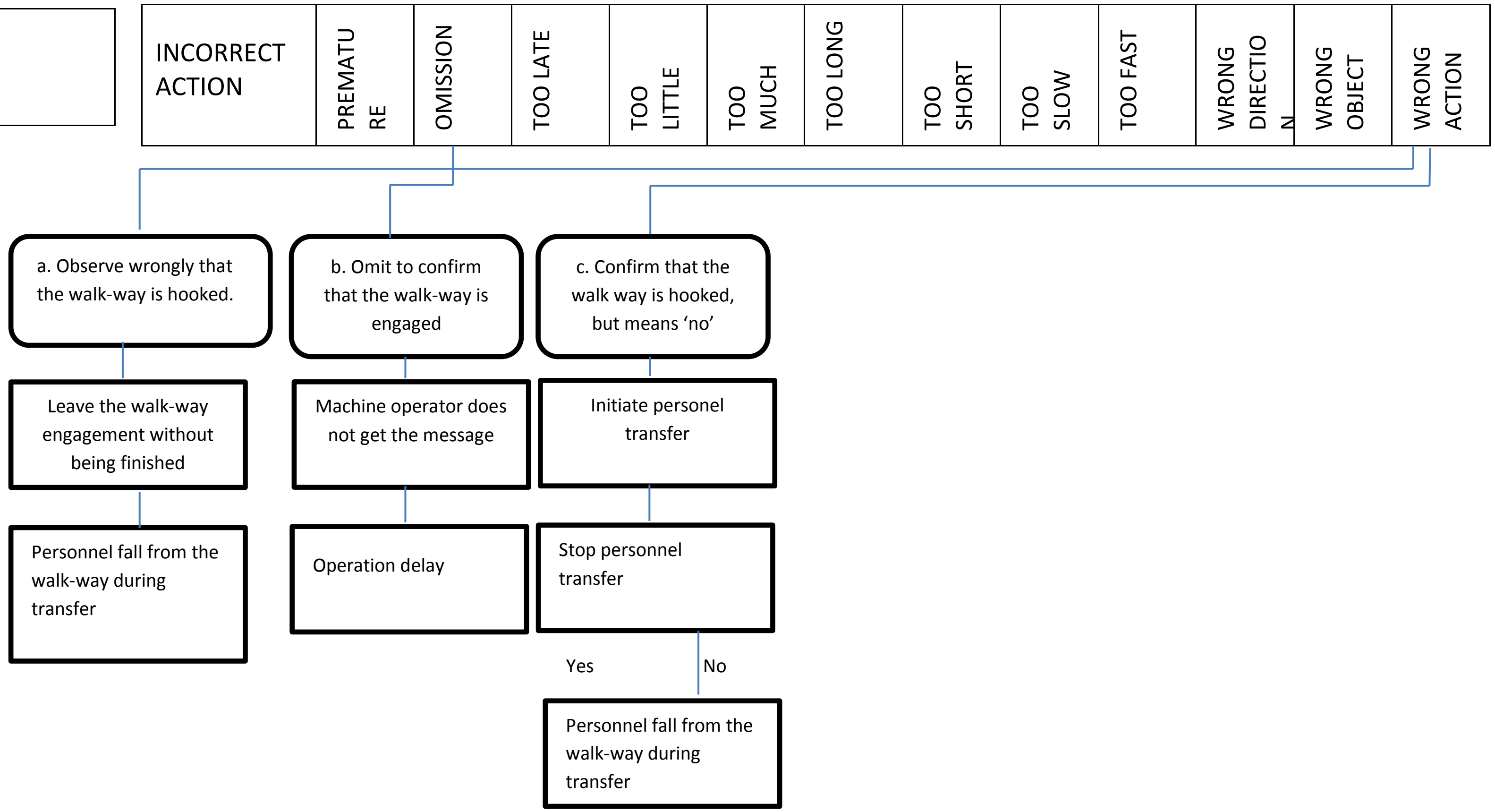
Ref: 4	**Action** Team leader observes if the walk-way is engaged	**Cue** Tell the machine operator (Ampelmann)	**Feedback** Check that machine operator receives the message	**Comments**

ASSUMPTIONS

LATENT FAILURE STATES

CONCLUTIONS

COMMENTS



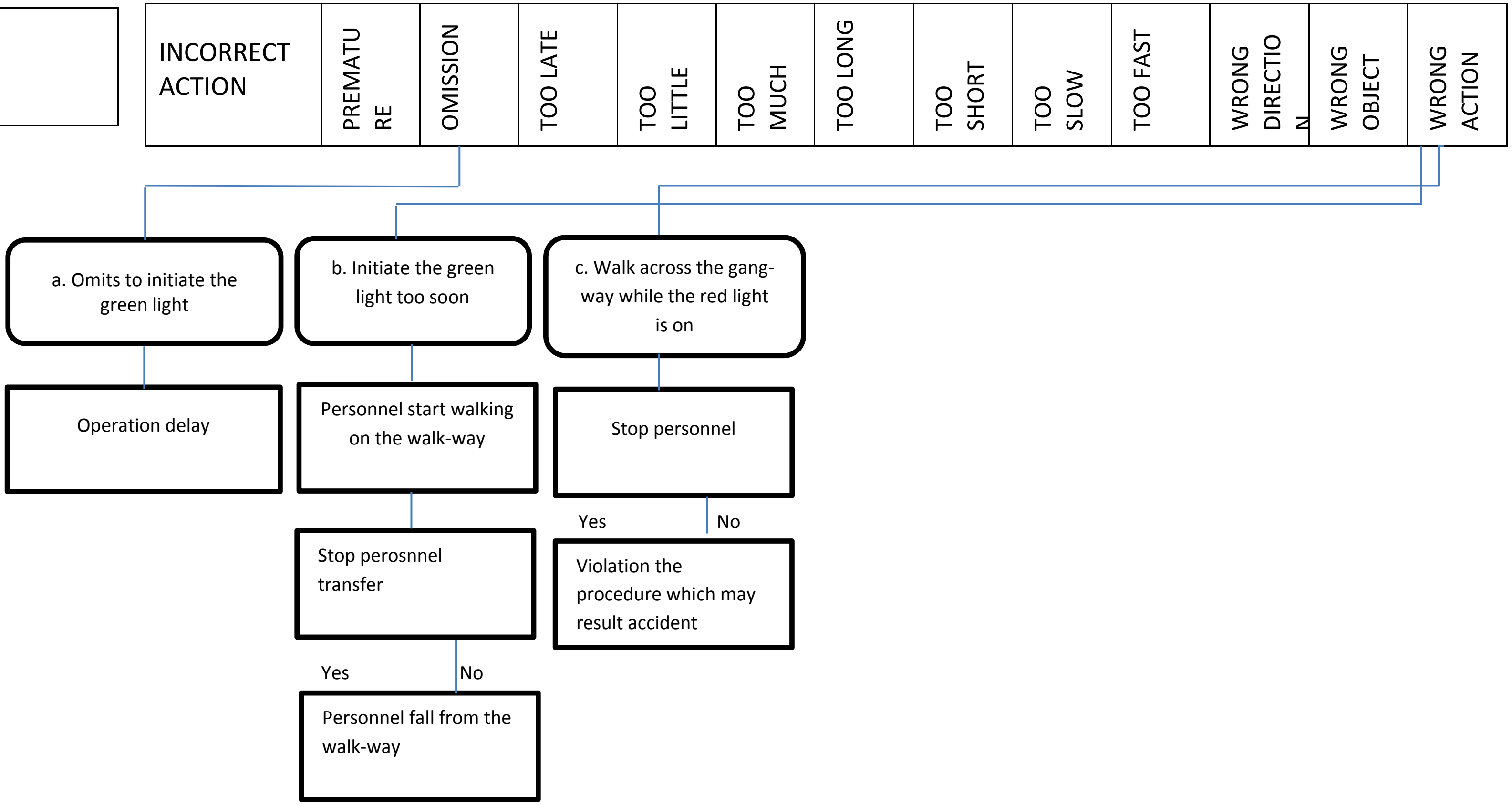
Ref: 5	**Action** Start personnel transfer	**Cue** Initiate the green light for personnel transfer	**Feedback** Observe that the green light is on	**Command**

ASSUMPTIONS

LATENT FAILURE STATES

CONCLUTIONS

COMMENTS



Qualitative screening

No	Action	Error	ID	Comments
1	The vessel operator approaches the wind turbine	Move the vessel too fast	MVF	The vessel operator approaches the wind turbine not identifying the correct moving speed. Critical if this happens.
		Position the vessel in the wrong angle	PVWA	Critical if the wind or the current direction is strong
2	The vessel operator informs that the vessel is ready	Deliver message before the vessel is actually ready	DMBVR	
3	Machine operator launches the walk-way after he was informed that the vessel is in position.	Launch the walk-way before the vessel is ready	LWBVR	
		Omit to stop the Amplemann operator	OTSAP	
		Engage the walk-way in the wrong order (Not hooked)	EWWO	Critical if the walk-way is not hooked
4	Team leader observes if the walk-way is engaged	Observe wrongly that the walk-way is hooked	OWWH	Critical if this happens.
		Omit to confirm that the walk-way is engaged	OCWE	This can cause only operation delay
		Say that the walk way is hooked but means 'No'	SWHBMN	
5	Start personnel transfer	Omits to initiate the green light	OIGL	Not critical, but the operation will be just delayed.
		Initiate the green light too soon	IGLTS	
		Walk across the gang-way while the red light is on	WAGWRL	

Appendix 2

1. The vessel operator position the vessel in the wrong angle against current or wind direction

Basic event name	Approach in the wrong angle	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It's assumed that adequate time is available
Stress/Stressors	High	2	It is assumed that stress will be higher than normal.
Complexity	Nominal	1	It is assumed necessary information available (e.g. Wind, wave directions)
Experience/Training	Nominal	1	It is assumed that the operator is expereinced. (e.g. More than 6 months)
Procedures	Available, but poor	5	The industry is new, so available procedure is poor.
Ergonomics/HMI	Nominal	1	The operator is provided with all the necessary equipments on the vessel.
Fitness for Duty	Nominal	1	The vessel operator is assumed to be fit.
Work Processes	Nominal	1	It is assumed to be norminal.

