POLITECNICO DI TORINO

Department of Environment, Land and Infrastructure Engineering

Master of Science in Petroleum Engineering

Risk Analysis of a Continuous Circulation System – Heart of Drilling (HoD®) applied to drilling operations

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DECLARATION

I declare that this project is my own work. It is being submitted for the degree of Master of Science in Petroleum Engineering in Politecnico di Torino, Italy. It has not been submitted for any degree or examination in any other university.

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ABSTRACT

In the current drilling environment, the industry is facing greater pressure-related challenges while developing mature and unconventional fields, both on land and offshore. Additionally, there is greater focus on improving the feasibility of tight pore-pressure/fracture-gradient wells, safety, and increasing efficiency.

The challenges that are present while drilling these wells with these tight conditions, are solved by a technique called Managed Pressure Drilling (MPD), which is defined by the International Association of Drilling Contractors (IADC), as an adaptive process used to control the annular pressure profile throughout the wellbore.

Among the MPD techniques, it is found one that maintains the pressure at the bottom of the well constant, and in order to face this challenge, Drillmec S.p.A. has developed a Continuous Circulation System (CCS) that accomplishes this goal, named Heart of Drilling (HoD).

It is important to notice that while the MPD techniques allows the drilling operation to be done in challenging environments it also adds more equipment to the drilling rig, turning the operations to be more complex and potentially riskier.

This study describes the risk assessment performed for the system, starting from a risk identification, then an analysis and an evaluation The principal part of this study is focused on a qualitative examination of the continuous circulation device and its potential consequences, then, a quantitative analysis that provides the probability of failure of the equipment. The methodology followed provides a rational framework that allows to quantify the risk from tools utilised on the offshore field.

The results of the analysis revealed that the possible failure scenarios that might arise from the utilisation of the CCS are directly connected with electrical failures of the tool while running, or the possibility of a malfunction on the software that controls the equipment, rather than mechanical problems.

DEDICATION

A mis padres, por todo el apoyo y amor incondicional que me han brindado. No hay palabras o idiomas suficientes para expresarles lo mucho que los quiero y lo importantes que son en mi vida.

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To all the professors in Politecnico di Torino, that helped me develop and improve myself throughout the course of the *"Laurea Magistrale"*, thank you so much for your dedication.

To my friends and family in Mexico, though I know we are far, but in reality we are always close. Thank you a lot Sandy, Jovanni, MariOH, Vane, Chava, Ishibashi-san, Milton, Alex, Cindy, Grecia, Vicky…without your support I would have never reached this point.

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Introduction

The quest for new energy and hydrocarbon resources is in continuous growth. Accordingly, the need to reach these resources and develop them is increasing day after day. The main way of reaching hydrocarbon resources is by drilling a well. The well drilling process involves a combination of equipment, systems, and methodologies that are together will give the ability to drill the well safely and effectively.

But as the normal and conventional fields (i.e., easy resources) started to deplete from its hydrocarbons, the quest continuous for more resources but in more harsh and strict conditions. These tight conditions that had been considered in the past un-drillable and unreachable. Thus, the drilling process started to enter a new phase of unconventional drilling. Unconventional drilling involves the use of more methods and equipment to drill in a controllable and safe environment in these harsh conditions.

Drilling process is full of Hazards. Oil and gas industry proved that, with the correct way of operation and mitigation of these hazards the process will be effective and safe for all of Personal, Environment, Reputation, and Assets.

The addition of more equipment to the drilling rig makes the drilling process more complex and vulnerable to risks. This complexity had to be studied thoroughly and all risks has to be identified and safeguards have to be set before using the system.

HoD® Continuous Circulation System by DRILLMEC S.p.A is one of the systems which can be added to the drilling rig ensuring a steady state circulation of the drilling fluid inside the wellbore. Consequently, reduce the bottom hole pressure surges, giving to be able to drill wells that have a tight pressure window. The system is composed of different subsystems that are going to be distributed around the rig floor and inside the well.

This study is a Risk Assessment of "HoD® Continuous Circulation System", that aims to identify and mitigate all of the hazards accompanied with the deployment of HoD® in the drilling process. Moreover, a target of this study is to set a recommendation about the critical parts processes or parts of the system that will need special care when utilized. Thus, This Study Aims to provide a qualitative and quantitative understanding about the risks accompanied with the utilization of HoD®.

The Risk Assessment process is done in accordance with *Machine Directive 2006/42/EC,* and with the *ISO 31000:2009, Risk Management and Guidelines*. So that the Continuous Circulation System, HoD® would be in compliance with the European regulations of health and safety in working places and fields.

This study started with the definition of the risk assessment frame work in Chapter1. Then, a background about the drilling process, and the need for HoD® system utilization in Chapter 2. Then, in Chapter 3, HoD® system had been defined, proceeded with the application of the Risk Assessment defined framework on it.

The brief steps of the risk Assessment study can be concluded by the following:

1. System Definition , With all of its different functions, Sub-functions, and Operating phases
    a. Drilling,
    b. By-Pass Drilling,
    c. Drill Pipe Connection and
    d. New Stand Filling.

2. Verification and study of provided piping and instrumentation diagram (P&ID's)

3. Study of measuring instruments, alarms, design specifications, safety control devices and safeguards .
4. Perform a short and concise Hazard Identification of the process of drilling HAZID and HAZOP.
5. Perform a qualitative analysis, by means of Fault Tree Analysis (FTA).
6. Identification and listing of remedial measures.

The last chapter of the study is a conclusion about the findings, and a recommendation about further work that can be done in the future

1 - Risk Assessment Framework for a Continuous Circulation System – HoD ®

"Risk comes from not knowing what are you doing"

-Warren Buffet

Safety is the primary concern in drilling an oil or gas well. The protection of personnel and the environment surpasses all other well objectives, even when this means changing the original action plan, incurring unexpected costs or delaying operations.

Failure to make safety the top priority on a rig can result in accidents, incapacitating injuries, losses (assets and reputation, for example) and even deaths.

1.1 Intention of the Assessment

Two of the main objectives of the Machine Directive 2006/42/EC are, to ensure a high level of protection of users and third parties (exposed) against risk, and to ensure the safety by design.

The principal stakeholders that take part on the implementation of this directive are manufacturers of machinery, importers and companies that are responsible of placing a product on the European market.

Any product (machinery) that is intended to be put in the European market needs to comply with the requirements of this directive.

"*The manufacturer or his authorised representative should also ensure that a risk assessment is carried out for the machinery which he wishes to place on the market. For this purpose, he should determine which are the essential health and safety requirements applicable to his machinery and in respect of which he must take measures*" (European Comission Enterprise and Industry, June 2010)

One of the motivations to perform this study is to have a risk assessment in accordance with the Machine Directive 2006/42/EC, so that the equipment will be in compliance with the European regulations to be commercialised within the territory.

1.2 Reference Standards

For the present assessment, the standards considered for the completion of the risk assessment are:

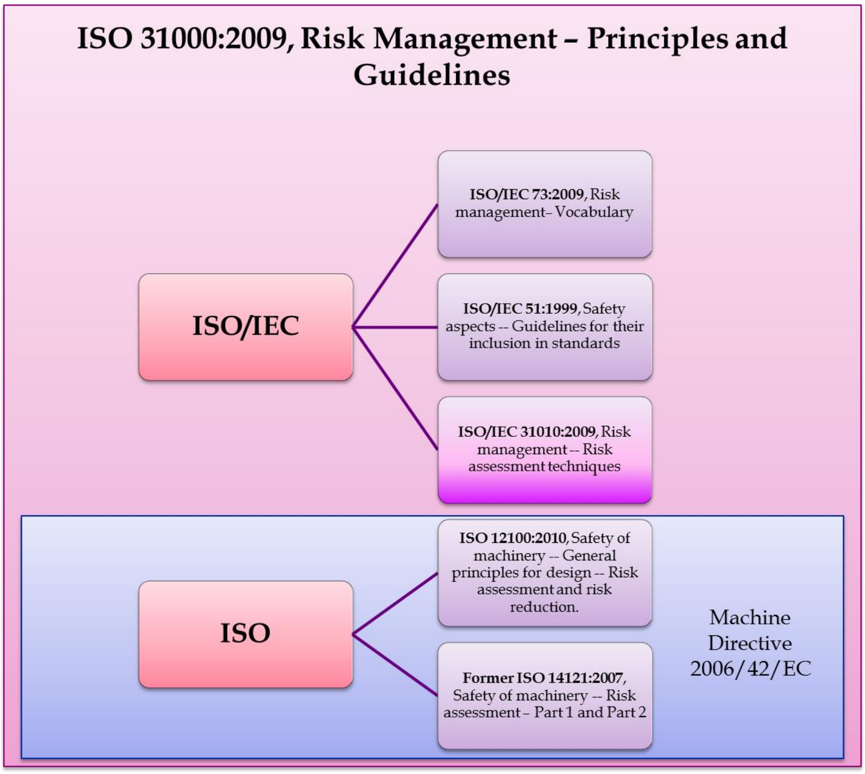


Figure 1. Machinery Safety applicable standards. Adapted from (Djapic Mirko, 2016)

- **"ISO 31000:2009 – Risk Management – Principles and Guidelines".** This International Standard can be applied throughout the life of an organization, and to a wide range of activities, including strategies and decisions, operations, processes, functions, projects, products, services and assets. (ISO 31000:2009, 2009)

- **"ISO/IEC 73:2009 – Risk Management – Vocabulary".** Provides the definitions of generic terms related to risk management. This standard, aims to encourage a mutual and consistent understanding, a coherent approach to the description of activities relating to the management of risk, and use of uniform risk management terminology in processes and frameworks dealing with the management of risk. (ISO/IEC 73:2009, 2009)

- **"ISO/IEC 51:1999 –** (ISO/IEC 51:1999, 1999)**".** Presents the requirements and recommendations for the drafters of standards for the inclusion of safety aspects in standards. It is applicable to any safety aspect related to people, property or the environment, or to a combination of these. (ISO/IEC 51:1999, 1999)

- **"ISO/IEC 31010:2009 – Risk Management – Risk Assessment Techniques",** whose object is to provide guidance on the selection an application of various techniques that can be used to help improve the way uncertainty is taken into account and to help understand risk. (ISO/IEC 31010:2009, 2009)

- **"Machine Directive 2006/42/EC"** It is a European Union directive concerning machinery and certain parts of machinery (Directive 2006/42/EC of the European Parliament and of the Council, 2006)

- **ISO 12100:2010 – Safety of machinery – General principles for design – Risk assessment and risk reduction".** The objective is to provide designers with an overall framework and guidance for decisions during the development of machinery to enable them to design machines that are safe for their intended use. (ISO 12100:2010, 2010)

- **"ISO 14121-1:2007 Safety of machinery – Risk assessment".** Provides guidance on information that will be required to enable risk assessment**.** (ISO 14121-1:2007, 2007)

These standards give the structure and the fundamentals for the specific analysis to be performed.

A detailed specification of the standards used for each analysis (HAZID, HAZOP, FTA, etc.) is detailed within the specific methodology to be followed in the next chapters.

1.3 Risk Assessment Methodology Steps

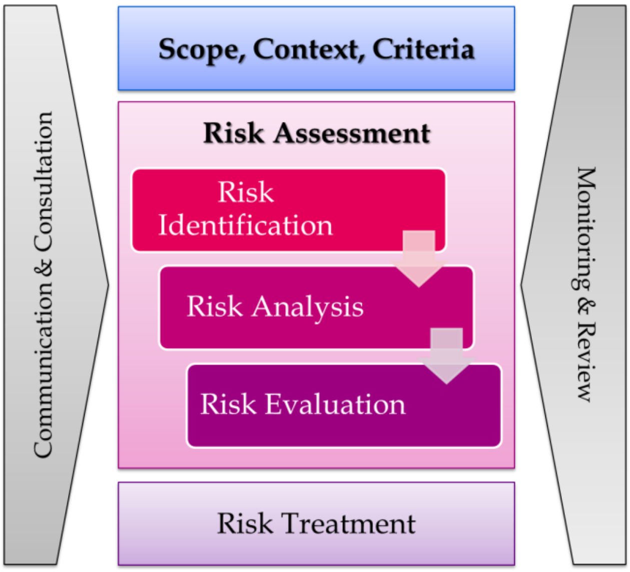


Figure 2. Risk Management Process. Taken from (ISO 31000:2009, 2009)

Following the phases of the risk assessment process according to the standard ISO 31000:2009, as it is considered to have a more general scope and it encompasses the methodologies of ISO 12100:2010 and ISO 14121:2007, is in accordance with the Machinery Directive 2006/42/EC, so the entire study will be based on ISO standards and its derivate references.

Figure 2, shows the Risk Management structure that ISO 31000:2009 suggests as part of a systematic process.

The process of Risk Management involves the complete understanding of the system/process subject to study, not only the associated risk but also the treatments to mitigate that risk, selecting the best strategy to mitigate those risks, and keep updated the assessments made.

However, this thesis is focused mainly on the Risk Assessment part. However, in order to proceed with the assessment there are some points that need to be described, and this is, as shown in figure 2, on the blue part, the establishment of a context and a criteria, this will set the bases from the Risk Assessment.

1.3.1 Establishing the Context

According to ISO 31000 (2009), *"by establishing the context, the organization articulates its objectives, defines the external and internal parameters to be taken into account when managing risk, and sets the scope and the risk criteria for the remaining process"* (ISO 31000:2009, 2009)

In this initial step of the Risk Assessment, the bases and fundamental facts of the system under study will be given. A background on why the system was developed is needed in order to understand the terms and the functionality of it.

Aside from the background, a full description of the equipment that conform the Continuous Circulation System – HoD ®, and the explanation of the pipe and instrumentation diagrams (P&ID) of the different configurations that the system perform on its normal operation.

1.3.2 Establishing Risk Criteria

This step is one of the most important of performing a Risk Assessment, on this step the limits of the system will be determined. These limits will help to comprehend whether the system is exposed to an acceptable or unacceptable risk level.

The risk criteria involve two components of risk:

- Likelihood (also called probability)
- Damage (also called impact or consequences)

In order to carry out this study, the team members of HoD® at Drillmec S.p.A., developed a risk matrix, which allowed to determine in a qualitative way not only the frequency of the hazardous events that might arise from the utilisation of the Continuous Circulation System – HoD, but also the consequences on four principal categories:

- Fatalities and Injuries →People
- Environment Impact → Environment
- Economy Losses → Asset loss and business interruption
- Damage to Reputation or Negative Publicity → Reputation

Table 1, shows the Risk Matrix developed for this study.

Damage	Consequence				Frequency index				
	Fatalities and Injuries (People)	**Environmental Impact (Environment)**	**Economy Losses (Asset loss and Business Interruption)**	**Damage to Reputation or Negative Publicity (Reputation)**	**A** Rare / Improbable	**B** Unlikely / Remote	**C** Moderate / Ocasional	**D** Likely / Probable	**E** Almost certain / Frequent
0	Insignificant harm	Insignificant impact	Insignificant damage < $10,000.00	Not mentioned in the media	A0	B0	C0	D0	E0
1	Minor Harm Possibility of minor injury on-site; no fatalities or injuries anticipated off site	Minor Impact Can be treated in the moment. Less than 1 month to recover	Very short-term (up-to 23 hours) business interruption /expense >$10,000 < $100,000	Very low or no impact or loss of reputation or business viability; mentioned in local press.	A1	B1	C1	D1	E1
2	Significant Harm On-site injuries that are not widespread but only in the vicinity of the incident location; no fatalities or injuries anticipated off site.	Significant Impact Site area only, less than 1 year to recover.	Short-term (>1 day to 1 week) business interruption/expense >$100,000 <$1,000,000	Low loss of reputation or business viability; query by regulatory agency; significant local press coverage.	A2	B2	C2	D2	E2
3	Serious Harm Possibility of widespread on-site serious injuries; no fatalities or injuries anticipated off site.	Serious Impact Environmental impact on-site and/or minor off-site impact, 1 year(s) to recover	Medium-term (1 week to 1 month) business interruption/expense >$1,000,000 < $10,000,000	Medium loss of reputation or business viability; attention of regulatory agencies; national press coverage.	A3	B3	C3	D3	E3
4	Major Harm Possibility of 1 to 3 on-site fatalities; possibility of off-site injuries.	Major Impact Large environmental impact on-site and/or large off-site impact, between 1 and 5 years to recover.	Long-term (1 month to 3 month) business interruption/ expense. >$10,000,000 < $100,000,000	High loss of reputation or business viability; prosecution by regulator, extensive national press coverage.	A4	B4	C4	D4	E4

Damage	Consequence				Frequency index				
	Fatalities and Injuries (People)	Environmental Impact (Environment)	Economy Losses (Asset loss and Business Interruption)	Damage to Reputation or Negative Publicity (Reputation)	A Rare / Improbable	B Unlikely / Remote	C Moderate / Ocasional	D Likely / Probable	E Almost certain / Frequent
5	Catastrophic Harm Possibility of any off-site fatalities from large-scale toxic or flammable release; possibility of multiple on-site fatalities.	Catastrophic Impact Environmental impact on-site and/or off site, more than 5 years/ poor chance of recovery	Very long-term (>6 month) business interruption/expense; large scale disruption to the national economy, public or private operations; loss of critical data. >$100,000,000	Very high loss of reputation or business viability; international press coverage.	A5	B5	C5	D5	E5

Table 1 Acceptance criteria. Risk Matrix, adapted from USCG Frequency/Consequence Categories and Risk Screening Criteria

1.3.3 Risk Assessment

To ISO 31000:2009, Risk Assessment, is "*the overall process of risk identification, risk analysis and risk evaluation.*" (ISO 31000:2009, 2009)

In order to perform the assessment in a logical way, and following the ISO 31010:2009 – Risk Assessment Techniques recommendations, the risk assessment is subdivided into:

- Risk Identification
- Risk Analysis
- Risk Evaluation

On the next sections each of the steps of risk assessment will be described and adapted accordingly to the necessities of this study.