Dependency factors

Crew	
Time	
Location	
Cues	
Dependency	zero

Summary

Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,03

Basic event name	Too late to detect wrong angle	Task type	Diagnosis - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It's assumed that adequate time is available
Stress/Stressors	Nominal	1	It is assumed that stress will be normal.
Complexity	Obvious diagnosis	0,1	It is assumed necessary information available (e.g. Wind, wave directions)
Experience/Training	High	0,5	It is assumed that the operator is highly expereinced.
Procedures	Available, but poor	5	The industry is new, so available procedure is poor.
Ergonomics/HMI	Good	0,5	It is assumed to be nominal.
Fitness for Duty	Nominal	1	The operator is assumed to be fit.
Work Processes	Nominal	1	It is assumed to be norminal.

Dependency factors	
Crew	Same
Time	Not close in time
Location	Same
Cues	Additional
Dependency	moderate

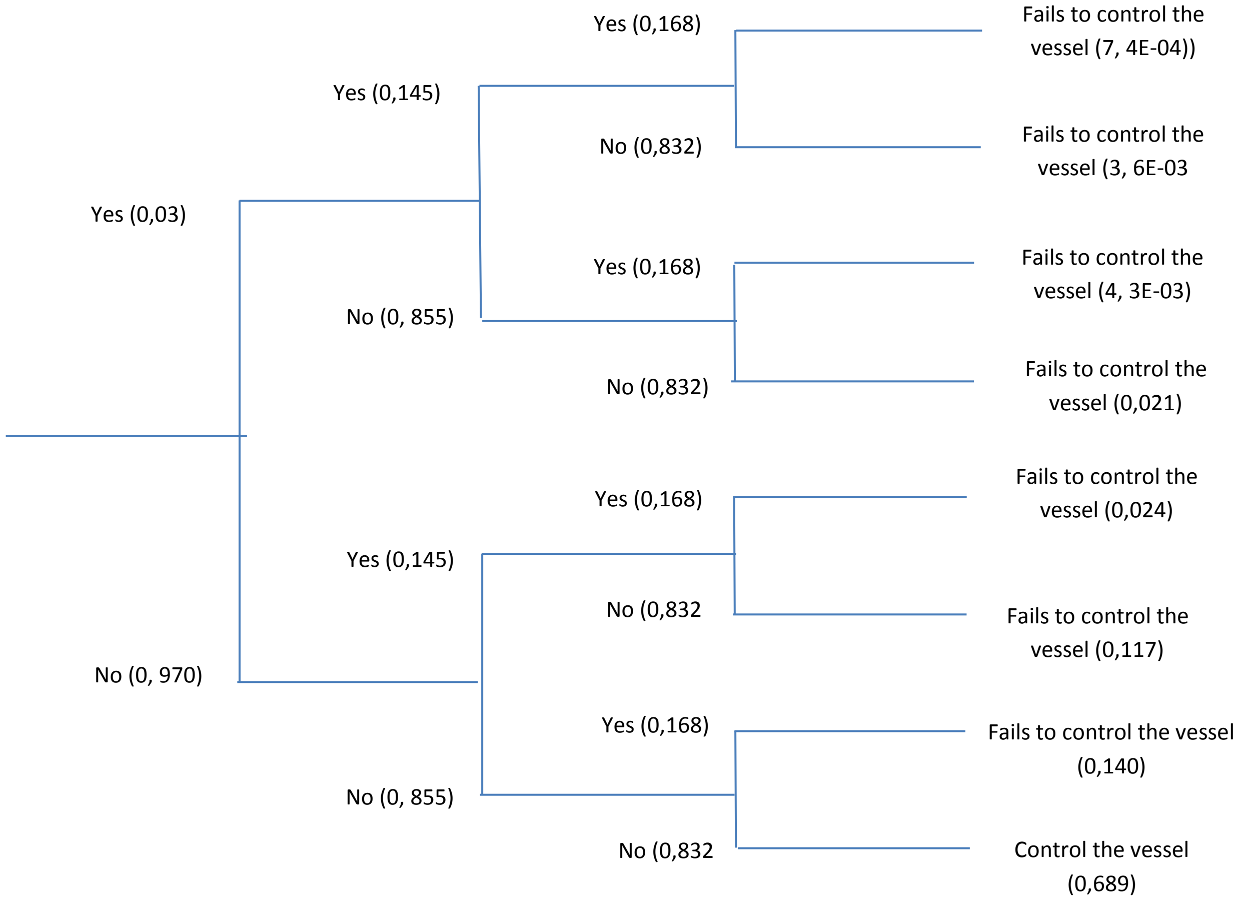
Summary	
Nominal HEP	0,02
PSF cor. fac.	0,125
HEP w/od	0,0025
HEP w/d	0,145

Basic event name	Fails to control the vessel	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that the time is available.
Stress/Stressors	Nominal	1	It is assumed that stress will be nominal.
Complexity	Moderately complex	2	It is assumed necessary information available (e.g. Wind, wave directions)
Experience/Training	Nominal	1	It is assumed that the operator is expereinced. (e.g. More than 6 months
Procedures	Available, but poor	5	The industry is new, so available procedure is poor.
Ergonomics/HMI	Nominal	1	It is assumed to be nominal.
Fitness for Duty	Nominal	1	The operator is assumed to be fit.
Work Processes	Nominal	1	It is assumed to be norminal.

Dependency factors	
Crew	Same
Time	Not close in time
Location	Same
Cues	Additional
Dependency	moderate

Summary	
Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,1685714

Wrong angle against current and wind	Too late to detect wrong angle	Fails to control the vessel	End result	Probability



2. The vessel operator delivers message to machine operator before the vessel is ready

Basic event name	Deliver message b4 vessel ready	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that the vessel operator has adequate (norminal)time.
Stress/Stressors	High	2	It is assumed that the stress level is high due to wave, wind, etc.
Complexity	Nominal	1	it is assumed to be nominal in this case.
Experience/Training	Nominal	1	The vessel operator is expected to have more than 6 months experience.
Procedures	Available, but poor	5	Expected that procedure is available but poor as the industry is new.
Ergonomics/HMI	Good	0,5	Assumed tasks are controlled by using the equipments onbord.
Fitness for Duty	Nominal	1	The vessel operator is expected to be fit.
Work Processes	Nominal	1	The work process is planned and specific.

Dependency factors

Crew	
Time	
Location	
Cues	
Dependency	zero

Summary

Nominal HEP	0,003
PSF cor. fac.	5
HEP w/od	0,015
HEP w/d	0,015

Basic event name	Launch walk-way b4 vessel ready	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that the vessel operator has adequate (norminal)time.
Stress/Stressors	High	2	It is assumed that the stress level is high due to wave, wind, etc.
Complexity	Nominal	1	it is assumed to be nominal in this case.
Experience/Training	Nominal	1	it is assumed to be nominal in this case. (This is Amplemann operator)
Procedures	Available, but poor	5	Expected that procedure is available but poor as the industry is new.
Ergonomics/HMI	Nominal	1	It si assumed to be norminal.
Fitness for Duty	Nominal	1	It is expected that the amplemann operator is assumed to be fit.
Work Processes	Nominal	1	The work process is planned and specific.