1.3.3.1 Risk Identification

According to ISO 31000:2009, "*the organization should identify sources of risk, areas of impacts, events (including changes in circumstances) and their causes and their potential consequences. The aim of this step is to generate a comprehensive list of risks based on those events that might create, enhance, prevent, degrade, accelerate or delay the achievement of objectives.*" (ISO 31000:2009, 2009)

The first step is to create an adequate set of scenarios, and account for all possible sources of risk, also to provide a description of the hazards and possible consequences.

As a starting point for this study with regard with risk identification, a classification of sources of risk by its origin was made, but it will be commented fully on the next chapters.

The output of risk identification is an inclusive list of events or processes, that might lead the system to an undesired effect on the system.

IEC/ISO 31010:2009 refers to a series of detailed risk identification techniques, providing an overview of each one of them.

1.3.3.2 *Risk Analysis*

According to ISO 31000:2009, *"risk analysis involves consideration of the causes and sources of risk, their positive and negative consequences, and the likelihood that those consequences can occur. Factors that affect consequences and likelihood should be identified."* (ISO 31000:2009, 2009)

The main point of performing a risk analysis is to define the scenarios as a series of combinations of the identified events or process that may contribute to the failure of the system; estimate the likelihood and assess the consequences under each scenario condition.

IEC/ISO 31010:2009 refers to a series of detailed risk analysis techniques, providing an overview of each one of them.

Risk analysis then be organised as:

1. Scenario definition
2. Probability estimation
3. Consequence assessment

1.3.3.2.1 Scenario Definition

It is not the same as Scenario Analysis (which is performed on Risk Identification), the scenario analysis is to give a broad perspective of how the system might fail while covering a large part of possibilities.

The scenario definition is usually based on Expert judgement, allows to obtain a failure scenario which turns out to be a meaningful combination of events and/or processes, together with a set boundary conditions.

The starting point of this step, is to take the events and processes selected in the risk identification phase, taking into consideration the likelihood of occurrence and the damage caused by it, in order to construct the scenarios.

The expected result of the analysis of risk is potentially a list of scenarios with their probability. Each scenario should be accompanied by the assumptions and boundary conditions taken in order to define it.

1.3.3.2.2 Probability Estimation

It can be qualitative or quantitative. It depends on the availability of data, and the information needed for the analysis.

In case that there are no relevant data about the scenarios, because of the complexity or because of the system itself, but there are data available about the individual events that together conform the scenario, some risk analysis techniques like event tree analysis or fault tree analysis result helpful to reach the scenario probability.

1.3.3.2.3 Consequence assessment

Provides the measurement of the consequences estimated.

1.3.3.3 Risk Evaluation

According to ISO 31000:2009, *"The aim of this step is to assist in making decisions, based on the outcomes of risk analysis, about which risks need treatment and the priority for treatment implementation."* (ISO 31000:2009, 2009)

On this stage, the results of risk analysis are collected and put together. It allows to determine if reduction of risk will be required or the level of risk is within the acceptable region.

IEC/ISO 31010 refers to a series of detailed risk evaluation techniques, providing an overview of each one of them.

1.3.4 Risk Assessment Techniques

As mentioned before, IEC/ISO 31010:2009, introduces a series of techniques for each part of the risk management process. However, due to the objective of this study, the techniques that will be performed should be inside the category of Risk Assessment and respectively, identification, analysis or evaluation.

Figure 3 shows the selected techniques that are used on this study, while table 2, presents the basic characteristics of each one of them.

Each technique and the results obtained from the application on the study case (Risk Assessment of a Continuous Circulation System – HoD ® are fully developed on their own chapter.

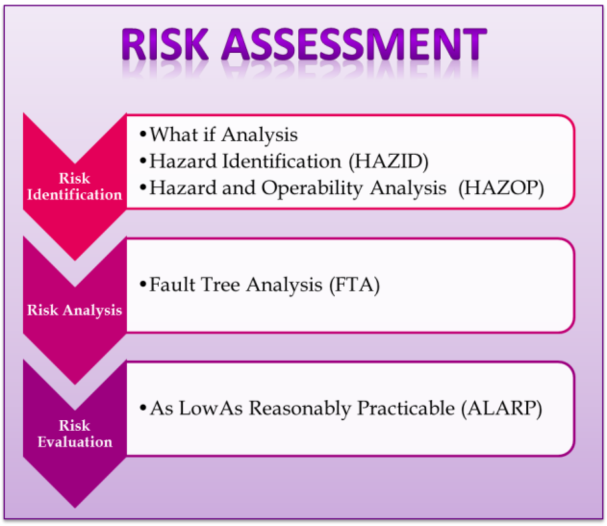


Figure 3. Risk Assessment procedure; adapted from ISO 31010:2009

Technique	Description	Application	Scope	Time Horizon	Decision level	Starting info/ Data needs	Specialist Expertise	Qualit/ Quantit	Effort to apply
Structured What if technique	A simpler form of HAZOP with prompts of"What if" to identify deviations from the expected	Identify risk	Enterprise Project/ Department	Medium	Operational Tactical	medium	low/ moderate	qualitative	Low/medium
Hazard Identification (HAZID)	Technique utilised to encourage the imaginative thinking towards a goal.	Identify risk	Enterprise Project/ Department Equipment/ Process	Short Medium Long	Strategic Operational Tactical	low	low/ moderate	qualitative	low
Hazard and Operability (HAZOP)	A structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that might represent risk to personnel or equipment, or prevent efficient operation	Identify and analyse risks	Equipment/ Process	medium / long	Operational Tactical	medium	facilitator-high participants-moderate	qualitative	Medium / High
Fault Tree Analysis (FTA)	Analyses causes of a focus event using Boolean logic to describe combinations of failures. Variations include a success tree where the top event is desiredand a cause tree is used to investigate past events,	Analyse likelihood Analyse causes	Enterprise Project/ Department Equipment/ Process	Medium	Operational Tactical	High for quantitative analysis	Depends on complexity	Either	Medium / High

Technique	Description	Application	Scope	Time Horizon	Decision level	Starting info / Data needs	Specialist Expertise	Qualit / Quantit	Effort to apply
As Low As Reasonably Practicable (ALARP)	Criteria for tolerability of risk	Evaluate Risk	Enterprise	Short Medium Long	Strategic Operational	High	High	quantitative	High

Table 2. Techniques and indicative characteristics. Taken from IEC 31010:2009 (ISO/IEC 31010:2009, 2009)

2 - Drilling Engineering Background on HoD® development

Drilling by definition is to make a hole in something using a special tool. (Cambridge Dictionary) Nevertheless in the oil and gas industry drilling a well is more than boring a hole into the earth, it suits a purpose; appraisal, exploration or production purposes on an area where economically viable amounts of hydrocarbons might be found.

2.1 Overbalanced and Underbalanced Drilling

Usually, wells are drilled in overbalanced conditions. In these wells, the wellbore fluid gradient is designed to be greater than the natural formation gradient, consequently preventing the influx of formation fluids to go inside of the well.

With a very few exceptions, the drilling activity is performed in overbalanced conditions and must comply with the international safety standards dictated by the well control rules.

The Overbalance drilling techniques are:

- Conventional Drilling (Stop/Start Circulation);
- Managed Pressure Drilling (MPD)

Despite that the majority of wells are drilled in overbalanced conditions, there are some exceptions, in which the drilling fluid gradient is designed on purpose to be lower than the natural formation gradient.

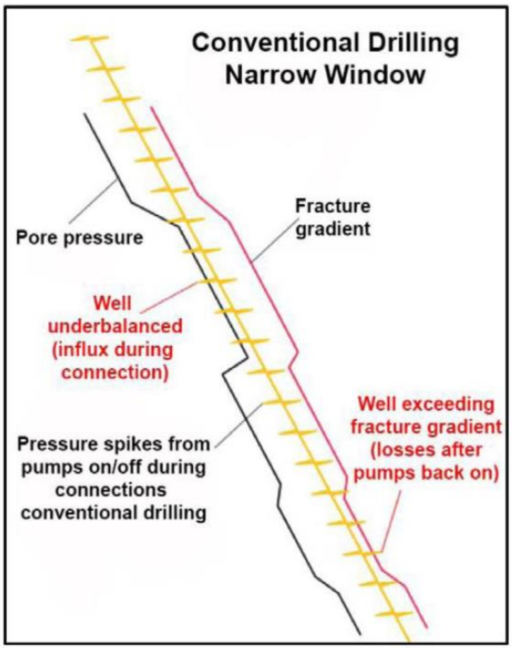


Figure 4. Conventional Drilling Narrow Window.

The underbalanced drilling is used mainly in shallow wells, that contain fractured limestone formations, for example, with low pore gradient. The technique by itself its more complex than the overbalanced one, but when implemented in the right way, it can overcome problems such as eliminating the mud invasion into the fractured system, or reducing the formation of more fractures.

The underbalance drilling techniques are, though, constrained to those that can apply a backup pressure from the top of the wellbore to control the allowed and controlled influx of the formation.

2.2 Conventional Drilling

The conventional drilling, or "start/stop circulation drilling", technique is until today the most used in onshore and offshore drilling applications.

Conventional drilling is practiced in an open vessel, this means it is open to the atmospheric pressure. In this mood of drilling, the drilling fluids exit at the top of the wellbore through a bell nipple, in order for them to pass through a mud-gas and a solid separator, to have the mud back in the tanks and ready to repeat the cycle.

The international well control procedures (safety standards) state that while drilling and also during well intervention activities there should be at least two tested and independent barriers in place, which have to be placed after setting the surface casing, in order to prevent the entrance of formation fluid into the annular space. In case that there is a loss of one of the two barriers, the operations must be stopped and the well control procedures should be implemented.

During the drilling phase, the primary barrier consists on maintaining the pressure exerted by the drilling fluid within the limits of the pore pressure and the fracture pressure. The secondary barrier is a mechanical one, and consists in a series of installed equipment, which is tested and monitored all the time.

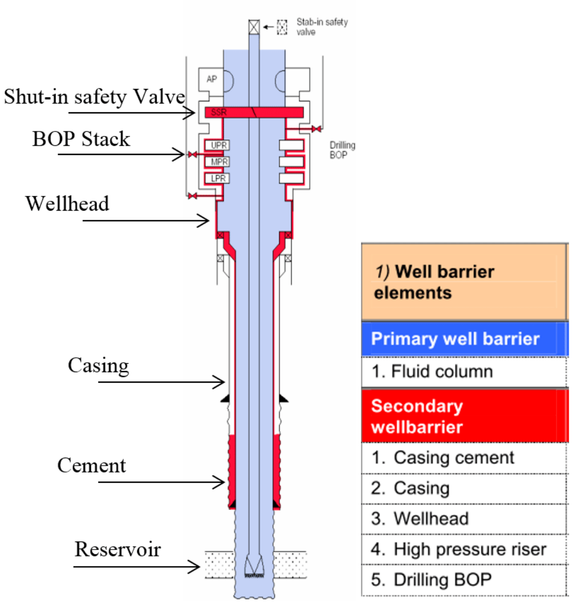


Figure 5. Conventional Well Barriers

While drilling in the conventional way, before each connection is made, the mud circulation is stopped and the bottom hole pressure drops rapidly, generally overshooting the balance by several hundred psi, before rising to the static level. This negative pressure surge may induce flow from the formation if it falls below the pore pressure.

2.3 Managed Pressure Drilling Techniques

A general definition of managed pressure drilling (MPD) states that it is an adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore[1].

Managed pressure drilling (MPD) uses a combination of surface pressure, hydrostatic pressure of the mud and annular friction to balance the exposed formation pressure[2].

The two type of MPD techniques are:

Open-loop MPD: it is a bottomhole pressure management technique that can be applied in an open-loop circuit with a standard configuration of the mud system in which the mud coming out from the well is keep at atmospheric pressure;

Closed-loop MPD: bottomhole pressure management techniques that require the installation of a Rotating Control Device (RCD). In order to have a closed-loop circuit of the mud system in which the mud is always pressurized (a structural change of the Flow Line is required in order to work under pressure).

[1] (American Bureau of Shipping, September 2017)
[2] (Drilling Matters)

The application of MPD does not allow an influx into the well, the applications, however, are determined mainly by the narrow drilling margins of the formation pore pressure and the formation fracture pressure of the ground that is going to be drilled.

2.3.1 Pressurized Mud Cap Drilling (PMCD)

The Pressurized Mud Cap Drilling technique, already implemented at the beginning of 2000 by ENI with the CHCD system (Closed Hole Circulation Drilling), is the only technique that allows drilling in total loss scenario.

IADC defines PMCD as "a variation of MPD that involves drilling with no returns to surface, and where an annulus fluid column, assisted by surface pressure (made possible using RCD), is maintained above a formation that is capable of accepting fluid and cuttings".

This technique employs two distinct fluids: the first is a sacrificial fluid, generally seawater or industrial water, pumped through the drillpipe in order to push the cuttings into the fractures and allow advancement; the second is a drilling mud pumped through the annulus (closed by the RCD) with hydrostatic weight of the mud column accurately calculated so as to have a lower value than the pore gradient in the range 200-400 psi. In this way, the annulus is pressurized and through the pressure monitoring it is possible to keep under control kick phenomena (increase of the annulus pressure) and mud losses (decrease of the annulus pressure).

A critical situation should be emphasized: in case of accidental rupture of the drill string during pipe connection and after having removed the top drive, there would be an uncontrollable influx inside the drill string generating a Blowout (the blind shear Rams do not cut if the pipe is under pressure).

The solution is to maintain the circulation of sacrificial fluid continuous throughout the drilling of all section: this technique, moreover, guarantees to push the cuttings inside the fractures and to avoid possible stuck pipe. Therefore, it is suggested to use continuous circulation together with the PMCD technique.

2.3.2 Constant Bottomhole Pressure (CBHP)

The Constant Bottomhole Pressure technique is applied if an accurate control of the wellbore's pressure profile, always in overbalance, is required, in formations characterized by a narrow window between pore gradient and fracture gradient that cannot be drilled with the conventional Stop/Start circulation technique: typical scenario of HPHT and DW / UDW wells.

IADC defines CBHP as "a MPD method whereby bottomhole pressure is kept constant during connections to compensate the loss of AFP and ECD when mud pumps are off.

Typical methods include:

- By trapping annular pressure prior to shutting down mud: Closed-loop MPD;
- By keeping continuous circulation: Open-loop MPD.

2.4 Common Drilling Problems

During the normal operations of drilling a well, there are some "common" problems that can appear and add risks, for people, environment and assets mainly, this problems should be avoided, either by means well control or by the right equipment implementation.

Some of this problems are stated as follows:

1. Kick and Blow Out

In conventional drilling bottom hole pressure is always in overbalance conditions. Meaning the Bottom hole pressure is always higher than the formation pressure. When the bottom hole pressure is lower than the formation pressure, the formation fluids will start to flow inside the wellbore. That process of formation fluids entering the well bore is called a kick.