Dependency factors	
Crew	Different
Time	Close in time
Location	Same
Cues	No additional
Dependency	moderate

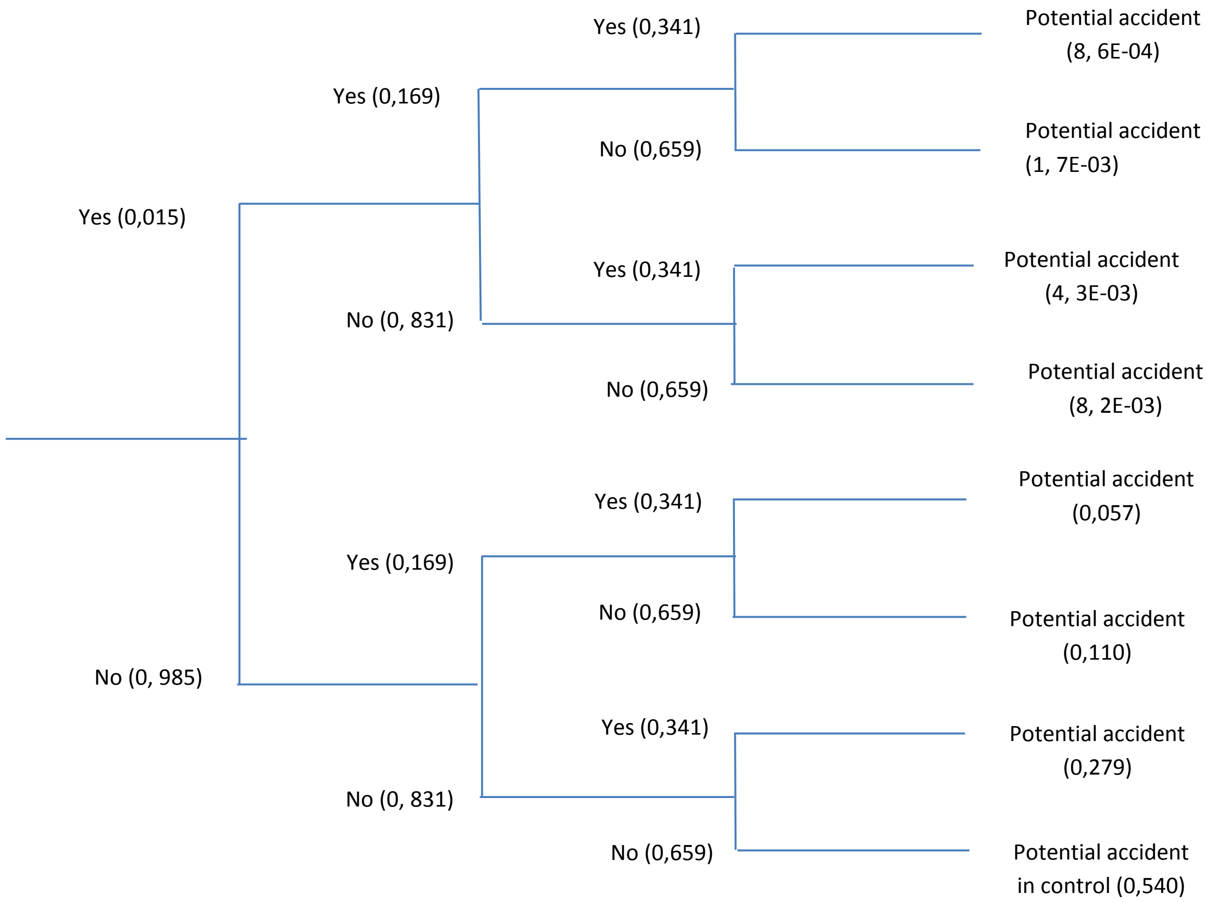
Summary	
Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,1685714

Basic event name	Fails to interrupt the Am. Operator	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Time available is approx. the time	10	It is expected that only a minute or less is availbe in this case.
Stress/Stressors	High	2	It is assumed that the stress level is high due to wave, wind, etc.
Complexity	Nominal	1	it is assumed to be nominal in this case.
Experience/Training	Insufficient Information	1	
Procedures	Available, but poor	5	Expected that procedure is available but poor as the industry is new.
Ergonomics/HMI	Insufficient Information	1	
Fitness for Duty	Insufficient Information	1	
Work Processes	Nominal	1	The work process is planned and it is assumed to be nominal.

Dependency factors	
Crew	Different
Time	Close in time
Location	Same
Cues	No additional
Dependency	moderate

Summary	
Nominal HEP	0,003
PSF cor. fac.	100
HEP w/od	0,231303
HEP w/d	0,3411169

Deliver message before the vessel is ready	Launch the walk-way before the vessel is ready	Fails to interrupt the Amplemann operator	End result	Probability



3. The machine operator launches the walk-way before the vessel is properly being positioned

Basic event name	Launch walk-way b4 vessel ready	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that the operator had adequate time.
Stress/Stressors	High	2	It is assumed that stress is higher than normal.
Complexity	Nominal	1	It is assumed that the complexity is nominal.
Experience/Training	Nominal	1	It is assumed that the operator has more than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Nominal	1	It is ssumed to be nominal in this case.
Fitness for Duty	Nominal	1	The amplemann operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Nominal	1	The access procedure is available, but doesnot play inportant role in this case.

Dependency factors

Crew	
Time	
Location	
Cues	
Dependency	zero

Summary

Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,03

Basic event name	Fails to detect wrg sequence oprat.	Task type	Diagnosis - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that time is adequtely available.
Stress/Stressors	Nominal	1	Stress is expected to be higher than normal.
Complexity	Nominal	1	It is assumed to be norminal.
Experience/Training	Nominal	1	It is assumed that the operator has less than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Good	0,5	It is assumed that the ship is designed especially for access and egress.
Fitness for Duty	Nominal	1	Everyone involved is expected to be trained and fit.
Work Processes	Good	0,8	The access procedure is available, but doesnot play inportant role in this case.

Dependency factors	
Crew	Different
Time	Close in time
Location	Same
Cues	Additional
Dependency	moderate

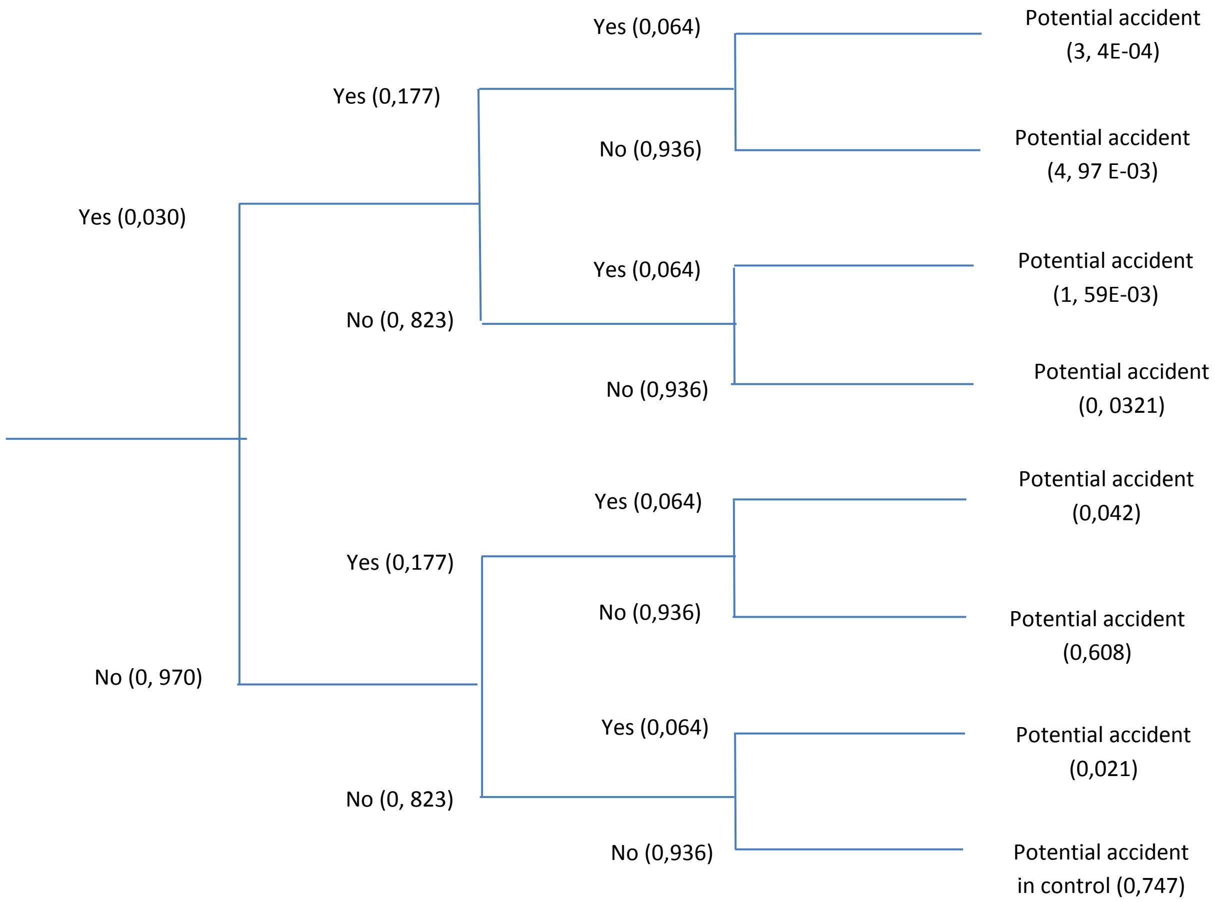
Summary	
Nominal HEP	0,02
PSF cor. fac.	2
HEP w/od	0,04
HEP w/d	0,1771429

Basic event name	Fails to interrupt the Am. Operator	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that time is adequtely available.
Stress/Stressors	High	2	It is assumed that the stress level is high due to wave, wind, etc.
Complexity	Nominal	1	it is assumed to be nominal in this case.
Experience/Training	Nominal	1	It is expected to be nominal.
Procedures	Available, but poor	5	Expected that procedure is available but poor as the industry is new.
Ergonomics/HMI	Good	0,5	It is assumed that the ship is designed especially for access and egress.
Fitness for Duty	Nominal	1	It is assumed to be nominal in this case.
Work Processes	Nominal	1	The work process is planned and it is assumed to be nominal.