When there is a detected kick inside the wellbore, the driller will close the well immediately in order to stop the formation fluid influx inside the wellbore, then the start of well control procedures to remove this kick out of hole and regain control over the wellbore.

When the formation fluids fills the wellbore, and reaches the surface without any control over it; that will be called a blowout.

2. Formation Fracturing and Loss of circulation

The formation fracturing happens when the pressure inside the wellbore surpasses the fracture pressure of the formation. The fracturing of the formation will cause the formation and propagation of a fracture inside the formation allowing the drilling fluid to enter to the formation. That will reduce the mud return in the surface which is defined as "Mud Losses". If the return in the surface is zero (i.e., all of the mud is injected into the fractured formation.) that will be called complete loss of circulation.

The result of lost circulation while drilling can be mainly: the non-productive time spent to regain the circulation, economic losses due to the lost drilling fluid and the NPT, but also, as it induces a reduction in pressure inside the well due to the loss of fluid head inside the wellbore, that can induce a kick.

3. Differential Sticking and Struck Pipe

Differential sticking happens when the wellbore pressure is higher than the formation pressure with a big differential in front of a permeable formation. The forces of the drilling fluid inside the wellbore will push the drill pipe to be stuck to the against formation sand face. And the formation of the filter cake in front of these permeable formation aids the mechanism of differential sticking.

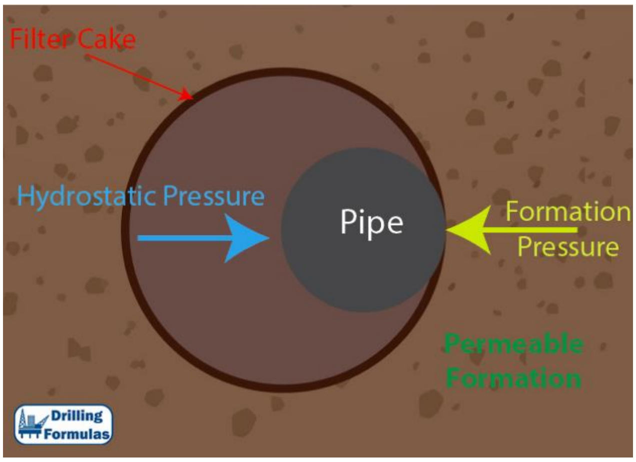


Figure 6. Differential Sticking and Struck Pipe. Taken from Drilling Formulas

The forces of the drilling fluid acting inside the well are shown in figure 6.

4. Hole Cleaning problems and Slugging of cuttings

Continuous removal of cuttings from the wellbore is very important. And the term hole cleaning expresses the ability of the drilling fluid to transport the fluids out of the well bore.

Optimum hole cleaning requires the control of multiple Parameters:

- Annular fluid Velocity.
- Hole Inclination.
- Mud Rheology.
- Cutting Size and characteristics.
- Rate Of Penetration ROP.

Bad hole cleaning might lead to a the accumulation of the cuttings inside the wellbore leading to a lot of other drilling problems:

- Change of mud rheological properties
- Change of mud weigh inside the annular space.
- Mechanical sticking of the drillstring.

5. **Narrow Pore/Frac pressure windows**

In conventional drilling the pressure window is expected to accommodate all of the pressure surges that happen in conventional operations.

When this pressure window between the formation pressure and fracture pressure is narrow, the pressure fluctuations can make the BHP to exceed the formation fracturing pressure causing loss of circulation and well integrity problems. On the other side, these fluctuations also could make the BHP to get less than the formation pressure causing kicks and well control issues.

Narrow pressure windows were the main drive for the MPD techniques to be invented, that the main mission of MPD techniques is to control the BHP, eliminating and reducing the pressure fluctuations that happen in conventional drilling.

6. **Extended Reach Wells Drilling ERD**

Extended reach wells are the wells that have the ratio between the measured depth to the true vertical depth at least 2 to 1.

ERD wells have a long horizontal sections, that are accompanied with its hole cleaning problems but also there are some challenges added due to the extended length of the horizontal section:

- Hole instability, due to time exposure, mechanical stresses, pressure surges, or even drilling fluid properties change.
- The long length of the drillstring inside the well bore will cause excessive drag.
- The annular friction losses inside the well bore becomes excessive due to the long length of the open hole section, and might cause well integrity issues if exceeded fracture or formation pressures.

7. **Surge and Swab**

Surge and Swab are pressure surges that happen downhole due to the tripping of the drillstring in or out of hole. Surge is the increase in BHP due to the movement of the drillstring in hole. Swab is the reduction of the BHP due to the movement of the drillstring out of hole. The effect of Surge and swab is shown in the following figure 7.

These pressure surges must be controlled in order to make sure that these surge and swab effect won't get the BHP out of the drilling window limits (i.e., More than fracturing pressure, or less than formation pressure.).

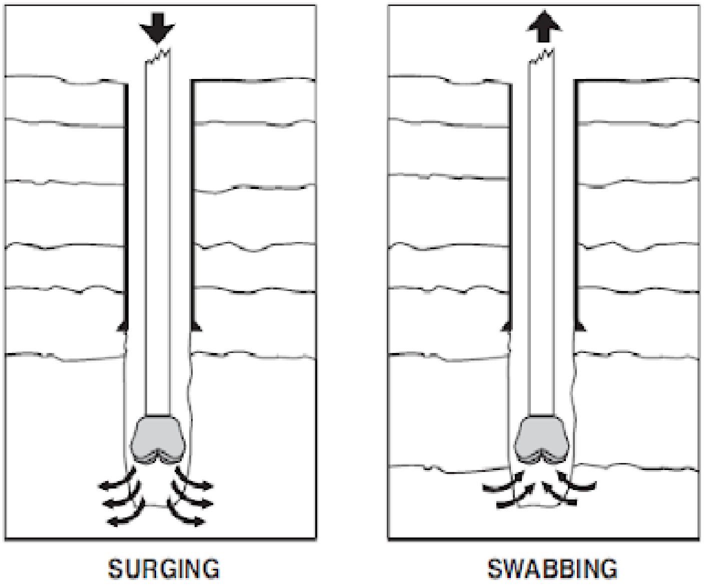


Figure 7. Surge and Swab

3 - Case of Study: Continuous Circulation System - HoD®

3.1 Establishment of Context

3.1.1 What is HoD ® ?

The HoD-Heart of Drilling system is the Open-loop MPD. It is the combination of Continuous Circulation with a high resolution kick and loss detection system through the use of a Mud Flow Meter. (Valcom, 2019)

This technique maintains the circulation of the drilling mud through the drill string even during connection, to ensure the continuity of the first hydraulic barrier in the well along the entire section of open hole. No substantial changes are required to the mud circuit.

The application of this technique aims to keep the BHP continuously constant during connection thus allowing to drill formations characterized by a narrow window between pore gradient and fracture gradient.

In addition, the Open-loop MPD technique:

- Improves the cleaning and the stability of the hole, through a continuous transport of the cuttings during connection;
- Allows to acquire well data without any blackout during connections;
- Facilitates the heat exchange between formation and the drilling fluid even during the connection, reducing the thermal stresses of the well bottom tools.

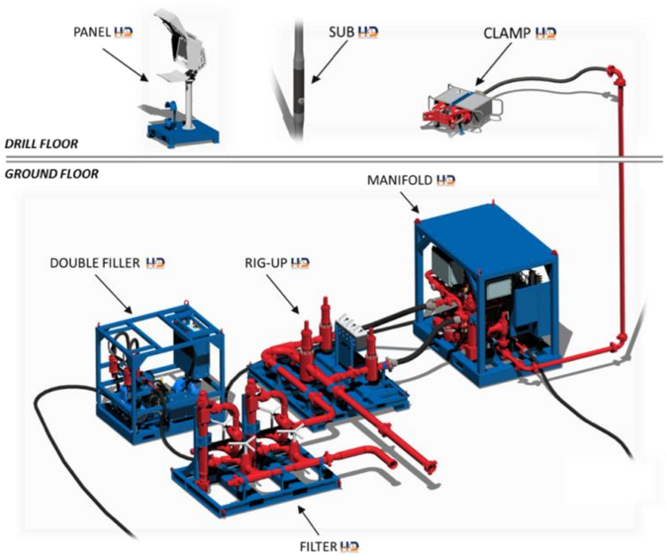


Figure 8. HoD general layout

3.1.2 What are the potential benefits of the utilization of this technique?

The application of the Open-loop MPD technique can bring enormous benefits in terms of safety and performance in full compliance with the international standards that regulate drilling activities. From a Shell statistic (Justin R. Cunningham, 2015), referring to offshore activities, it is possible to assert that 50% of the time kicks are related to tripping the DP in and out of the well, 25% of the time kicks are related to making connections and 25% of kicks happen during drilling and circulating.

With the use of the HoD system during the drilling and trip out phases in the open hole it is possible to eliminate 75% of the kicks, i.e. those that occur during making connection and tripping phases. The remaining 25% of the kicks occur during drilling and can be immediately detected and mitigated thanks to the kick and loss detection system with Venturi flow meter. (Valcom, 2019)

The main benefits of using the HoD system during drilling are:

- Greater ECD control at all times during drilling, connection, tripping, and fluid displacement;
- Elimination of potential gas influx during connections (kick connection) and tripping phase;
- Reduc (Justin R. Cunningham, 2015)ed formation damages and improved wellbore stability;
- Less chance of ballooning effects in close to balance wells and NPT associated;
- Easier influxes detection due to no pumps start/stop;
- Permanent hole cleaning, no cuttings accumulation and improved ROP;
- No downhole temperature fluctuations.

From a relational point of view, the main benefits would be:

- High safety levels without added time to conventional connections;
- No circulation time spent prior connection;
- No time spent by re-drilling cuttings accumulated after connection;
- Reduced tripping time by avoiding undesirable events due to cuttings accumulation and reducing circulation time prior POOH;
- Minimized NPT associated to pack off, stuck pipe and fishing job;
- Allowed real-time monitoring during connections.

3.1.3 Benchmark of Continuous Circulation Technologies

Several important oil companies at the beginning of the 2000s tried to improve the safety and efficiency standards in drilling activity, looking for a technical solution that would lead to continuity. This need was linked to the new challenges that were emerging, such as HPHT environments that with the conventional Stop / Start Circulation Drilling technique could not reach the target due to the phenomena of kick connection and ballooning.

This necessity gave rise to a collaboration that involved, in addition to numerous oil companies, the Maris International Ltd and the Varco (today NOV) in the development of a first continuous circulation system (NOV CCS) that would not stop the circulation of drilling mud during connection (concept of continuity).

The NOV CCS system was successfully used for the first time in Val d'Agri (Italy) and then in Egypt; however, because of the great size and slow operational, the market has moved in the direction of a simpler and more compact solution (concept of the sub): the e-cd system was developed by ENI, now managed by Halliburton.

A few years later the NABOS Non Stop Drilling system was born. Both systems are manual: this constitutes a great limit for the safety of operations and personnel on the rig floor. To improve this type of solution, Weatherford has invested to develop a remotely controlled clamp system, Continuous Flow System, but has not led to important results.

The Drillmec system (with international patent) HoD is composed of a sub installed on the top of the standpipe, a clamp, a manifold and an automated control system.

The operators on the rig floor are only needed to connect and remove the clamp: the concept of the two Well Control barriers is always respected. The HoD system has been applied with excellent safety and performance results.

Figure 9. Continuous Circulation Technologies Timeline

In recent years, Schlumberger (Schlumberger CCS) and Halliburton (e-cd Plus) are trying to develop their own remote controlled continuous circulation system but, for the time being, the most advanced and safe system remains Drillmec HoD.

3.1.4 Equipment Requirements and Description

3.1.4.1 Wellsite constraints

The HoD operations involve adding additional equipment to be installed on the rig location. The optimum location and spacing on the rig for the HoD equipment shall be evaluated by an operator, a rig contractor and the HoD service company.

Before planning the HoD operations, the drilling rig should be inspected by the Company Drilling & Completion Manager, the Drilling Rig Contractor Representative and HoD service superintendent to verify the wellsite/drilling rig spacing and layout, the status of the existing facilities and assess the drilling rig modifications/upgrading required for the HoD activity.

3.1.4.2 Equipment General Description

SYSTEM KEY FEATURES:

- Working Pressure (WP): up to 68.9 MPa (10,000 psi).
- Flow rate: up to 3,785 l/min (1,000 gpm) – 4,545 l/min (1,200 gpm).
- Drill pipes sizes: subs can be scaled to customer specification for DP 4”1/2, 5”, 5”1/2, 5”7/8, 6”5/8 (1).

- Lateral side port design: Two (2) independent safety barriers characterizing HoD Subs later side valve (Drillmec patented technical solution).
- No manual actions on pressurized subs: HoD Subs later side valve opening/closing provided by a fully automated Clamp remoted controlled using the remote control pannel.
- Pressure relief valve installed in the HoD side to immediately detect and adjusted abnormal pressure and divert the mud flow to the bleed off line.

General Standards used to design the HoD:

- API 5DP / ISO 11961:2008 Specification for Drill Pipe
- API 6A / ISO 10423:2009 Specification for Wellhead and Christmas Tree Equipment
- API 7-1 Specification for Rotary Drill Stem Elements
- API 7K Drilling and Well Servicing Equipment
- API RP 7G Recommended Practice for Drill Stem Design and Operating Limits
- API RP 500 Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1and Division 2
- ATEX Product Directive 94/9/EC
- IRP 1 Industry Recommended Practice (IRP) for the Canadian Oil and Gas Industry Critical Sour Drilling Vol. 1 2005
- NACE MR0175 / ISO 15156 Petroleum and natural gas industries Materials for use in H2S-containing Environments in oil and gas production

3.1.4.3 Double Filler Pump

The pump is used to partially load the side empty pipe. It is calibrated in the workshop to an automatic shutdown of around 600 psi for both operation drilling and tripping.

The pump must be used appropriately and does not require special maintenance, if during installation are taken appropriate precautions.

It is connected to the HoD Manifold, it can be managed by remote position using the Remote Control Panel.

Figure 10. Double Filler Pump

Power	29 kW (39 hp)
Maximum flow rate	150 l/min (39.6 gpm)
Pressure range	100 bar (1,450 psi)
RPM	800
Weight	90 kg (198 lbs)

Table 3. Double Filler Pump specifications

3.1.4.4 HoD Manifold

HoD Manifold, is connected to the rig mud circuit and crossed by the mud flow only during drill pipe connection phase by means of the HoD rig-up manifold, allows flow switching from the standpipe to HoD Valve and back.

The mud flow switching sequence performed in a fully automated way by means of the Remote Control Panel, which acts on the hydraulic plug valves, providing in real time the status of each valve and value of pressure inside the Top Drive side and the HoD side.

Figure 11. HoD Manifold

Consists of:

- ESD system acting on by-pass line connected to the bleed off line to immediately isolate the top drive side and the HoD side in case of emergency from the mud circuit.
- Pressure relief valve installed in the HoD side to immediately detect and adjusted abnormal pressure and divert the mud flow to the bleed off line.
- HPU and X-HoD Control System.
- Manual Controls of HoD Manifold, Clamp and HoD Rig-up Manifold.

Note:

- ❖ Reduction of mud pumps rate is not required during mud switching sequences.
- ❖ Reduction of mud pumps rate is strictly required only in case of emergency when the ESD system has been activated.
- ❖ Manifold by-pass during normal drilling phase by means of the HoD Rig-up Manifold allows to perform manifold maintenance and service while drilling.

3.1.4.5 Hydraulic Power Unit (HPU)

The HPU, integrated in the HoD Manifold, provides hydraulic power to:

- HoD Clamp hydraulic actuators,
- HoD Manifold hydraulic actuated valves.

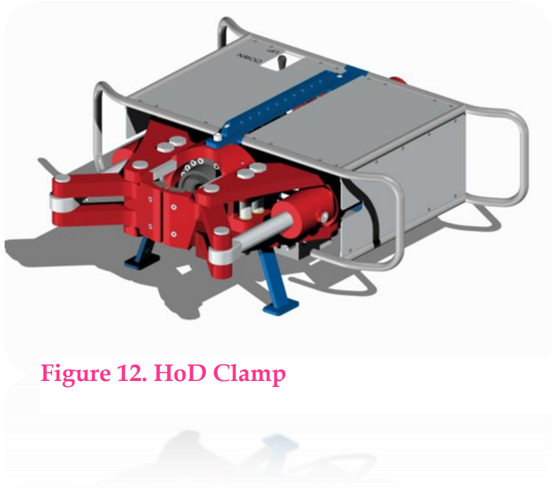
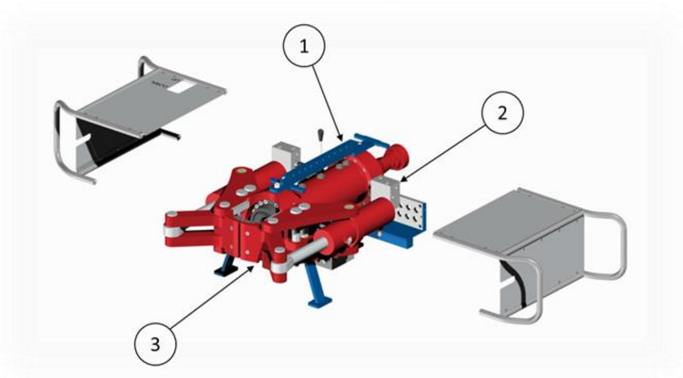


Figure 12. HoD Clamp

HPU with electric motor composed by:

- Hydraulic pumps,
- Electric motor with explosion-proof design,
- Oil tank,



ITEM	DESCRIPTION
1	FRAMES
2	ELECTRICAL AND HYDRAULIC COMPONENT
3	MECHANICAL COMPONENTS

Figure 13. HoD Clamp Configuration and components

- Box for hydraulic power station,
- Complete with hoses for line and return line, both with quick disconnect and dust cover installed.

3.1.4.6 Clamp

The HoD clamp is a fully automated hydraulic connection device that enables the system to perform the connection of the HP mud hose on the axial valve of the HoD Sub, while the top drive is not attached.

This action will avoid manual operations on the pressurized vessel during the drill pipe connections; thus, increasing the security for the personnel on the rig floor.

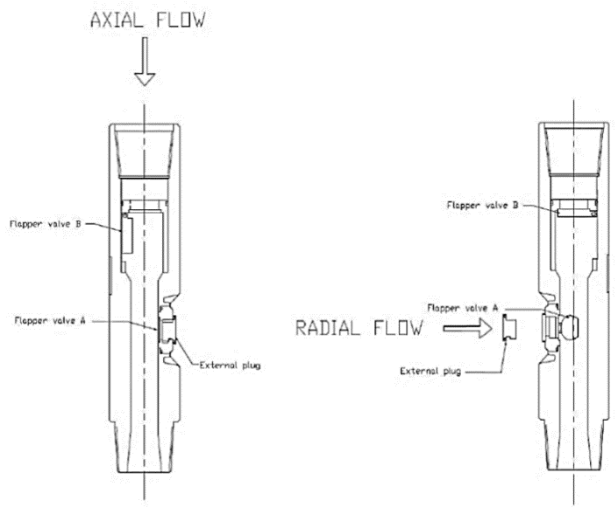
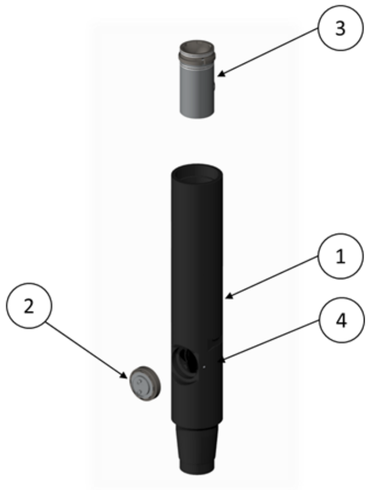


Figure 14. HoD double valve Sub

The HoD clamp is managed remotely by the XHoD Control System Panel, and have the possibility to be managed manually in case of failure of the Control System..

3.1.4.7 Double Valve (DV) Subs

Special subs are threaded to be installed in the drilling string to allow uninterrupted circulation of the drilling fluid into the well, even when adding or removing elements within the drilling string (i.e. during drill pipe connections, or tripping pipes in/out of the hole), through a special lateral valve integrated in each special subs.



ITEM	DESCRIPTION
1	HOD SUB
2	HOD RADIAL VALVE
3	HOD AXIAL VALVE
4	SCREW

Figure 15 Sub Configuration and components

HoD Double Valve (DV) Subs, where mud flow switching from axial flow to later flow and vice versa is ensured by two independent flapper valve bodies inside the sub:

- Flapper A: lateral flapper valve body to manage only the flow through the lateral valve.
- Flapper B: axial flapper valve body to manage only the flow through the axial direction.

3.1.4.7.1 Sub Body

Figure 16. HoD Sub Body

The HoD Sub body is manufactured considering the API 7K for the applied loads and the API 5DP for the API connections. The sub can be realized according NACE MR-0175 or IRP 1.8 standards if required.

3.1.4.7.2 External Plug

The external plug represents the lateral external (second) barrier protecting the personnel during pipe connection/disconnection and guaranteeing the separation of the pumped mud from the well annulus when the sub is inside the well.

The external plug is hinged inside the lateral valve body during the mud axial flow, acting, as aforementioned, a double and second mud barrier. During the radial mud flows, i.e. during continuous circulation phases, the external plug is removed from the valve body by the HoD clamp, allowing the opening of the internal barrier, i.e. the flapper valve A.

The external plug is designed to resist to the design stresses in compliance with API 6A. The external plug is manufactured in accordance to NACE MR-0175 or IRP 1.8 standards if required.

3.2 Risk Identification

3.2.1 Scenario Definition

According to ISO 12121-1:2007, in order to perform a hazard identification, on any machine, a essential step is to systematic identify all the reasonably, foreseeable hazards, hazardous situations and/or hazardous events during all phases of the machine life cycle.

As part of the CCS-HoD® life cycle, there are 4 important phases:

1. Start-up of the CCS-HoD®
2. **Normal Operations**
3. Shutdown
4. Maintenance

However for the present assessment, the general phase that needs to be accounted for, is the "Normal Operations", due to the fact that it is needed to know the hazards that are present during each one of its sub-phases.

For normal operation , the phases are subdivided into:

- Drilling
- Bypass drilling
- Drillpipe Connection
- New Standpipe Connection

To accomplish this hazard identification, it is necessary to identify the operations to be performed by the machinery and the tasks to be performed by persons who interact with it, taking into account the different parts, mechanisms or functions of the machine, the materials to be processed, if any, and the environment in which the machine can be used.

3.2.1.1 Operational Phases of the HoD

There are four operational phases of the Continuous Circulation System - HoD®, which will be studied and defined through the next pages in order to be able to study the risks that might arise from each one.

3.2.1.1.1 Operational Phase: Bypass Drilling

The first phase that we can have during the normal operation of the HoD is the By-Pass Drilling Phase whose P&ID is schematised on figure 17. During this phase, the equipment of the HoD involved on the operation are:

- XHoD control System
- HPU
- HoD Manifold
- HoD Sub

During the by-pass drilling phase, the mud is taken from the HP Mud Pump Manifold through a pipe to the HoD Manifold. In order to avoid any strange body inside the manifold that might affect the flow of the mud through it, at the entrance of the manifold there is a filter, after the filter the valve PV8 is fully open while PV9 and PV10 are closed directing the mud to the Mud Standpipe Manifold and so, to the Top Drive.

Once the mud is in the Top Drive, it passes through the HoD Sub; within the HoD Sub, the Axial Valve is open and the Radial Valve is closed. The Clamp is disconnected from the system during the drilling phase, the XHoD control system and the HPU remain on and fully functioning while controlling the operation of the HoD Manifold.

It is important to mention, that the by-pass drilling operational mode starts when the sub is on the height of the top drive, and then switches to Drilling Phase, when the HoD Sub is about to reach the rig floor.

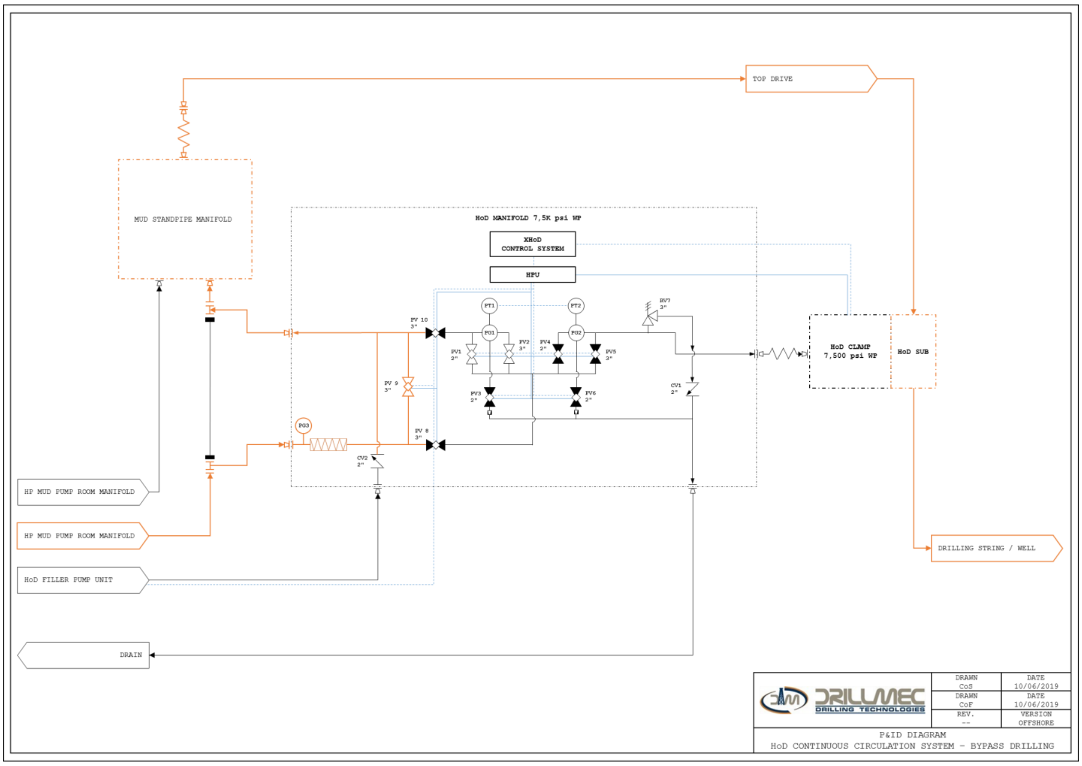


Figure 17. P&ID of By-Pass Drilling Phase

3.2.1.1.2 Operational Phase Drilling

As mentioned before, the drilling phase starts when the HoD-Sub is above the rig floor, in this moment, the HoD manifold changes the sequence of valves to prepare for the new drillpipe connection.

The figure 18 presents the P&ID of the drilling phase.

During this phase, the equipment of the HoD involved on the operation are:

- XHoD control System
- HPU
- HoD Manifold
- HoD Sub

In order not to interrupt the flow of mud to the system, as the mud coming from the HP Mud Pump Room reaches the HoD Manifold and passes through the filter, the valve PV9 is open and the valve PV8 is closed. After the valve PV9 is open, the valve PV1 and PV2 are consequently opened and PV10, so that the mud circuit just changes the direction inside the manifold to the Mud Standpipe Manifold and Top Drive.

Once again, as the previous phase the mud passes through the HoD Sub; the Axial Valve is open and the Radial Valve is closed. The Clamp is disconnected from the system during the drilling phase, the XHoD control system and the HPU remain on and fully functioning during the entire operation time.

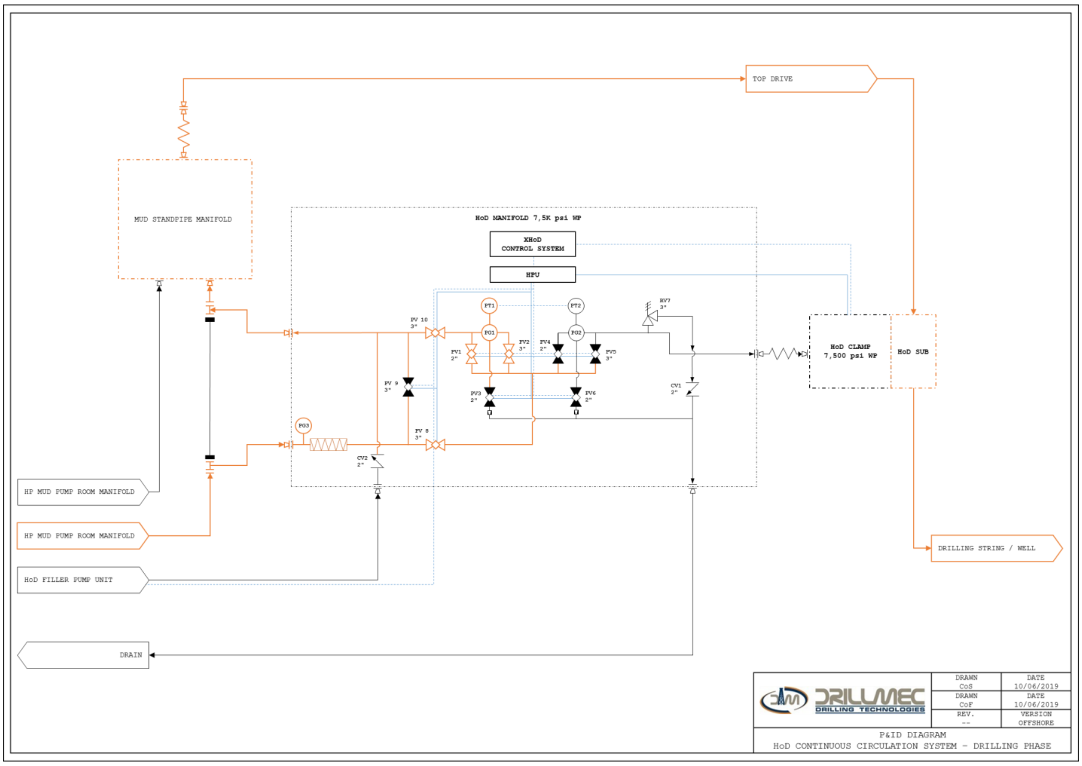


Figure 18. P&ID of Drilling Phase

3.2.1.1.3 Operational Phase Drill Pipe Connection

When the HoD sub reaches the rig floor, the operational phase of Drilling changes to the Drill Pipe Connection, as shown in figure 19. During this phase, the equipment of the HoD involved on the operation are:

- XHoD control System
- HPU
- HoD Manifold
- HoD Clamp
- HoD Sub

At the beginning of the operative phase the flow continues to come from the top drive side. When the Drilling phase finishes, the operators in the rig floor bring the clamp manually to make the connection to the sub radial port (valve).

The manifold will switch to a new configuration which involves closing PV2, then PV3, and open subsequently PV4 and PV5. The flow will be directed to the clamp.

Once the mud reaches the clamp and this one is connected to the sub. The top drive is still connected. The radial port will be opened, and the flow will enter to the sub from the radial valve. The pressure exerted by the mud entering from the clamp will allow the axial valve to close. In this moment the top drive is disconnected and the circulation to the well keeps constant through the radial side.

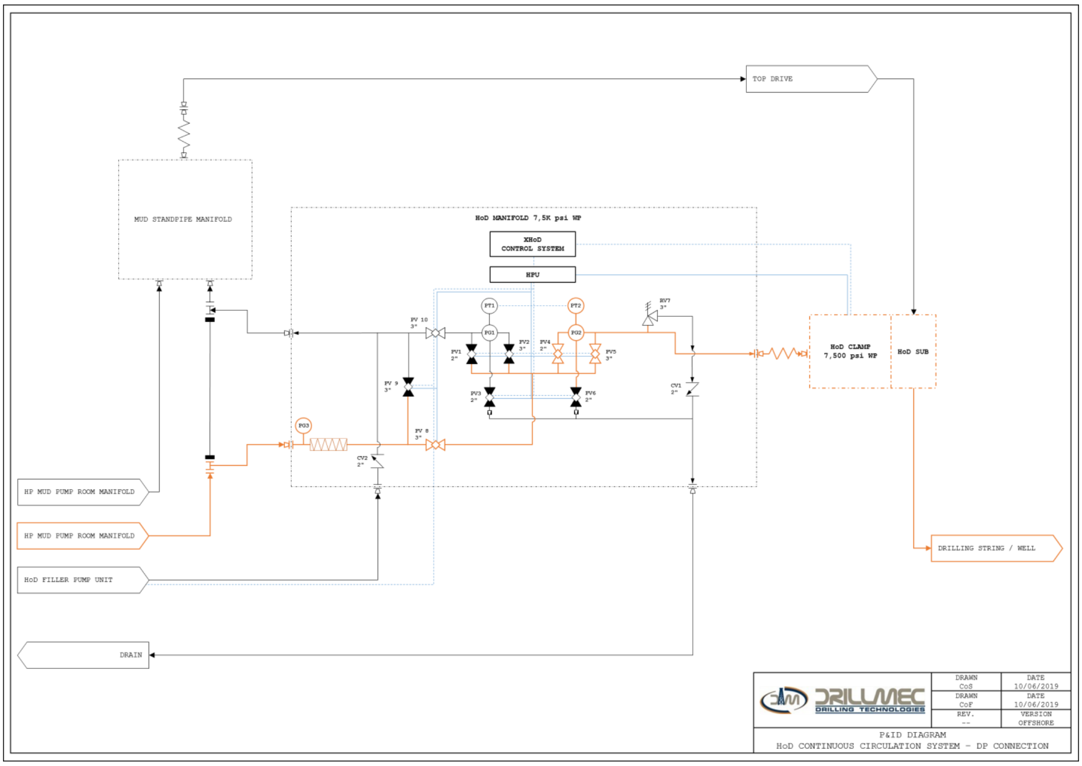


Figure 19. P&ID Drill Pipe Connection

3.2.1.1.4 Operational Phase: New Stand Filling

Finally, the last operative phase of the HoD, is called New Stand Filling, this phase starts after the top drive have been disconnected from the HoD Sub, the operational mode is shown in the figure 20.