Dependency factors	
Crew	Different
Time	Not close in time
Location	Same
Cues	Additional
Dependency	low

Summary	
Nominal HEP	0,003
PSF cor. fac.	5
HEP w/od	0,015
HEP w/d	0,06425

Launch the walk-way before the vessel is ready	Fails to detect the wrong sequence operation	Fails to interrupt the Amplemann operator	End result	Probability



4. The machine operator has launches the walk-way too early and it is omitted to stop the wrong operation.

Basic event name	Omit to stop the ample mann operat	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It's assumed that adequate time is available
Stress/Stressors	High	2	It is assumed that stress will be higher than normal.
Complexity	Insufficient Information	1	
Experience/Training	Insufficient Information	1	It is assumed that experience does not play any role in this case
Procedures	Available, but poor	5	The industry is new, so available procedure is poor.
Ergonomics/HMI	Insufficient Information	1	
Fitness for Duty	Insufficient Information	1	
Work Processes	Nominal	1	The access procedure is available, but does not play important role.

Dependency factors

Crew	
Time	
Location	
Cues	
Dependency	zero

Summary

Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,03

Basic event name	Omit to stop the Apm. Operator	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Barely adequate time (approx. 2/:	1	it is expected that only a few minutes are available.
Stress/Stressors	High	2	It is assumed that stress will be higher than normal.
Complexity	Insufficient Information	1	
Experience/Training	Insufficient Information	1	It is assumed that experience does not play any role in this case
Procedures	Available, but poor	5	The industry is new, so available procedure is poor.
Ergonomics/HMI	Insufficient Information	1	
Fitness for Duty	Insufficient Information	1	
Work Processes	Nominal	1	The access procedure is available, but does not play inportant role.

Dependency factors	
Crew	Different
Time	Close in time
Location	Same
Cues	No additional
Dependency	moderate

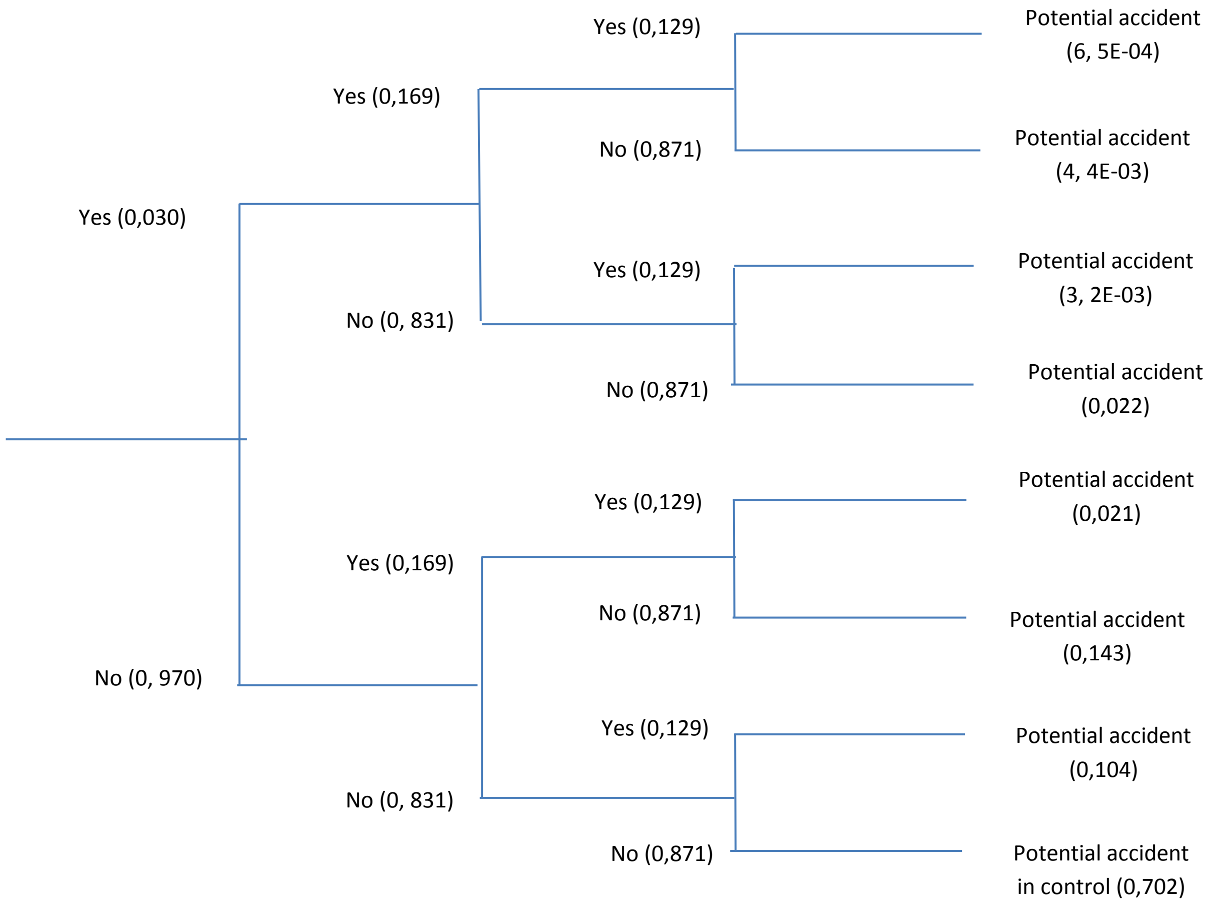
Summary	
Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,1685714

Basic event name	Fails to cancel walk-wy engagement	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is expected that time is barely available
Stress/Stressors	High	2	It is assumed that stress is highter than nomal in this case.
Complexity	Insufficient Information	1	
Experience/Training	Low	3	The industry is new so it is expeced that personnel are inexperienced.
Procedures	Available, but poor	5	The industry is new, so available procedure is poor.
Ergonomics/HMI	Insufficient Information	1	
Fitness for Duty	Nominal	1	It is assumed that people involves this operation are fit.
Work Processes	Nominal	1	It is expected that the work process is available.

Dependency factors	
Crew	Different
Time	Not close in time
Location	Different
Cues	Additional
Dependency	low

Summary	
Nominal HEP	0,003
PSF cor. fac.	30
HEP w/od	0,08279669
HEP w/d	0,1286569

Omit to stop the Amplemann operator	Fails to stop the walk-way from being hooked	Fails to cancel the walk-way engagement	End result	Probability



5. The machine operator engages the walk-way in the wrong order

Basic event name	Fails to properly engage walk-way	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that there is adequate time.
Stress/Stressors	High	2	It is assumed that stress is higher than normal due to wind, wave, etc.
Complexity	Nominal	1	It is assumed that the complexity is nominal.
Experience/Training	Nominal	1	It is assumed that the operator has more than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Nominal	1	It is assumed to be norminal in this case.
Fitness for Duty	Nominal	1	The Amp. Operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Nominal	1	The access procedure assumed to be available.

Dependency factors

Crew	
Time	
Location	
Cues	
Dependency	zero

Summary

Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,03

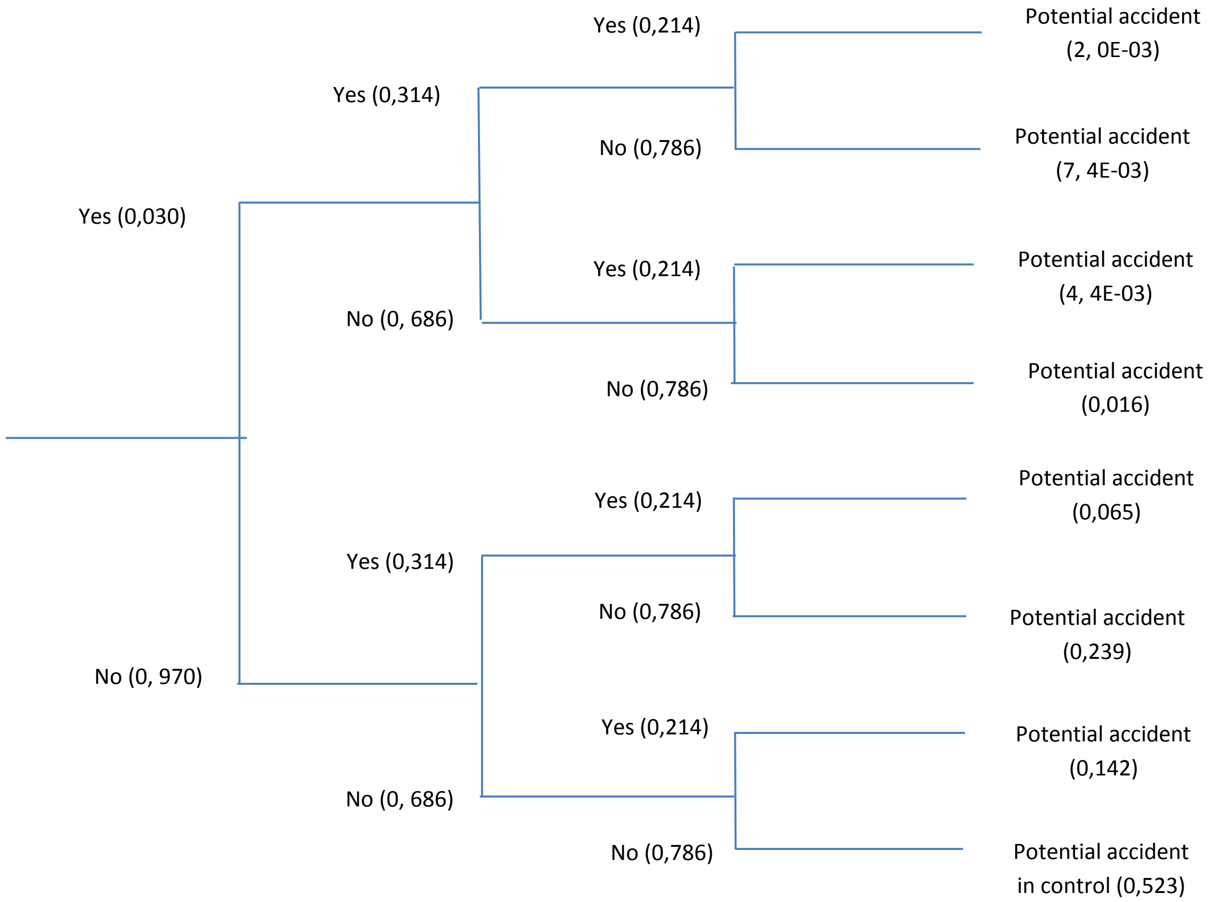
Basic event name	Fails to identify or wrong engagem.	Task type	Diagnosis - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that there is adequate time.
Stress/Stressors	High	2	It is assumed that stress is higher than normal due to wind, wave, etc.
Complexity	Nominal	1	It is assumed that the complexity is nominal.
Experience/Training	Nominal	1	It is assumed that the operator has more than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Insufficient Information	1	
Fitness for Duty	Nominal	1	It is assumed to be nominal
Work Processes	Nominal	1	The procedure is available and it is assumed to be nominal.