For this operational mode, we use an extra piece of equipment, which is the Double Filler Pump (figure 21), this equipment pumps the mud through the HoD Manifold to the Mud Stand Pipe Manifold to allow us fill up the new standpipe.

The Double Filler Pump, is a set of two parallel reciprocating pumps connected to an electric motor. When the DFP starts working, the mud is directed towards the HoD Manifold passing through a check valve (one way) CV2. The valve PV10 is open to allow a pressure measurement through PT1 and PG1.

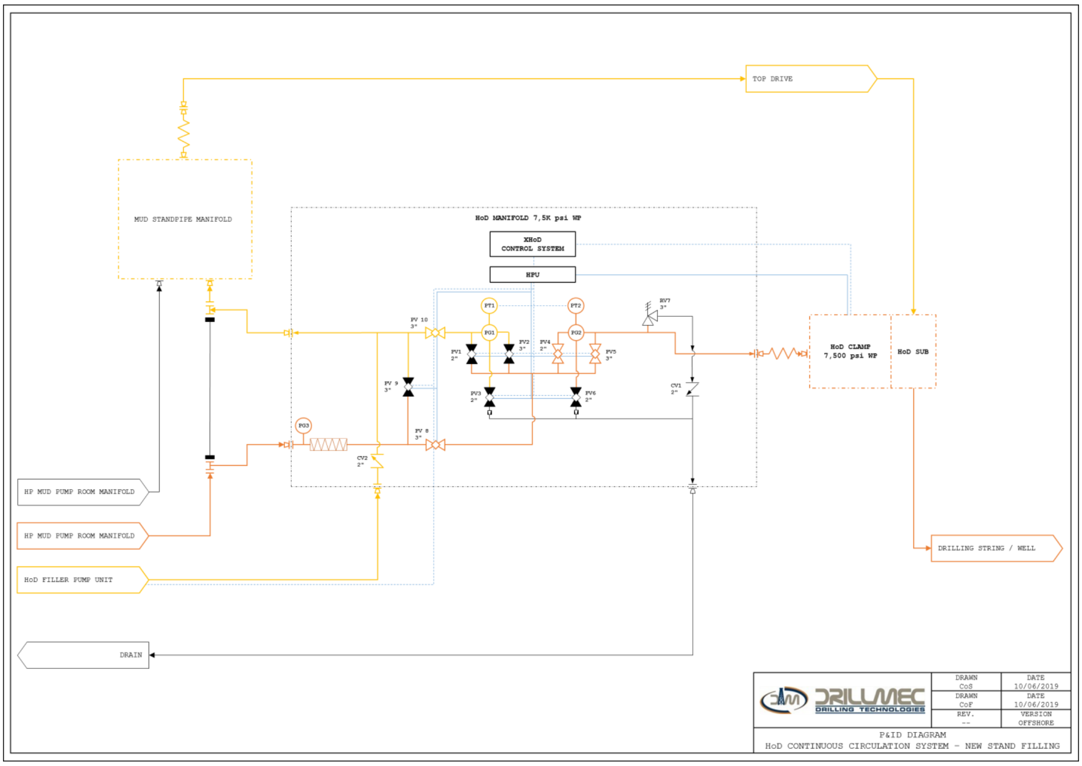


Figure 20. P&ID New Stand Filling

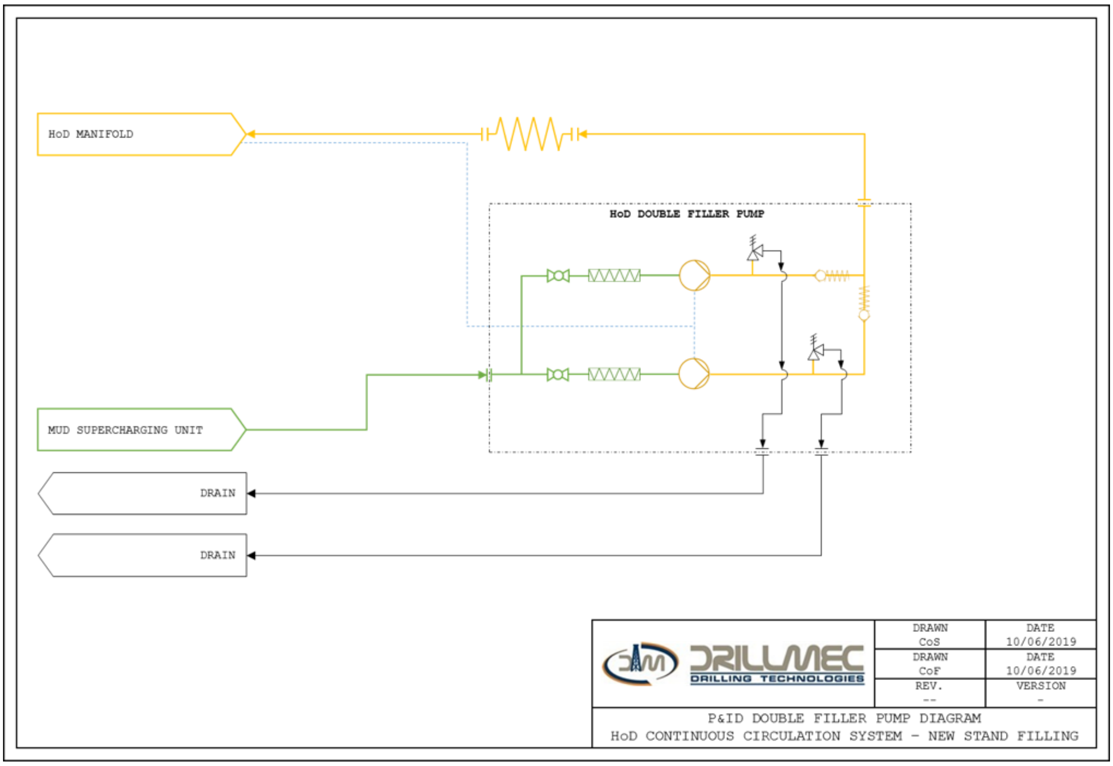


Figure 21. P&ID Double Filler Pump

3.2.2 What if analysis

This technique is defined by ISO 31010:2009 as a *"high-level risk identification, which can be used as part of a staged approach to make bottom up methods such as HAZOP more efficient"* (ISO/IEC 31010:2009, 2009)

The utilisation of this technique involves a brainstorm about a given process or system, in order to enable a comprehensive review of the risk or the sources of risk.

3.2.2.1 Objectives of What if for CCS-HoD®

- The specific objective of this Risk Identification technique, is to highlight the hazards deriving from the process of drilling a well, on normal operation phase.
- Identify hazards due to design and evaluate the potential consequences.
- Establishment of safeguards

3.2.2.2 Assumptions taken for the development of the analysis

- Reservoir conditions are "normal", which implies that, no High Pressure, High Temperature conditions are considered.
- The BOP stack arrangement is suitable for the drilling well, fully compliant with the relevant Codes and Standards.
- The equipment that is considered for the identification is belonging to the CCS- HoD® system, all the rig equipment, is considered to be suitable for the operation in the rig, also it is considered to be fully compliant with codes and standards.
- There are two safety barriers present during the operation (mud, and BOP).

3.2.2.3 Outputs expected of what if analysis

What is expected to have by the end of the analysis, can be briefed as follows:

- A register of hazards and consequences that might be present during drilling activities.
- A register of risks ranked actions that might enable the awareness of developing technology that allows to prevent hazards.

Along with identification made for the CCS-HoD, it is expected also to provide a qualitative ranking of the importance of the severity of the identified risks as it is also combined for the evaluation with the ALARP technique.

3.2.2.4 Benefits and limitations of What if analysis

The benefits and limitations of the present identification technique are summarised on the table 4.

Benefits / Strengths	**Limitations /Weakness**
Minimal knowledge of the process	The generality of the technique does not allow to identify all the risks or hazards
Wide applicable on systems and process	Recommendations arising from it, are generic

Benefits / Strengths	Limitations /Weakness
Permits the identification of opportunities for improvement	Application of the technique does not allow to reveal complex causes.
Quick an easy way to bring out the major risks of a process or system.	

Table 4. Benefits and limitations of what if analysis. Adapted from IEC 31010:2017

3.2.2.5 *Development of What if Analysis for CCS-HoD®*

As stated before, the analysis is a brainstorm technique with questions starting often with "what if".

It had been identified one scenario and to deviations from that main scenario:

- Drilling a well under normal operations
  - Natural and conventional risks during drilling operations
  - Utilisation of CCS-HoD
  - Human Factors

The natural and conventional risk found during drilling operations are found on table 5:

Normal operation: Drilling a well	
Natural and Conventional Risks during drilling operations	What if there is high Equivalent Circulating Density?
	What if there is a hole Instability?
	What if there is Insufficient cutting removal during drilling?
	What if there is high bottom hole pressure?
	What if there is an unsuccessful well control?
	What if there is Lost circulation?
	What if is a wellbore influx?
	What if there is surge?
	What if we have fracture of formation?
	What if we have a kick - Well Control Incident?
	What if we have a blowout - Well Control Incident?

Table 5. What if brainstorm of Natural and Conventional Risks during drilling operations

The utilisation of CCS-HoD while drilling a well give the following brainstorm are found on table 6:

Normal operation: Drilling a well	
CCS-HoD®	What if there is a high environment temperature of the Bottom Hole Assembly while installing the CCS-HoD?
	What if there are problems colligated to the installation of CCS-HoD?
	What if there is an unplanned event originated because of the CCS-HoD?
	What if there is damage to equipment?
	What if there is a lack of containment fluids?
	What if the system not operational?
	What if we loss of electrical power?

Normal operation: Drilling a well	
	What if we loss of hydraulics?
	What if we loss the mud in the system?
	What if the system is exceeding pressure limits of equipment?
	What if the pressure relief valves activate but undetected?
	What if the pressure relief valves do not activate and undetected?

Table 6. What if brainstorm of CCS-HoD

Finally the brainstorm referring to human factors during drilling operations are referred on table 7:

Normal operation: Drilling a well	
Human Factors	What if there are untrained personnel or with lack of experience?
	What if the Work plan not followed?
	What if there are injured personnel?
	What if there is an unclear definition of duties?
	What if the operation of CCS-HoD is overstaffed?
	What if the personnel is not familiar with equipment?
	What if the operation of CCS-HoD is understaffed?
	What if there are communication issues?

Table 7. What if brainstorm for Human Factors

Once the brainstorm is finished, the matrix containing the causes, consequences, safeguards, as well as a qualitative evaluation of the risks found on tables 5, 6 and 7, are elaborated.

3.2.2.5.1 What if? Matrix general description

For the present study the worksheets or matrices of What if? will be presented as follows (figure 22):

System	Well	What if? Number:	1
	Natural & Conventional Risks	Prepared By:	Magdalena Vera Chena
		Date:	13/11/2019
		Revision Date:	23/11/2019

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.

Figure 22. What if worksheet description

In the body of the matrix, it will be present the basic data of the system to be analysed, the sub-system, the operational phase and the mode of operation.

The headers of the matrix will be defined as:

1. **What if?**. Departures from the intention of how the system is expected to operate.
2. **Consequences.-** Results of the deviations, if they occur
3. **Safeguards.-** Current control designs, that prevent the deviations of the parameters to happen.

4. **Mitigation.** Further actions that need to be taken in order to reduce the risk frequency or the damage that the deviation might cause.
5. **Frequency Index**.- Expected number of occurrences of an undesirable event.
6. **Damage**. Represents the last impact of accidents on the people, environment, assets or reputation, evaluated accordingly to the risk criteria matrix found in the Risk Evaluation Section.
7. **Risk**.- Defined as the combination of the Frequency Index and the Damage, it is evaluated by the ALARP methodology described on the chapter 8 of this thesis.

The matrices made for the what if scenarios presented, are found on Annex I.

3.2.3 Hazard Identification (HAZID)

This technique is used as a preliminary risk identification for the process of drilling with a continuous circulation device. With this we can state the fundamentals of why the HoD tool, needs to have a concrete risk assessment for all the operational phases.

This technique is used to systematically list the hazards of the process in a detailed, structured and methodical way. The HAZID is a qualitative technique used for the early identification of potential hazards an threats that might affect the process.

During the developing of this methodology, it is possible to locate the potential incidents and the causes as well as present a general action plan in order to reduce the process incidents.

This technique is selected for the present study since the CCS-HoD®, is still in development phase.

3.2.3.1 Benefits and limitations of HAZID

The benefits and limitations of the present identification technique are summarised on the table 8.

Benefits / Strengths	Limitations /Weakness
Does not require a detailed knowledge of the process	Requires a follow up analysis
Screens and prioritizes hazards	Subjective assessment

Table 8. Benefits and limitations of HAZID. Adapted from IEC 31010:2017

3.2.3.2 Development of HAZID for CCS-HoD®

The first phase of HAZID is to make a functional analysis of the CCS-HoD®, which is developed on table 9.

CODE	FUNCTION
1	CCS-HoD® To Maintain Circulation to the well in all phases of operation
1,1	Drilling & Bypass Drilling Phase : To keep the flow inside the drillstring from the Top Drive while drilling
1.1.1	Manifold divert the flow to the mud standpipe manifold
1.1.2	HoD Sub maintain the axial valve open
1.1.3	HoD Sub maintain the radial valve closed
1.1.4	The Plug on the Radial Valve to maintain Seal
1,2	Drillpipe connection Phase: To Maintain Circulation while top drive is disconnected
1.2.1	Clamp Attaching in the right position to the sub
1.2.2	Clamp Make Pressure Seal Around the Sub Radial Valve
1.2.3	Clamp removes the plug of the radial valve of the sub
1.2.4	Manifold divert the flow to the clamp

CODE	FUNCTION
1.2.5	Radial Valve of the sub opens
1.2.6	Axial Valve of the Sub closes
1,3	New Stand Filing Phase: To fill the new stand with the mud from the Top drive Side, while keeping the circulation from the Sub Side Valve
1.3.1	Double filler pump delivers mud to manifold (low pressure line)
1.3.2	Manifold delivers mud to the mud standpipe manifold (through low pressure line)
1.3.3	Manifold delivers high pressure mud to the clamp
1.3.4	Clamp maintains circulation
1.3.5	Clamp maintain pressure seal around subs radial valve
1.3.6	Sub maintains radial valve open
1.3.7	Sub maintains axial valve closed
1.4	Continue Drilling Phase: To Divert the Flow to the Top Drive Side and Prepare to continue Drilling
1.4.1	Manifold to Divert the Flow to the Standpipe manifold and top drive
1.4.2	Sub Axial Valve To open completely
1.4.3	Sub Radial Valve to close
1.4.4	Clamp to put the Plug and Securing it
1.4.5	Clamp detach from the Sub
1,5	Auxiliary Services
1.5.1	Electrical Power Unit
1.5.1.1	Provide energy to the Control System, Manifold, Clamp, and Double filler pump
1.5.2	Hydraulic Power Unit
1.5.2.1	Provide hydraulic power to Manifold, Clamp, and Double filler pump
1.5.3	XHoD Control System
1.5.3.1	Control of the system during all phases

Table 9. Functional Analysis of CCS-HoD®

3.2.3.2.1 HAZID Matrix general description

The deviations arising from the Functional Analysis, of the present study are developed on worksheets or matrices of HAZID and are established as follows (figure 23):

System	HoD	HAZID Number:	3
Subsystem	HoD Operation	Prepared By:	Magdalena Vera Chena
Operational Phase	**Drilling**	FMEA Date:	25/10/2019
Mode	Open Hole	Revision Date:	04/11/2019

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.