Dependency factors		Summary	
Crew	Different	Nominal HEP	0,02
Time	Close in time	PSF cor. fac.	10
Location	Same	HEP w/od	0,2
Cues	Additional	HEP w/d	0,3142857
Dependency	moderate		

Basic event name	Fails to stop personnel transfer.	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that there is adequate time.
Stress/Stressors	High	2	It is assumed that stress is higher than normal due to wind, wave, etc.
Complexity	Nominal	1	It is assumed that the complexity is nominal.
Experience/Training	Low	3	It is assumed that the operator has less than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Insufficient Information	1	It is assumed that ergonomics does not play important role.
Fitness for Duty	Nominal	1	The Amp. Operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Nominal	1	The procedure is available and it is assumed to be nominal.

Dependency factors		Summary	
Crew	Different	Nominal HEP	0,003
Time	Close in time	PSF cor. fac.	30
Location	Same	HEP w/od	0,08279669
Cues	Additional	HEP w/d	0,2138257
Dependency	moderate		

Engage the walk-way in the wrong order	Fails to identify the wrong engagement (wrong observation)	Fails to stop personnel transfer with wrong engagement	End result	Probability



6. The team leader wrongly observes that the walk-way is engaged, but it is not hooked properly.

Basic event name	Observe wrongly_walk-way hooked	Task type	Diagnosis - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It's assumed that adequate time is available
Stress/Stressors	High	2	It is assumed that stress will be higher than normal.
Complexity	Obvious diagnosis	0,1	It is assumed there is no complexity just to identify if it is hooked.
Experience/Training	Nominal	1	It is expected to be norminal in this case.
Procedures	Available, but poor	5	The industry is new, so available procedure is poor.
Ergonomics/HMI	Insufficient Information	1	
Fitness for Duty	Nominal	1	Personnel observing this is expected to be fit.
Work Processes	Nominal	1	The access procedure is available, but doesnot play inportant role in this case.

Dependency factors

Crew	
Time	
Location	
Cues	
Dependency	zero

Summary

Nominal HEP	0,02
PSF cor. fac.	1
HEP w/od	0,02
HEP w/d	0,02

Basic event name	Fails to identify wrong obersv.	Task type	Diagnosis - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that there is adequate time.
Stress/Stressors	High	2	It is assumed that stress is higher than normal due to wind, wave, etc.
Complexity	Nominal	1	It is assumed that the complexity is nominal.
Experience/Training	Nominal	1	It is assumed that the operator has more than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Insufficient Information	1	
Fitness for Duty	Nominal	1	It is assumed to be nominal.
Work Processes	Nominal	1	The procedure is available and it is assumed to be nominal.

Dependency factors	
Crew	Different
Time	Close in time
Location	Same
Cues	Additional
Dependency	moderate

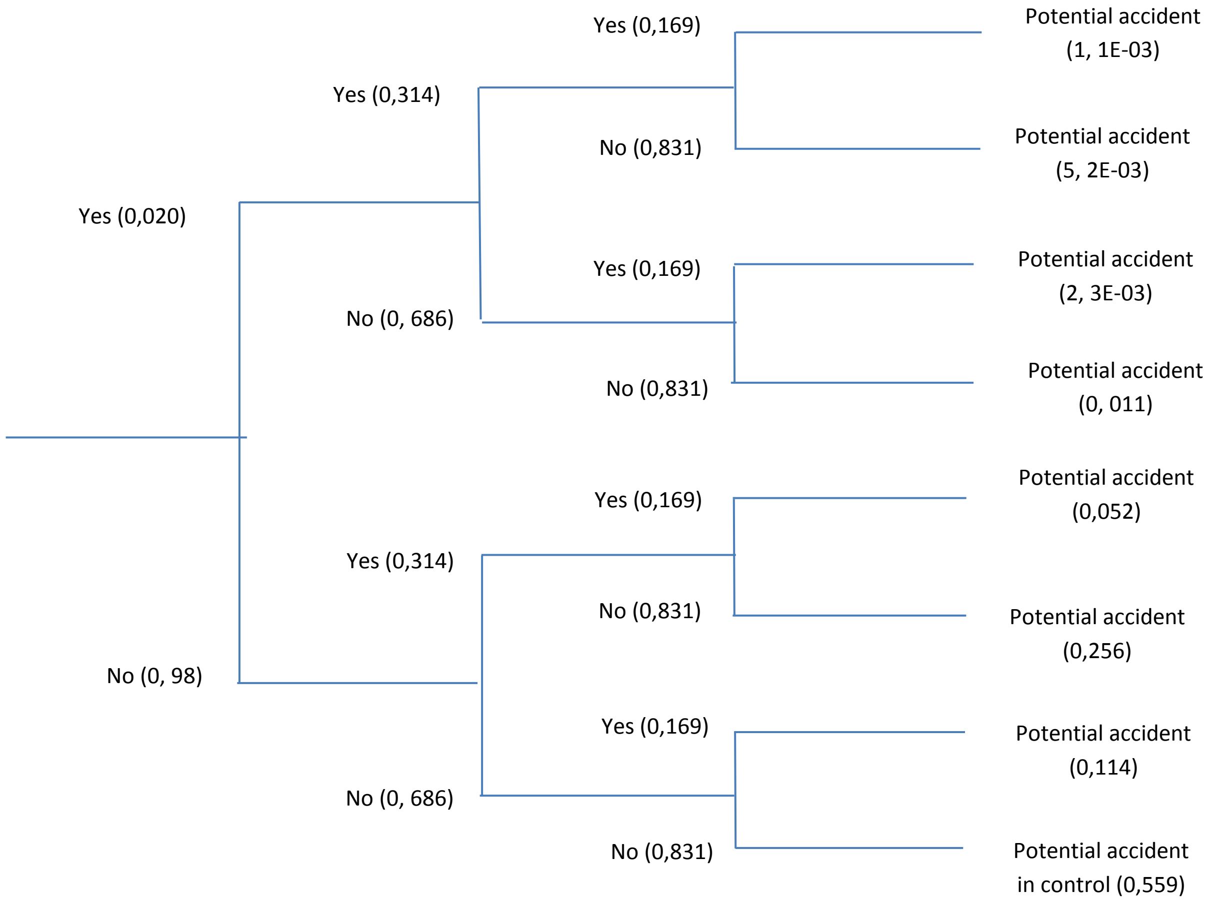
Summary	
Nominal HEP	0,02
PSF cor. fac.	10
HEP w/od	0,2
HEP w/d	0,3142857

Basic event name	Fails to cancel personel transfer.	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that there is adequate time.
Stress/Stressors	High	2	It is assumed that stress is higher than normal due to wind, wave, etc.
Complexity	Nominal	1	It is assumed that the complexity is nominal.
Experience/Training	Nominal	1	It is assumed that the operator has more than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Insufficient Information	1	It is assumed that ergonomics does not play important role.
Fitness for Duty	Nominal	1	The Amp. Operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Nominal	1	The procedure is available and it is assumed to be nominal.

Dependency factors	
Crew	Different
Time	Close in time
Location	Same
Cues	Additional
Dependency	moderate

Summary	
Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,1685714

Observe wrongly that the walk-way is hooked	Fails to identify the wrong engagement (wrong observation)	Fails to cancel personnel transfer with wrong engagement	End result	Probability



7. The team leader says that the walk-way is hooked, he means 'No'.

Basic event name	Say walk-way hooked_means 'No'	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It's assumed that adequate time is available
Stress/Stressors	High	2	It is assumed that stress will be higher than normal.
Complexity	Insufficient Information	1	
Experience/Training	Nominal	1	It is expected to be nominal in this case.
Procedures	Available, but poor	5	The industry is new, so available procedure is poor.
Ergonomics/HMI	Insufficient Information	1	
Fitness for Duty	Nominal	1	Personnel is expected to be fit.
Work Processes	Insufficient Information	1	The access procedure is available, but doesnot play inportant role in this case.

Dependency factors

Crew	
Time	
Location	
Cues	
Dependency	zero

Summary

Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,03

Basic event name	Fails to stop the machine perator	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is expected that there is availbe in this case.
Stress/Stressors	High	2	It is assumed that the stress level is high due to wave, wind, etc.
Complexity	Nominal	1	it is assumed to be nominal in this case.
Experience/Training	Nominal	1	It is expected to be nominal.
Procedures	Available, but poor	5	Expected that procedure is available but poor as the industry is new.
Ergonomics/HMI	Insufficient Information	1	
Fitness for Duty	Nominal	1	It is assumed to be nominal.
Work Processes	Nominal	1	The work process is planned and it is assumed to be nominal.

Dependency factors	
Crew	Different
Time	Close in time
Location	Same
Cues	Additional
Dependency	moderate

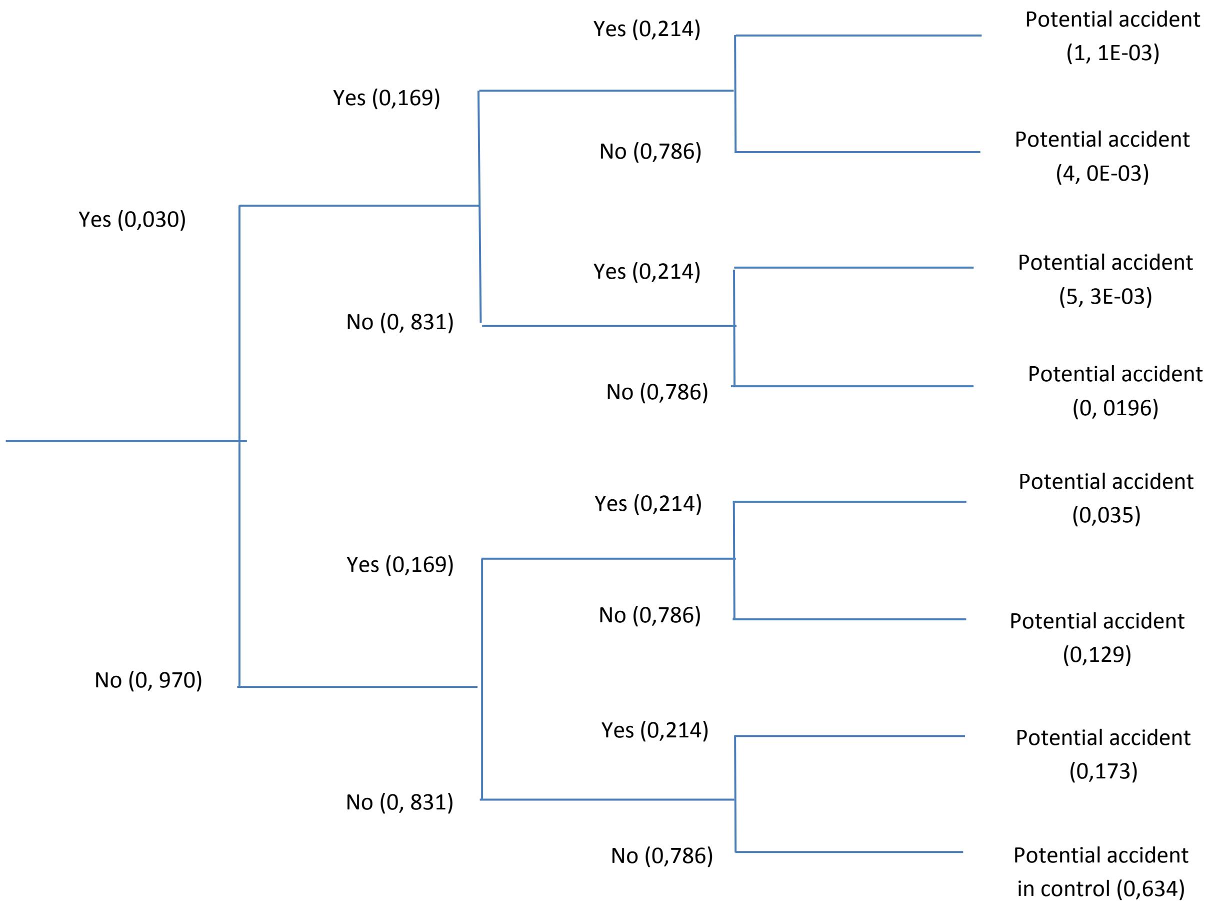
Summary	
Nominal HEP	0,003
PSF cor. fac.	10
HEP w/od	0,03
HEP w/d	0,1685714

Basic event name	Fails to cancel personnel transfer	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Barely adequate time (approx. 2/:	1	It is expected that only a minute or less is availbe in this case.
Stress/Stressors	High	2	It is assumed that the stress level is high due to wave, wind, etc.
Complexity	Nominal	1	it is assumed to be nominal in this case.
Experience/Training	Low	3	Low experience is assumed in this case.
Procedures	Available, but poor	5	Expected that procedure is available but poor as the industry is new.
Ergonomics/HMI	Nominal	1	It is assumed to be nominal.
Fitness for Duty	Nominal	1	It is assumed to be nominal.
Work Processes	Nominal	1	The work process is planned and it is assumed to be nominal.

Dependency factors	
Crew	Different
Time	Close in time
Location	Same
Cues	No additional
Dependency	moderate

Summary	
Nominal HEP	0,003
PSF cor. fac.	30
HEP w/od	0,08279669
HEP w/d	0,2138257

Say that the walk-way is hooked but means 'No'	Fails to stop the Amplemann operator from initiating personnel transfer (Green light)	Fails to cancel personnel transfer with wrong engagement	End result	Probability



8. The machine operator initiates the green light too soon.

Basic event name	Initiate green light too soon	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that the operator had adequate time.
Stress/Stressors	High	2	It is assumed that stress is higher than normal.
Complexity	Nominal	1	It is assumed that the complexity is nominal.
Experience/Training	Low	3	It is assumed that the operator has less than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Nominal	1	It is assumed to be nominal.
Fitness for Duty	Nominal	1	The machine operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Nominal	1	The access procedure is assume to be available.

Dependency factors

Crew	
Time	
Location	
Cues	
Dependency	zero

Summary

Nominal HEP	0,003
PSF cor. fac.	30
HEP w/od	0,08279669
HEP w/d	8,279669E-02

Basic event name	Fails to cancel the operation	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that the operator had adequate time.
Stress/Stressors	Nominal	1	It is assumed that stress is higher than normal.
Complexity	Insufficient Information	1	It is assumed that there is no complexity in this case.
Experience/Training	Nominal	1	It is assumed that the operator has less than 6 months experiences.
Procedures	Available, but poor	5	It is assumed that the industry is new. Procedures available but poor.
Ergonomics/HMI	Good	0,5	It is assumed that the walk-way machine is easy to use.
Fitness for Duty	Nominal	1	The amplemann operator is expected to be fit (No sickness, no drug use, etc.)
Work Processes	Nominal	1	The access procedure is available, but doesnot play inportant role in this case.

Dependency factors	
Crew	Same
Time	Not close in time
Location	Same
Cues	Additional
Dependency	moderate

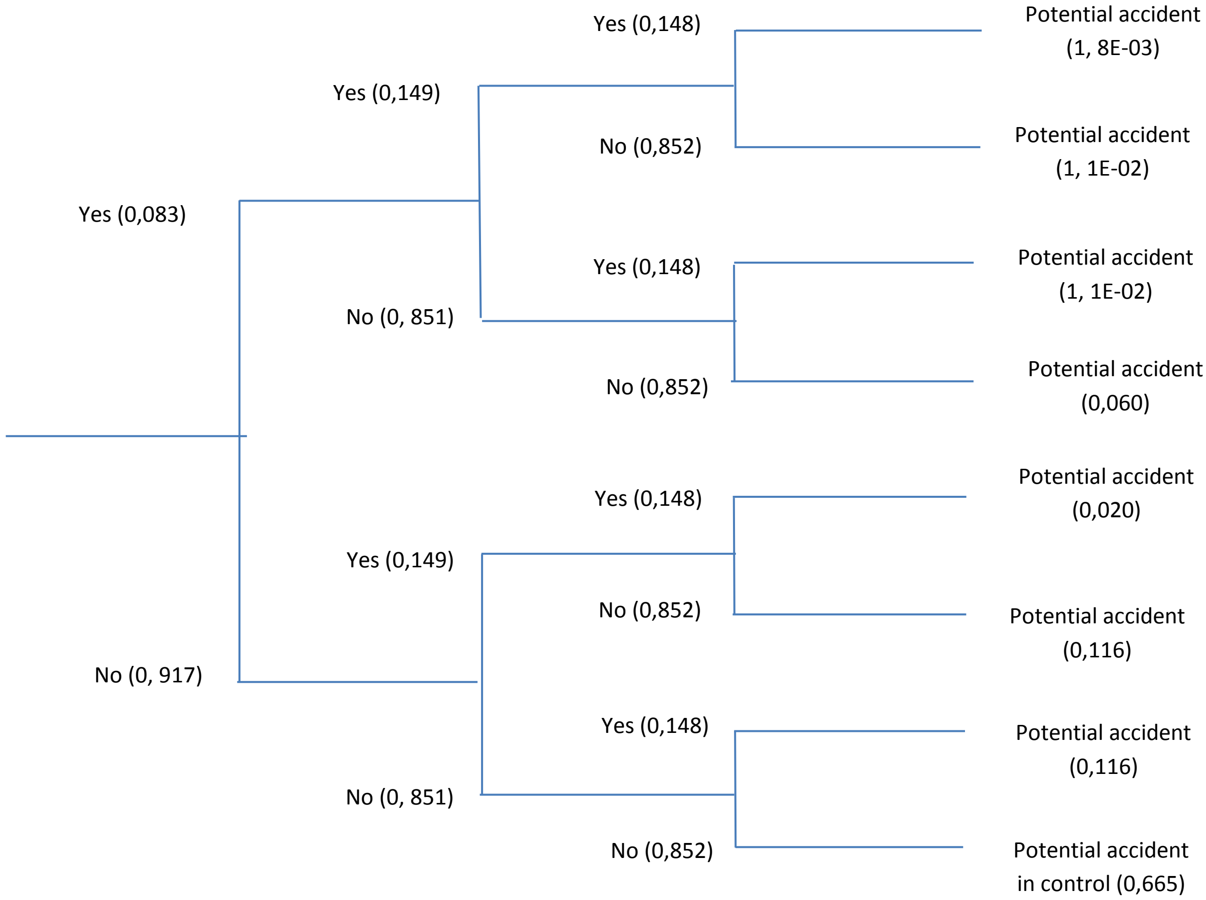
Summary	
Nominal HEP	0,003
PSF cor. fac.	2,5
HEP w/od	0,0075
HEP w/d	0,1492857