Figure 23. HAZID worksheet description

In the body of the matrix, it will be present the basic data of the system to be analysed, the sub-system, the operational phase and the mode of operation.

The headers of the matrix will be defined as:

8. **Deviation**. Departures from the intention of how the system is expected to operate.
9. **Consequences.-** Results of the deviations, if they occur
10. **Safeguards.-** Current control designs, that prevent the deviations of the parameters to happen.
11. **Mitigation.** Further actions that need to be taken in order to reduce the risk frequency or the damage that the deviation might cause.
12. **Frequency Index**.- Expected number of occurrences of an undesirable event.
13. **Damage**. Represents the last impact of accidents on the people, environment, assets or reputation, evaluated accordingly to the risk criteria matrix found in the Risk Evaluation Section.
14. **Risk**.- Defined as the combination of the Frequency Index and the Damage, it is evaluated by the ALARP methodology described on the chapter 8 of this thesis.

The matrices made with this technique are found on Annex II

3.2.4 Hazard and Operability Analysis (HAZOP)

The Hazard an Operability Analysis (HAZOP) is one of the most common systematic approaches that is used to study the deviations of the parameters of a process. This kind of analysis, is constructed by working with the analysis of operations and processes that are carried on in plants.

"HAZOP is a technique which provides opportunities for people to let their imaginations go free and think of all possible ways in which hazard or operating problems might arise, but to reduce the chance of something being missed. It is done in a systematic way" (Kletz, 1986)

By performing a HAZOP, the teams might be able to identify how the unwanted sequences are initiated; the technique allows the user to approach the initiating event in an inferential way, searching for causes, in order to induce the consequences and prioritize them.

The main objective of performing this kind of analysis is to identify single failures that can turn out into major events (accidents).

In order to investigate a combination of single failures that can lead into a major accident, there are other kind of techniques like the Fault Tree Analysis, nevertheless this kind of technique will not be studied or developed in this thesis work.

The HAZOP technique was first developed at the beginning of the decade of 1960 by engineers of the Imperial Chemical Industries in Great Britain, after accepting that the causes of the accidents can be avoided, or even that the frequency or the amount of damage caused can be significantly lowered.

3.2.4.1 *HAZOP methodology*

A HAZOP study involves a systematic and methodologic examination of the design documents of the installation (in this case machinery). The deviations of the design values and the key parameters are defined by guide words for the analysis. This will assure that the design values of flow, pressure, temperature, and other values are secure for the operation.

This kind of analysis can be performed at any moment, pre-design, design, or even during the operation of the machinery, and it can provide a truly analytical method for risk identification as the study is developed with a multidisciplinary team in order to identify the important aspects of the operability that might end up in an accident.

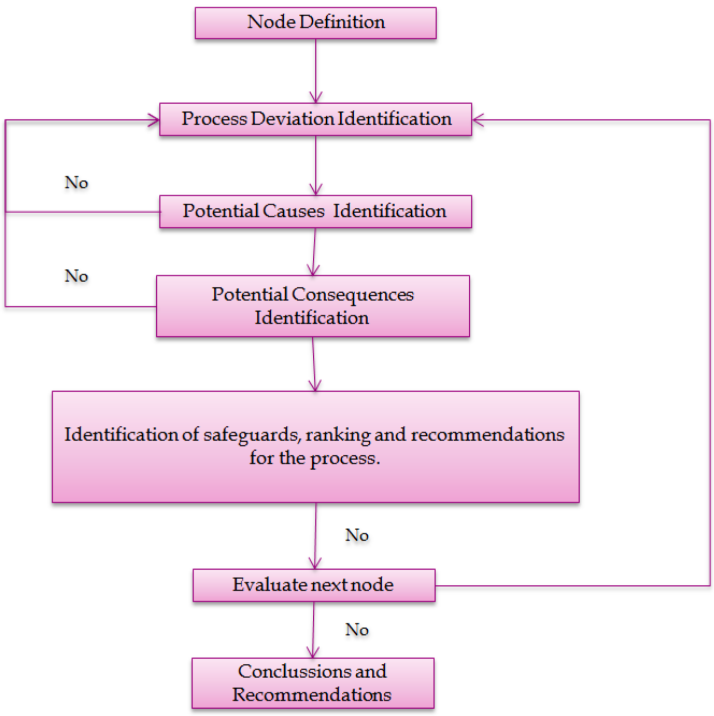


Figure 24. Examination steps for a HAZOP analysis adapted from IEC Standard 61882

The first step into the realisation of a HAZOP study is to define the scope, boundaries of the system and the team that will perform the analysis.

The data collection and the division of the process into nodes are followed up by the deviation identification for each node. The guide words, and the deviations that might arise from those are then identified. (See table 12)

The result of the HAZOP should be independent of the node selection. After the nodes had been chosen, a team meeting for a brainstorm is required. For each node and deviation, the potential causes, safeguards, recommendations and a ranking is given for each node, and in the case of this thesis, for each node under each operational mode. The conclusions for each operative mode and for each node are made.

A simplified diagram with the main steps of performing the HAZOP analysis can be found on figures 24 and 25, both based on the IEC 61882.

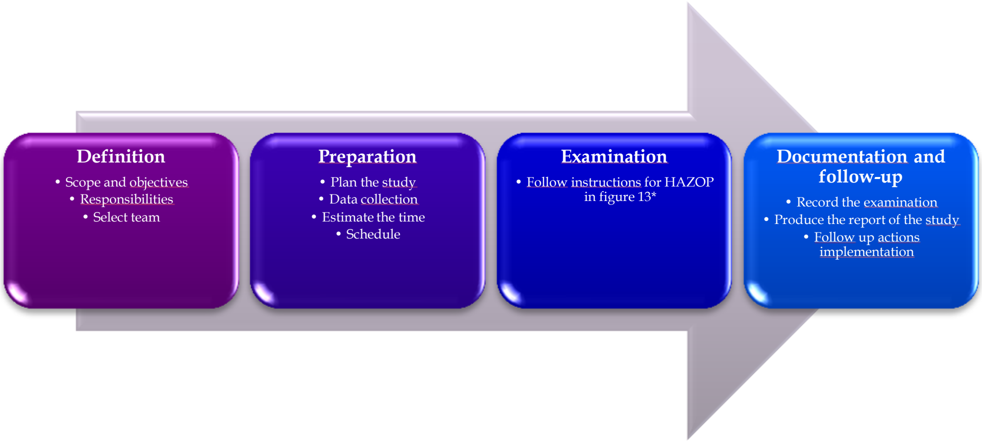


Figure 25. HAZOP procedure simplified. Adapted from IEC61882

3.2.4.1.1 Benefits and Limitations of HAZOP

According to IEC 61882:2006 and to ISO 31010:2018, the HAZOP, carries out different benefits and limitations

Benefits / Strengths	Limitations /Weakness
Generates solutions and risk treatment actions	It is constrained by the design and the scope and objectives.
Applicable to a wide range of systems, procedures and processes	Process relies on the expertise of the designers who might not be objective enough to seek and find problems in their designs
Allows explicit consideration of the causes and consequences of human error	Technique tends to be repetitive as it might find the same issues multiple times
Provides the means to systematically examine a system, process or procedure to identify how it might fail to achieve its purpose	A really detailed analysis can be time consuming and therefore expensive
Identifies potential problems at the design state of a process.	A detailed analysis, requires a high level of documentation or system/process, and procedure specifications

Table 10. Benefits and Limitations of HAZOP analysis.

3.2.4.1.2 Standards used to perform the HAZOP analysis

For the performance of this analysis, it was mainly used:

- IEC 61882 (2001) Hazard and operability studies (HAZOP studies)- Application guide.

3.2.4.2 Development of HAZOP for CCS-HoD®

The conduction of HAZOP analysis as part of Hazard Identification has been developed following all the steps described as follows.

3.2.4.2.1 Objectives of HAZOP for CCS-HoD®

- The specific objective of this Hazard and Operability analysis is to highlight the hazards deriving from the process of drilling a well, on normal operation phase.
- Identify hazards due to design in each one of the operative phases defined on the Scenario Analysis and evaluate the potential consequences.
- Establishment of safeguards.

3.2.4.2.2 Assumptions made for HAZOP

- Reservoir conditions are "normal", which implies that, no High Pressure, High Temperature conditions are considered.
- The BOP stack arrangement is suitable for the drilling well, fully compliant with the relevant Codes and Standards.
- The equipment that is considered for the HAZOP is belonging only to the CCS-HoD®, all the rig equipment, is considered to be suitable for the operation in the rig, also it is considered to be fully compliant with codes and standards.
- There are two safety barriers present during the operation (mud, and BOP).

3.2.4.2.3 Outputs expected of HAZOP

What is expected to have by the end of the analysis, can be briefed as follows:

- Worksheet containing a screening the deviations of the parameters, the causes, effects, existing controls and safeguards, and the consequences of the deviation of parameters.
- A worksheet containing a list of events characterised by a qualitative level of risk,

3.2.4.2.4 Node Selection

The first activity performed, as described on figure 23, is the node selection. This activity allows to visualize each stage of the process (and the operative phases) according to a functional unit.

For each operative phase of the process, the system had been subdivided into smaller and more manageable nodes. Table 11 shows the nodes selection for the CCS-HoD®

Node	Operational Phase			
	Drilling	Bypass Drilling	Drill Pipe Connection	New Stand Filling
1	HoD-Manifold	HoD-Manifold	HoD-Manifold	Double Filler Pump
2	HoD-Sub	HoD-Sub	HoD-Sub	HoD-Manifold
3			HoD-Clamp	HoD-Sub
4				HoD-Clamp

Table 11. Node definition for Operational Phase

A representation of the nodes on the P&ID layouts is found on Annex III

The intention of each node refers to the operational physical parameters that the equipment sustain,(pressure, flow, level, temperature). This are the limits that each "node" cannot surpass,.

3.2.4.2.5 Node Deviations

In order to continue with the assessment, the deviations of the process caused by a single node were identified.

The deviations of a node are identified with a guideword. Table 12 shows the most common guide words and the definitions of each one.

This guidewords describe the alteration of a parameter that can create a dysfunction on the system.

Guide Words	Definition	Example
No or not	No part of the intended result is achieved or the intended condition is absent.	No flow
More (higher)	Quantitative increase	Higher pressure
Less (lower)	Quantitative decrease	Lower temperature
As well as	Qualitative modification / increase	Additional Material
Part of	Qualitative modification / decrease	Only one of two components in a mixture
Reverse / opposite	Logical opposite of the design intent	Backflow
Other than	Complete substitution, something completely different happens	Wrong material
Early	Relative to clock time	
Late	Relative to clock time	

Table 12 Guide words and the meaning for the development of HAZOP. Taken from the (ISO/IEC 31010:2009, 2009)

From the deviations, found on each node, there will be a reason why it occurs, this is described as a cause, which also is stated on the HAZOP worksheet.

The current control designs, and the ways of the system detecting one of the possible deviations thus preventing a consequence to happen are defined as safeguards.

3.2.4.2.6 HAZOP Matrix general description

For the study carried on the CCS-HoD®, the worksheets or matrices of HAZOP will be presented as follows (figure26):

System	HoD	NODE	BPD-2
Subsystem	HoD Sub		
Operational Phase	BY PASS DRILLING		
Mission	To allow the connection of the top drive or the clamp according to the phase		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ.	Rep.	People	Envi	Econ.	Rep.	

Figure 26. HAZOP Worksheet description

In the body of the matrix, it will be present the basic data of the system to be analysed, the sub-system, the operational phase, the mode of operation, the function of the node defined and the number of node.

The headers of the matrix will be defined as:

15. **Process parameter**. Defined on table 6.
16. **Guide word**.- Simple words used to quantify the intention.
17. **Deviation**. Departures from the intention of how the system is expected to operate.
18. **Causes.-** Reasons of why deviations might occur
19. **Consequences.-** Results of the deviations, if they occur
20. **Safeguards.-** Current control designs, that prevent the deviations of the parameters to happen.
21. **Frequency Index**.- Expected number of occurrences of an undesirable event.
22. **Damage**. Represents the last impact of accidents on the people, environment, assets or reputation, evaluated accordingly to the risk criteria matrix found in the Risk Evaluation Section.
23. **Risk**.- Defined as the combination of the Frequency Index and the Damage, it is evaluated by the ALARP methodology described on the chapter 8 of this thesis.

The complete matrices made with this technique are found on annex IV

3.3 Risk Analysis

3.3.1 Fault Tree Analysis (FTA)

The fault tree analysis is a graphic technique that allows the analysis of the factors that might contribute to the development of an unwanted event, called also top event. This top event is analysed by first identifying its immediate causes.

The causes are identified deductively and organised in a logical manner, that the FTA causes can be understand, analysed and if necessary, rearranged in a clear way.

The fault tree analysis is a top-down method, this means that the analysis starts from the "top event" and continues down until the basic causes of this event are reached. This top-down methodology is contrary to the Risk Identification techniques, which almost all of them are bottom-up, which means start from the basic causes until it reaches the last consequences, or the undesirable events.

The FTA, then, it's a complementary technique for the bottom-up ones, that will allow to corroborate the basic events identified by the risk identification techniques; hazard identification and hazard and operability analysis.

FTA, includes only the events that actually contribute to the occurrence of a top event and permits the user to identify the combinations (cut sets), that are more probable to happen during the normal operation of the equipment.

ISO/IEC 31010:2009 states the following: "*Many risk events may have a range of outcomes with different associated probability. Usually, minor problems are more common than catastrophes. There is therefore a choice as to whether to rank the most common outcome or the most serious or some other combination. In many cases, it is appropriate to focus on the most serious credible outcomes as these pose the largest threat and are often of most concern. In some cases, it may be appropriate to rank both common problems and unlikely catastrophes as separate risks. It is important that the probability relevant to the selected consequences is used and not the probability of the event as a whole.*"

3.3.1.1 Common Cause Failure Analysis

The analysis of the common cause failures consider that two or more components can fail at the same time due to a single root cause.

Common cause failures can be triggered by coupling mechanisms joining two or more components. Table 13 shows some of the usual CCF and the related coupling mechanisms.

Common Cause Failure	Coupling Mechanism
• Manufacturing Error • Raw material of poor quality	Same manufacturer
Maintenance Error	Same maintenance team
• Flooding • Fire • Humidity	Same room
Operator error	Same kind of action

Table 13. Common cause failure and coupling mechanisms. Taken from (Carpignano, 2009)

3.3.1.1.1 Explicit modelling of the CCF

The basic events in a fault tree model are considered as specific causes. Therefore, it is modelled explicity.

Explicit modelling of CCF's means to add each specific cause.

Specific causes might include:

- Human Error
- Utility Failures
    - Electric Power Failure
    - Hydraulic Power Unit Failure

It is chosen when data is available. An example of explicit modelling of CCF is shown in figure 27.

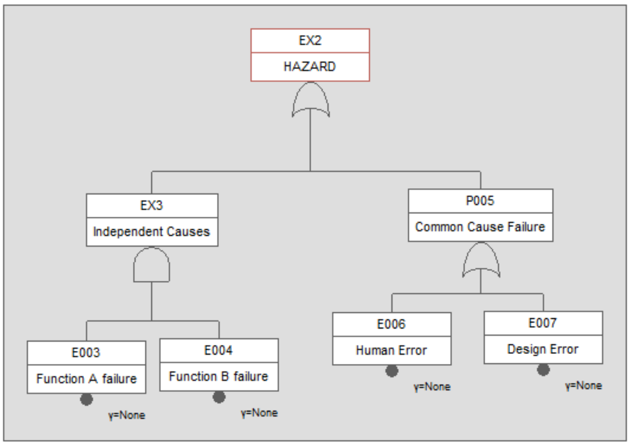
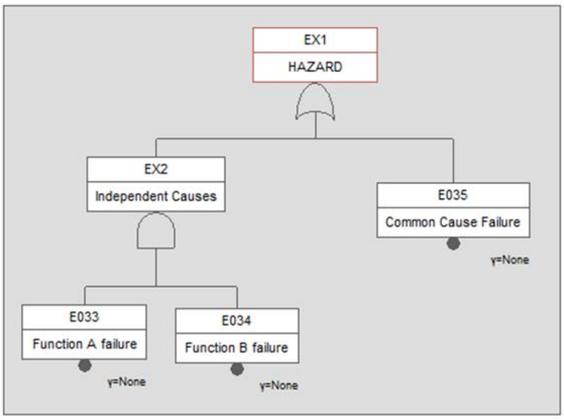


Figure 27. Explicit Modelling of CCF

3.3.1.1.2 Implicit modelling of the CCF

Add a single event that cover for all the hidden causes. It is commonly utilised when data for a specific event it is not available. An example is shown in figure 28.