Basic event name	Fails to cancel personnel transfer	Task type	Action - Outdoor normal weather
PSFs	**PSF Levels**	**Multiplier**	**Reasons for PSF level selection**
Available Time	Nominal time	1	It is assumed that the operator had adequate time.
Stress/Stressors	High	2	It is assumed that stress is higher than normal.
Complexity	Nominal	1	It is assumed to be norminal in this case.
Experience/Training	Insufficient Information	1	
Procedures	Insufficient Information	1	
Ergonomics/HMI	Insufficient Information	1	
Fitness for Duty	Nominal	1	It is assumed that personnel involving to do this task is fit.
Work Processes	Nominal	1	It is assumed to be norminal in this case.

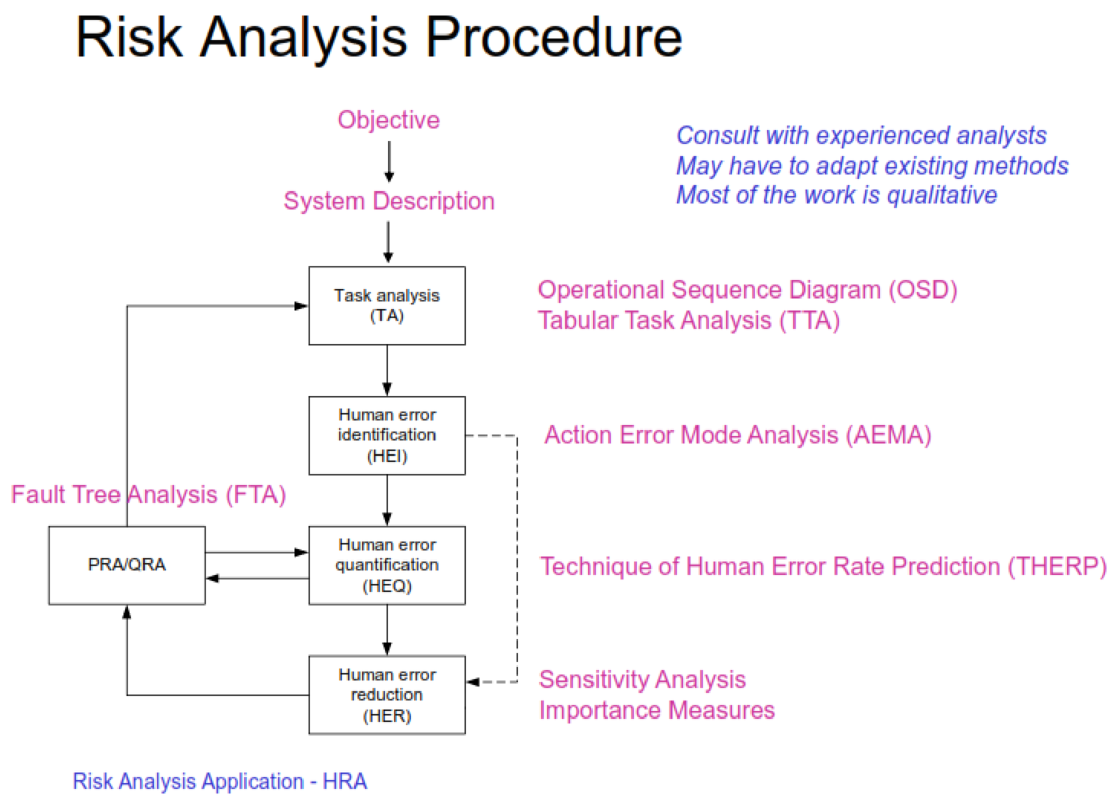
Dependency factors	
Crew	Same
Time	Not close in time
Location	Same
Cues	Additional
Dependency	moderate

Summary	
Nominal HEP	0,003
PSF cor. fac.	2
HEP w/od	0,006
HEP w/d	0,148

Initiate the green light too soon	Fails to cancel the operation with green light too early	Fails to cancel personnel transfer	End result	Probability

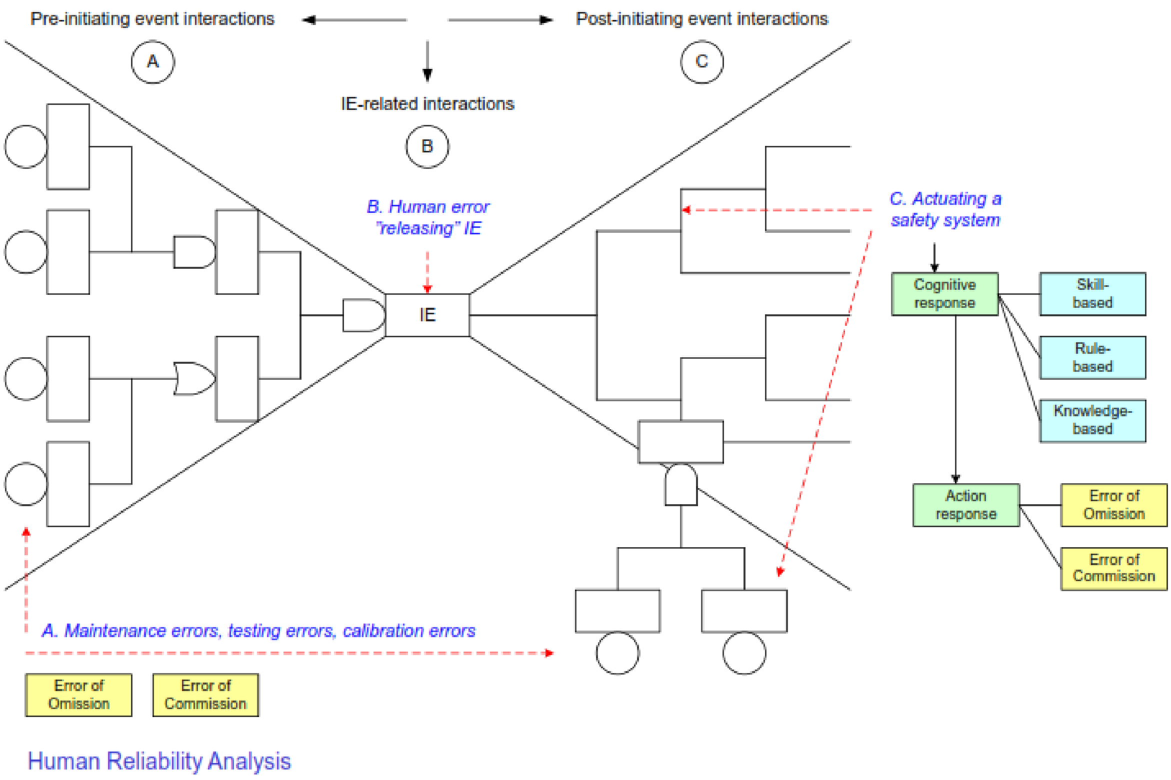


Appendix 3



Risk Analysis Procedure
Objective
System Description
Consult with experienced analysts
May have to adapt existing methods
Most of the work is qualitative
Task analysis (TA)
Operational Sequence Diagram (OSD)
Tabular Task Analysis (TTA)
Human error identification (HEI)
Action Error Mode Analysis (AEMA)
Fault Tree Analysis (FTA)
PRA/QRA
Human error quantification (HEQ)
Technique of Human Error Rate Prediction (THERP)
Human error reduction (HER)
Sensitivity Analysis
Importance Measures
Risk Analysis Application - HRA

Illustration of Inclusion of HRA in PRA



Appendix 4

Models developed for collision probability estimation (Joanne Ellis 2005)