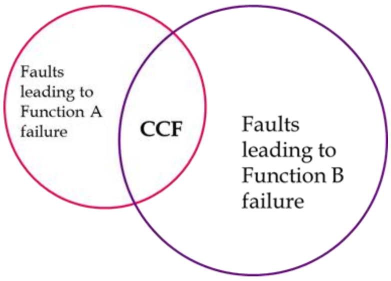


Figure 28. Implicit Modelling of CCF

3.3.1.2 *Reliability Analysis*

Reliability Analysis considers a set of items, to which a failure event may occur at some point during the lifetime.

Not all components (items) behave the same within a system, that is why, on section 3.3.1.2.1 there is a brief description of each type of component and the estimation of the reliability and availability of them.

3.3.1.2.1 Types of components and the estimation of unavailability and unreliability

Unrepairable.- A component failure mode requiring the cancellation of the mission system in order to carry out the repair.

Repairable.- A component failure mode whose repair does not compromise the mission and whose failure is immediately revealed.

Tested.- Component whose failure mode does not compromise the mission and whose failure does not reveal itself. For these components it is necessary to carry out tests or preventive inspections in order to verify the proper functioning.

Unavailability Q(t), and Unreliability F(t), are calculated differently depending the type of component to be assessed. (Rausand & Arnlijot, 2004)

Availability (A) defines the ability of a component X to be healthy at time t.

Reliability (R) defines the ability of a component X to be healthy from time t=0 to t.

Unavailability (Q) → Q(t) = 1 – A(t)

Unreliability (F) → F(t) = 1 – R (t)

The equations to calculate the unavailability and the unreliability, based on the type of component are shown in table 14.

Component	λ [1/h]	μ [1/h]	θ [h]	F(t)	Q(t)
Unrepairable	x			$F(t) = 1 - e^{-\lambda t} \cong \lambda \cdot t$	$Q(t) = 1 - e^{-\lambda t} \cong \lambda \cdot t$
Repairable	x	x		$F(t) = 1 - e^{-\lambda t} \cong \lambda \cdot t$	$Q(t) = \frac{\lambda}{\lambda + \mu}$
Tested	x		x	$F(t) = 1 - e^{-\lambda t} \cong \lambda \cdot t$	$Q(t) = \frac{1}{2}\lambda \cdot \theta$

Table 14. Formulas to determine Unreliability and Unavailability. Taken from (Carpignano, 2009)

Where:

- θ: date of the first test
- λ: Failure rate
- μ: Repair rate (and its inverse the repair time, MTTR)

3.3.1.3 General Methodology of FTA

As stated before, the FTA is a top-down methodology that allows to introduce the top event as the objective of the study, then going down to find the causes, which can, actually be combined with the failure modes found on HAZOP and HAZID.

To simplify the development of the FTA, the software ARBRE ANALYSTE is used to perform the analysis.

During the development of the FTA, the basic definitions we can find are:

- **Top Event:** Major undesirable event. All the paths are directed towards this event
- **AND Gate**: Produces an output only if all the inputs are present at the same time.
- **OR Gate**: Produces an output if any input happens at a given time.
- **Basic Event**: Initiating failure. It defines the limit of the resolution for the analysis.

And its graphic representation is shown on the figure 29.

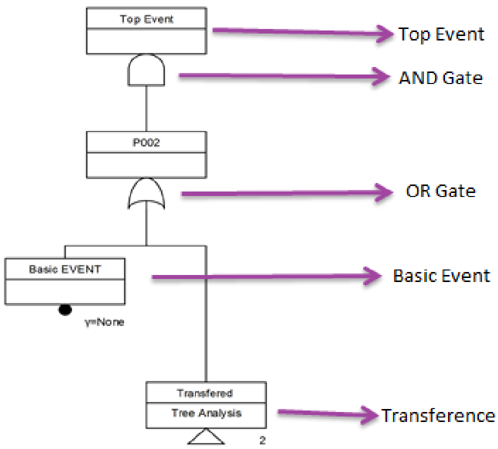


Figure 29. FTA construction and definitions. Adapted from IEC 61025:2006

The basic steps that have to be followed in order to identify the top event and the development of the FTA are summarised on the figure 30.

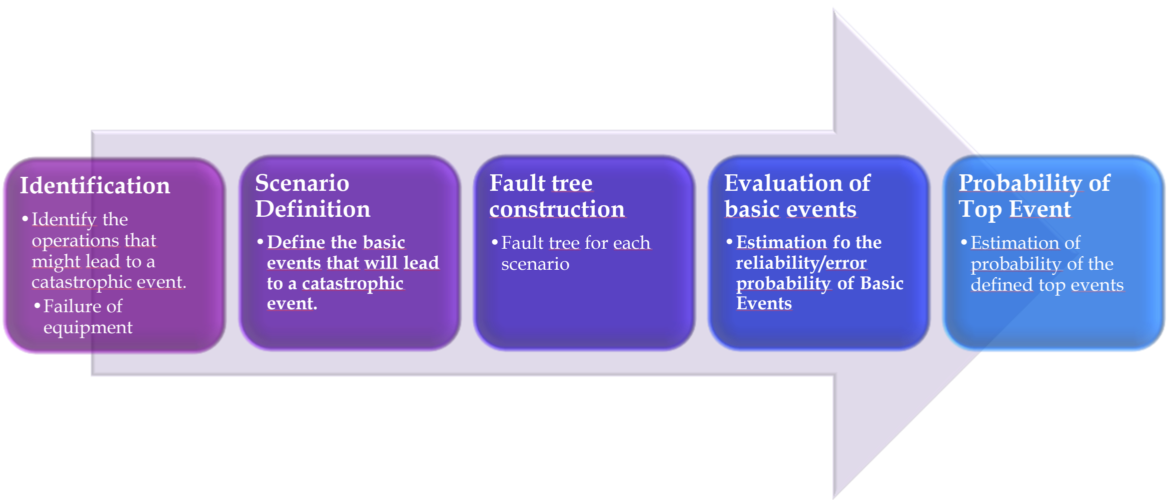


Figure 30. Methodology of the FTA. Adapted from IEC 61025:2006

3.3.1.3.1 Standards used to perform the Fault Tree Analysis

For the performance of this analysis, it was mainly used:

- IEC 61025 (2006) Fault tree analysis
- NASA (2002) Fault Tree Handbook with Aerospace Applications

3.3.1.3.2 Benefits and Limitations of FTA

According to IEC 61025:2006 and to ISO 31010:2017, the Fault Tree Analysis, carries out different benefits and limitations, among which:

Benefits / Strengths	Limitations /Weakness
Highly systematic but flexible enough to allow the analysis of the interaction of humans and physical phenomena	Deals only with binary states (success/failure)
Provides a graphical representation that is easy to understand	Human error modes are difficult to define
Can be adapted to simple or complex problems	Analyses one top event at the time
Helpful to analyse systems with a wide range of interfaces and interactions.	Can be very large depending on the scale of the process / project

Table 15. Benefits and Limitations of FTA analysis, adapted from IEC 31010:2017

3.3.2 Development of Fault Tree Analysis for CCS-HoD®

3.3.2.1 Objectives of FTA for CCS-HoD®

- Obtain the probability (unreliability and unavailability) of top event for all operative phases.
- Get the graphic representation of the top event, not providing mud to the system, which means total failure of the CCS-HoD® for all the operative phases studied in HAZOP.
- Calculate Birnbaum and Fussel Vesely Indices for the unreliability and unavailability of the system.
- Recommendations based on the analysis.
-

3.3.2.2 Assumptions for FTA

- Reservoir conditions are "normal", which implies that, no High Pressure, High Temperature conditions are considered.

- The equipment that is considered for the FTA is belonging only to the CCS-HoD®, all the rig equipment, is considered to be suitable for the operation in the rig, also it is considered to be fully compliant with codes and standards.

- There are two safety barriers present during the operation (mud, and BOP).

- All components are defined as "unrepairable" during the mission time (set to 24 hours).
- The CCF's are defined as probabilities of independent failure of an utility component.
- The CCF's are introduced explicitly on the FTA.

- Two different simulations of the FTA were performed:
  I. One considering the human error on each equipment (it is consider a different operator on each equipment) the diagrams for this scenario are found on annex VI, and their complete report on annex VII

     a. The probability of error of the operators is calculated per operator (per equipment), through the HEART methodology (Annex V).
     b. The probability of error of the operators in the development of FTA is kept constant.

  II. One considering the equipment as independent of the human error, the complete report for this scenario is found on Annex VIII.

- In order to realise this analysis, as the equipment is still in development phase, the failure rates were taken mainly from OREDA database. All the failure rates are summarised on table 16, along with the source from where it was taken.

3.3.2.3 *Outputs expected of FTA*

What is expected to have by the end of the analysis, can be briefed as follows:

- Graphic representation of how the top events can occur, and which are the actions that lead to a failure result.
- Top events for all operative phases will be marked as total failure of the CCS-HoD® during the specific operational phase.
- List of minimal cut sets (failure pathways), with the occurrence probability of each one.
- Probability of top event(s) to happen and the importance of the base events.

3.3.2.4 *Failure Rate data of equipment*

The following data was retrieved from databases, in order to set the basic data of events for the CCS-HoD® analysis.

	FAILURE	Mode of Failure	λ1	λ2	λ3	Source 1	Source 2	Source 3
BOP	Failure control Panel BOP Pipe RAMP (pneumatic)			**1,80E-05**		Blue book		
	Failure control Panel BOP Pipe Superintendent Area (Pneumatic)			**1,80E-05**		Blue book		

	FAILURE	Mode of Failure	λ1	λ2	λ3	Source 1	Source 2	Source 3
	Failure control panel on BOP Accumulators (mechanical)			1,10E-06		Dossier Ambiente 26		
	Failure BOP accumulator / Command line		2,40E-06	4,20E-05		Oreda 2002	Blue Book	
	Failure IBOP activation system		2,40E-06	4,20E-05		Oreda 2002	Blue Book	
	Failure IBOP (Fails to seal)		1,60E-06	1,10E-06		SPE 35773	Dossier Ambiente 25	
	Shear Ram (fails to cut)		2,90E-04					
	Shear Ram (fails to seal after cut)		9,30E-04	1,60E-04				
	Pipe Ram (fails to seal)		5,80E-06					
	Annular Preventer (fails to seal)		2,50E-04	2,10E-04				
	Choke Kill/Line		1,80E-06	5,30E-06				
	Electrohydraulic pod			2,60E-04				
	Accoustic system failure					DNV		
	Failure BOP connector			7,10E-06		SINTEF		
DOWNHOLE SENSORS	Failure downhole sensors (Mud)		2,20E-05	1,10E-05	6,00E-07	Dossier ambiente 30	Oreda 2002	SPE 35778
	Failure downhole sensors (Level)		2,20E-05	1,10E-05	6,00E-07	Dossier ambiente 26	Oreda 2002	SPE 35774
	Failure downhole sensors (ROP)		2,20E-05	1,10E-05	6,00E-07	Dossier ambiente 27	Oreda 2002	SPE 35775
	Failure downhole sensors (Gas)		2,20E-05	1,10E-05	6,00E-07	Dossier ambiente 28	Oreda 2002	SPE 35776
	Failure downhole sensors (Flowmeter)		2,20E-05	1,10E-05	6,00E-07	Dossier ambiente 29	Oreda 2002	SPE 35777
OTHERS	Pipe leaks above BOP			6,80E-08		DNV		
	Drillpipe leaks			6,80E-08		Well Master		
HoD- MANIFOLD	PV	External leakage		1,40E-07		Oreda 2002		
		Fail to open		3,81E-06		Oreda 2002		
		Fail to close		3,03E-06		Oreda 2002		
		Critical		7,67E-06		Oreda 2002		
	CV	Critical		4,53E-07		Oreda 2002		
	RV	External leakage		1,20E-06		Oreda 2002		
		Fail to open		3,36E-06		Oreda 2002		
		Leak in closed position		2,24E-06		Oreda 2002		
	Pressure Sensor	Complete failure		1,76E-06		Oreda 2002		
	Valve Position Sensor	Complete failure		4,50E-06		Oreda 2002		
	Control System	Complete failure		1,82E-04		Oreda 2002		
	HPU	Complete failure		1,39E-05		Oreda 2002		
	Filter	Complete failure		7,45E-08			Oreda 2002	
	Pipe (hard pipe)	Complete failure		1,79E-07			Oreda 2002	
Double Filler	Pump 1- Reciprocating	Breakdown		5,00E-06		Oreda 2002		
	Electric motor	Fail to start on demand		5,24E-06		Oreda 2002		
		Breakdown		2,06E-06		Oreda 2002		

	FAILURE	Mode of Failure	λ1	λ2	λ3	Source 1	Source 2	Source 3
	DFP-BV1	Low output		**1,00E-07**		Oreda 2002		
		Incipient		**1,39E-05**		Oreda 2002		
		External leakage		**3,90E-07**		Oreda 2002		
	Pipe	Complete failure		**1,70E-07**		Oreda 2002		
	Hose	Blocked		**1,19E-06**		Oreda 2002		
	DFP-F1	Blocked		**7,45E-08**		Oreda 2002		
	DFP-CV	Fail		**4,03E-06**		Oreda 2002		
	DFP-PSV1	Degraded		**8,26E-06**		Oreda 2002		
		Leaks in closed position		**1,78E-06**		Oreda 2002		
		Spurious operation		**1,78E-06**		Oreda 2002		
HoD- SUB	Failure Radial Valve	Complete failure		**1,49E-06**		Expert group		
	Metal to Metal seal fails to seal	Failure due to threads being out with mannufacturing tolerances		**5,70E-10**		HSE - Health and Safety executive		
		Galling on seal face		**3,43E-08**		HSE - Health and Safety executive		
		Insufficient make up torque		**3,43E-08**		HSE - Health and Safety executive		
		Excesive loading on thread an seal		**4,30E-07**		HSE - Health and Safety executive		
		Critical		**3,43E-08**		HSE - Health and Safety executive		
	Failure Axial Valve	Complete failure		**1,49E-06**		HSE - Health and Safety executive		
	Sub body	Leaking		**6,80E-08**		Expert group		
HoD - CLAMP	Electrical component	Complete failure		**4,94E-12**		Expert group		
	Clamping Actuator	Complete failure		**1,00E-06**		Expert group		
	Internal Actuator	Complete failure		**6,40E-06**		Expert group		

Table 16. Equipment Failure Rate data, and sources (Database, 2002) (Database, 2006) (Database, 2010)

3.3.2.5 Human Error Probabilities

The calculation of human error probability, is calculated through the HEART (Human Error Assessment & Reduction Technique) methodology. The values used for the assessment are present on table 17.

The methodology and the full table of calculation of human error probability are found in annex V.

Task	Human Error Probability

Task	Human Error Probability
Decision Error / Delayed intervention MANIFOLD utilisation	0,008320435
Decision Error / Delayed intervention CONTROL PANNEL utilisation	0,0002079168
Wrong action / Delayed intervention CLAMP utilisation	0,0056595
Wrong action / Delayed intervention DOUBLE FILLER PUMP utilisation	0,002983512
Wrong action / Delayed intervention HPU utilisation	0,002983512
Wrong action / Delayed intervention EPU utilisation	0,002983512

Table 17. Human Error Probabilities calculated through Heart Methodology

3.3.2.6 FTA of CCS-HoD®

For the elaboration of this analysis, the critical scenarios were taken from the HAZID and HAZOP, which are the Risk Identification methodologies.

The scope of the present thesis, assess the probability of total failure of the equipment CCS-HoD®, which can be used, for example, to address the probability of losing the first safety barrier (mud), or even, in case that the second barrier is lost, to have a blowout.

Figure 31 shows a basic FTA for a Blowout event while drilling containing the contribution of failure of the CCS-HoD®.