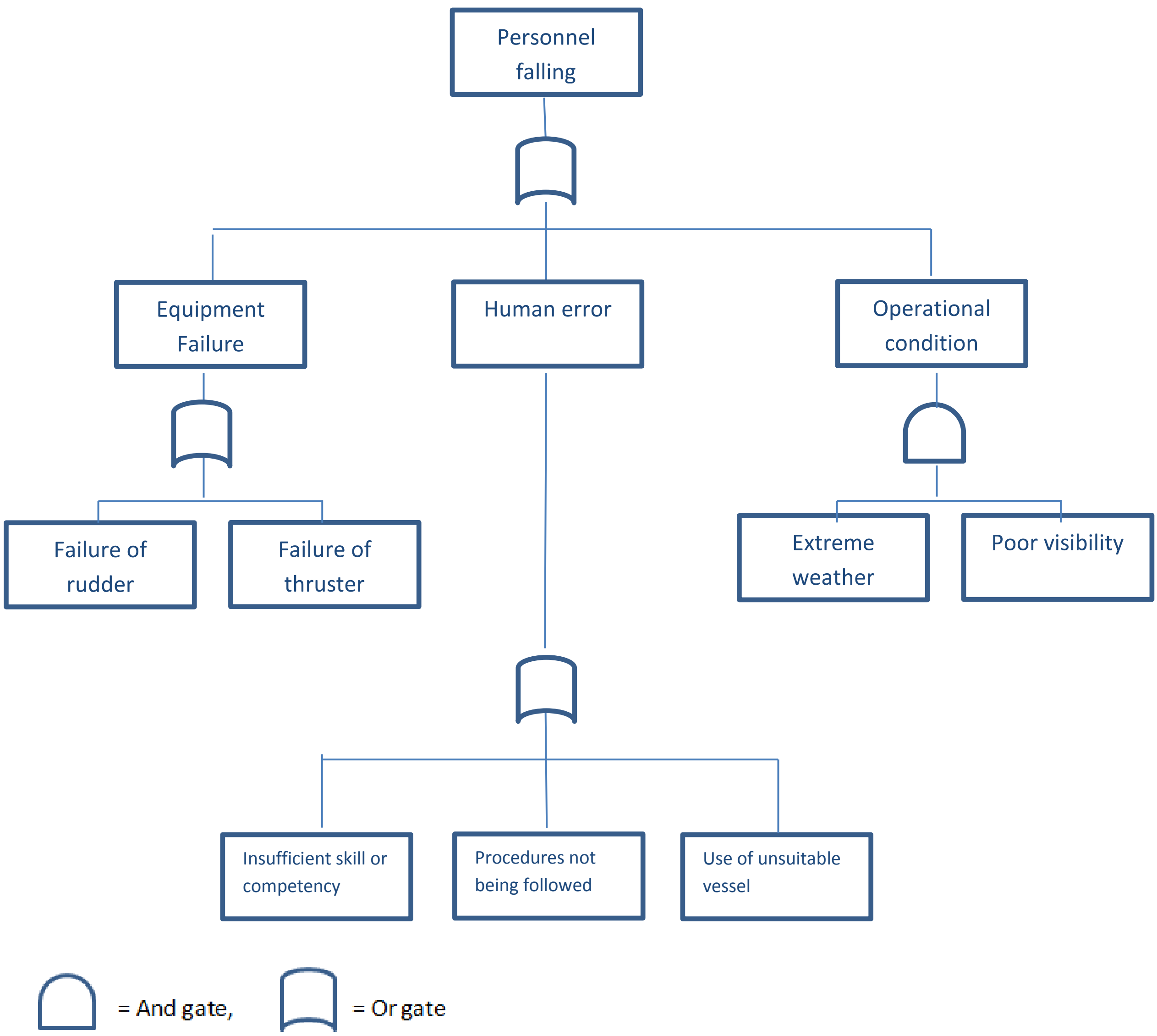
Model	Company/Organization	Selected References
COLLIDE	Safetec Nordic A	Haugen (1998) Spouge (1999) Safetec (2002)
SOCRA[1]/SAMSON[2]	MARIN (Maritime Research Institute Netherlands)	van der Tak and Glansdorp (Year unknown) van der Tak und Rudolph (2003) van der Tak (2005a) van der Tak (2005b) SAFESHIP (2005) SAFESHIP (2006) Kleissen (2006)
CRASH/MARCS[3]	DNV (Det Norske Veritas)	Spouge (1999) SAFESHIP (2005) Christensen (2007)
COLWT	GL (Germanischer Lloyd)	Germanischer Lloyd (2002) Neuhaus and Thrun (2003) Otto and Petersen (2003) Povel et al. (2004) Otto (2004) Povel and Petersen (2004) SAFESHIP (2005) SAFESHIP (2006) Povel (2006)
COLLRISK	Anatec UK Ltd	Anatec UK Limited (2002) SAFESHIP (2006)
DYMITRI	BMT (British Maritime Technology) Limited	Safety at Sea (2005)

[1] SOCRA (Ship Offshore platform Collision Risk Assessment) is a module in MANS (Management Analysis North Sea)
[2] SAMSON (Safety Assessment Models for Shipping and Offshore in the North Sea)
[3] CRASH (Computerized Risk Assessment of Shipping Hazards), MARCS (Marine Accident Risk Calculation System)

Appendix 5

Access and regress

There are different access methods to the wind turbine. These accesses are mainly categorized into 4: assess by helicopter, direct boat landing, crane hoist and boat landing with motion compensation. Maintenance requires approximately 4 to 6 visit per year for each wind turbine. When access and egress is required the challenge is not only operational condition such as unfavorable wind and wave condition, but other factors like human error and equipment failures should also be taken into account from a HSE point of view.



Fault tree analysis (FTA) of personnel falling from the wind turbine

As shown in Figure 8, the potential accident considered in this challenge is working personnel falling from the wind turbine when access is conducted by boat landing. This accident may occur during installation or when maintenance is required. If this happens during installation, there will be different actors getting involved in the accident cause: for example, working personnel, operator, contractor, supplier, etc. The working personnel can fall down from the turbine due to human error. The machine operator can make a mistake due to lack of training. The contractor may press the working personnel or machine operator due to the project timetable being fallen behind schedule. Other possible causes can be, for example, mechanical failure (hydraulic system failure or thruster failure) or sea state (strong wind or high wave).

Human error

Human error can be often a significant cause that plays the role and is considered to be the most contributing factor in a case of accident. The operator working at the sharp end is vulnerably exposed to risk and the operational contractor should consider that safe access cannot be achieved only by advanced technology and good operational condition, but it can also be limited by human factors. The human factors contributing the accident in this case could be often fatigue, bad commination, inadequate information etc. The operational contractor is responsible to give proper training and sufficient information to reduce the risk before the work is executed. Avoiding excessive work load should also be taken in to account.

Equipment failure

The main contributing factor to equipment failure is due to lack of maintenance. Proper maintenance to the equipment and vessel can reduce the risk. Using new advanced access equipment such as OAS can also reduce the risk.

Operational condition

This event includes bad operational condition due to extreme weather which may be due to unfavorable wave, wind or mist. Following rules and procedures, for example, should be adapted.

Appendix 6

METHOD	APPLICABILITY														
	Operating Mode		Hazard level		Process or Task Complexity		Number of Scenarios Found		Process Type		Experience with Process or Task		Details Available for Process		
	Continuous	Batch, Startup, Shutdown, online maintenance	Low	High	Low	High	Low	High	Flow	Mechanical, Electrical	Low	High	Low (i.e., conceptual design)	Medium (i.e., detailed design)	High (i.e., pre-startup or operating unit)
QUALITATIVE – Identify and evaluate hazards and judge risk by voting of multi-disciplinary team															
Checklist	X	X	X		X		X		X	X	X	X	X		
Preliminary Hazard Review	X	X		X		X	X		X	X	X		X		
What-If	X	X	X		X		X		X	X	X	X	X	X	X
What-If/Checklist	X	X	X		X		X		X	X	X	X	X	X	X
2 Guide Word		X		X	X			X	X	X		X			X
HAZOP (full set of guide words)	X	X		X		X		X	X		X	X		X	X
FMEA	X			X		X		X		X	X	X		X	X
QUANTITATIVE – Numerically estimate the risk to aid in judgment of a scenario that is already identified; typically not a team															
Fire/Explosion Index	X	X		X	X	X	NA	NA	X			X		X	X
Toxicity Index	X	X		X	X	X	NA	NA	X			X		X	X
LOPA	X	X		X	X	X	NA	NA	X	X		X		X	X
Fault Tree Analysis	X	X		X		X	NA	NA	X	X		X		X	X
Event Tree Analysis	X	X		X		X	NA	NA	X	X		X		X	X
Human Reliability Analysis		X		X		X	NA	NA	X	X	X	X		X	X

Copied from (Bridge, 2004)

Curriculum Vitae

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Education

2010-2012	Norges teknisk-naturvitenskaplige universitet	Master i RAMS (Aktiv)
2006 – 2010	Høgskolen i Telemark	Bachelor i Allmenn Bygg
2005 – 2006	Høgskolen i Telemark	Norsk språk og samfunnskunnskap for utenlandske studenter

Computer Skills

- Microsoft word
- Excel
- Power point

Experience

2005-2012 Tolk i tolketjenester i Norge (Deltid job)

Hobbies and Other Activities

- Swimming, Football, Karate