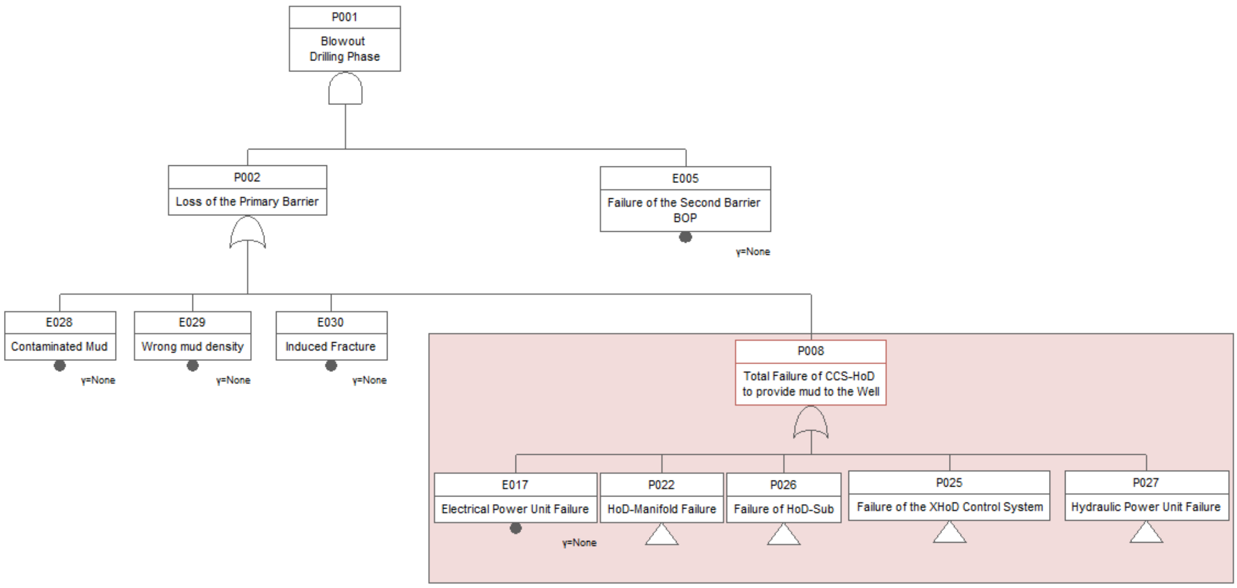


Figure 31. Fault Tree Analysis of a Blowout while drilling and using CCS-HoD®

The study performed, then, shows the probability of the equipment to fail completely (in all of the operative phases).

The top event then is: **Total Failure of the Equipment to provide mud to the well.**

Figure 32 shows the principal fault tree analysis for the bypass drilling phase.

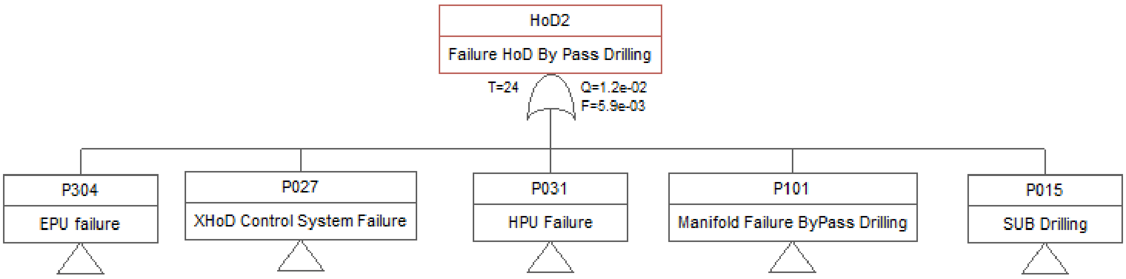


Figure 32. Figure 31. General FTA for failure of the CCS-HoD®, on Bypass Drilling Phase

In order to evaluate the unreliability of the equipment to perform for 24 hours (it is considered in the assumptions of this FTA, that the equipment will perform an operational phase for one day).

Each one of the transfer events that are shown in the principal Fault Tree Analysis, were studied as well for the operational phase. Figures 33, and 34.

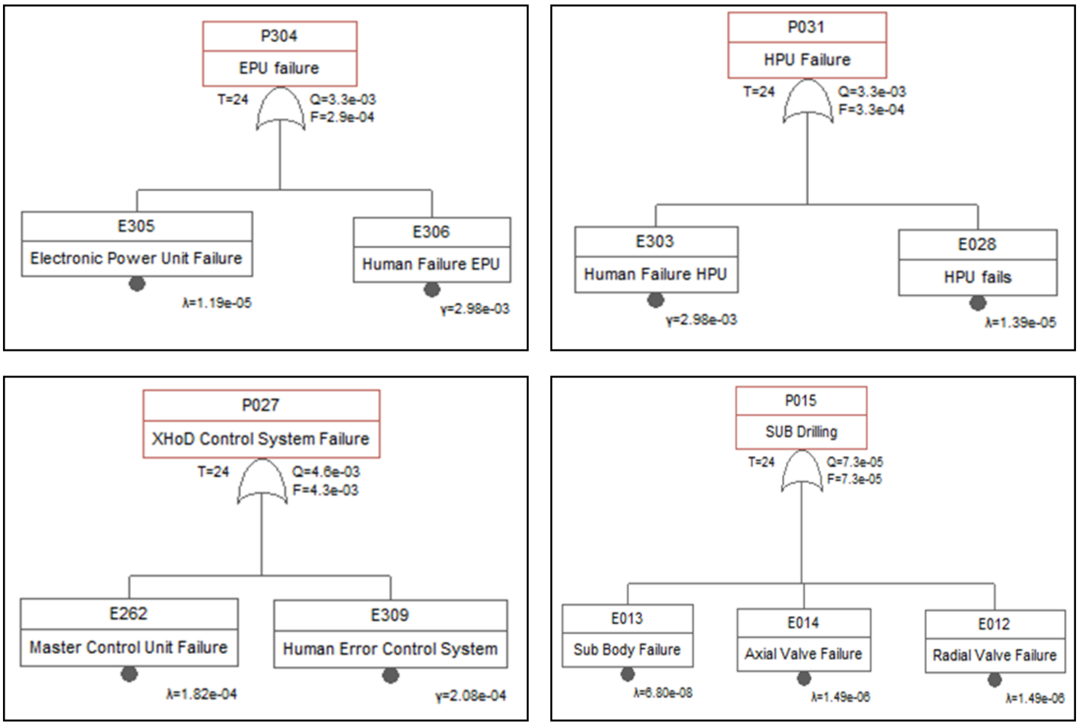


Figure 33. Specific FTA for Drilling Phase (EPU, HPU, Control System & Sub)

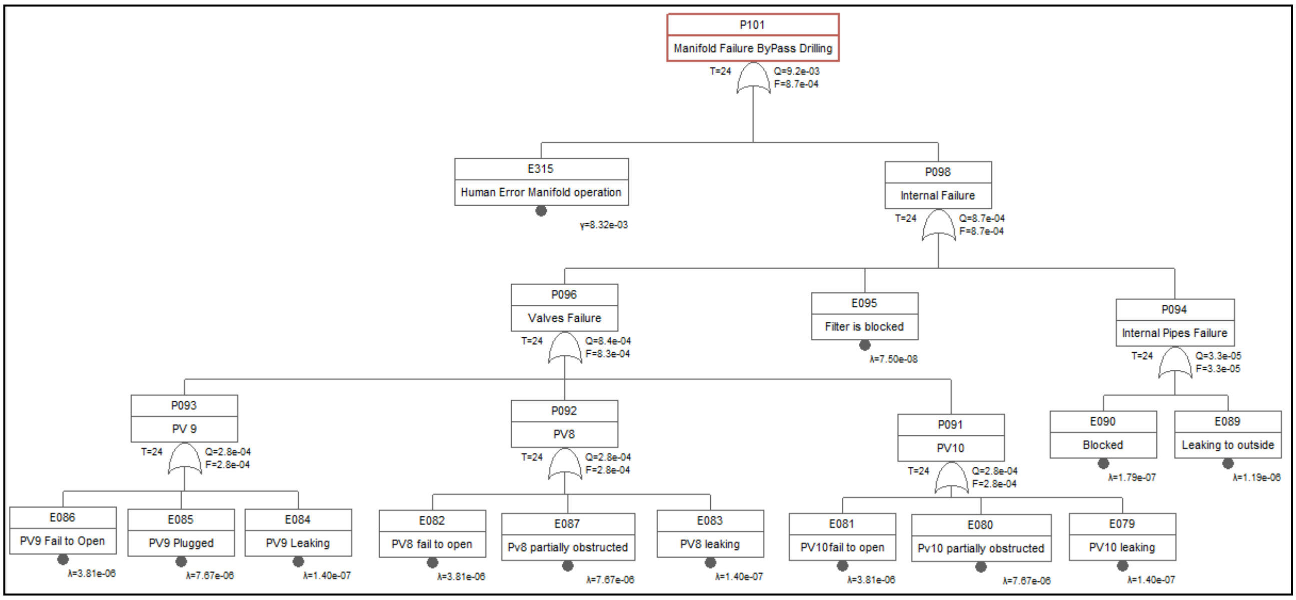


Figure 34. Specific FTA for Drilling Phase (HoD-Manifold)

The fault tree analysis had been made for all the operational phases along with the transfer tree analysis of each one of them. All of them are found on Annex VI.

3.3.2.6.1 *Common Cause Failure Analysis of CCS-HoD®*

For the present analysis as stated in the assumptions the, common cause failures identified are represented in an explicit way.

The approximations set for the CCF's present on the CCS-HoD®, are statistically estimated according to the probability of independent failure of the following:

- Hydraulic Power Unit (HPU) failure
- XHoD Control System failure
- Electrical Power Unit (EPU) failure

This is due to the fact that all the equipment of the CCS-HoD®, is legated to this three utility systems, any failure of the above, will result in the failure of the system.

The human factor errors, are also part of the common cause failure, nevertheless, for the development of this study, is considered that one person is responsible of an equipment only, (i.e., HPU is operated by the HPU operator, Control System, by the XHoD-Control system Operator), and that, the equipment can be operated through the control system, or manually.

Figure 34, represents how the common cause failure is taken into account inside the development of the fault tree analysis.

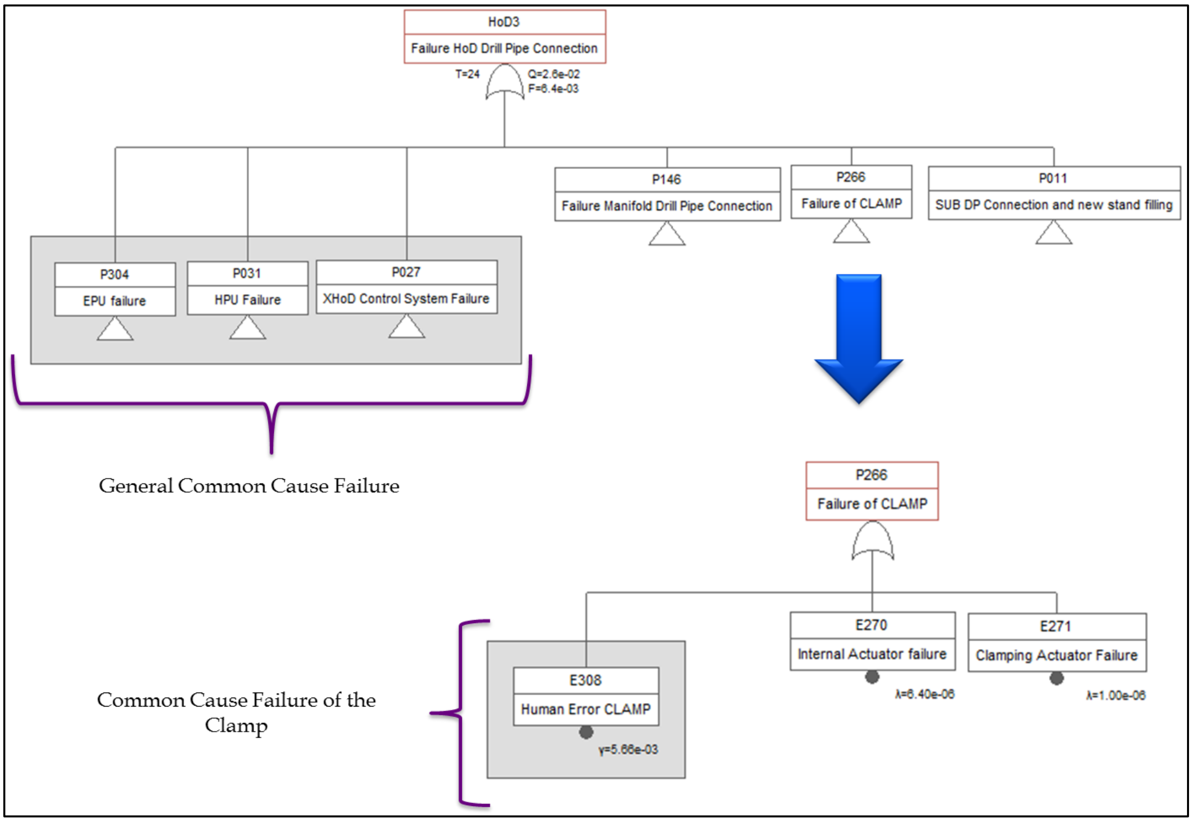


Figure 35. Common Cause Failure representation on the FTA

3.4 Risk Evaluation

3.4.1 ALARP

ALARP it is the short version of "As Low as Reasonably Possible", it is a criteria utilised to decide and prioritise the risks that need to be mitigated. The ALARP model allow to classify risks into three categories:

- **Intolerable Risk**, the activities that fall on this category must be stopped in order to treat the risk and mitigate it to an acceptable level.

  The intolerable region is presented in the red-coloured zone. In this part, all the proper measures to decrease the level risk should be taken, such as inspection, maintenance, design, etc.

- **ALARP Region**, all the activities that fall within this zone have acceptable risk levels in principle, but additional safety measures should be implemented for to add more safety to the system.

  The ALARP region, is presented on a yellow-coloured zone, this zone lies between the intolerable and the tolerable areas of risk .

- **Broadly acceptable risk** , any activity within this region is broadly tolerable, and further safety actions for risk reduction are not necessary but not out of the line for continuous improvement.

  The negligible region is identified on the green -coloured zone.

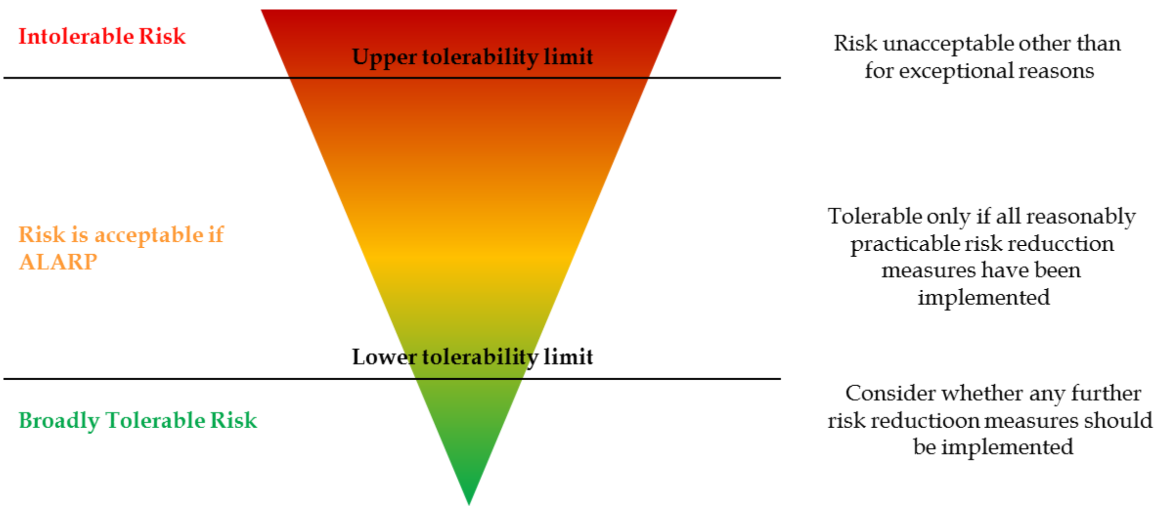


Figure 36. ALARP criteria. Adapted from IEC-31010:2017

The matrix is therefore fully compliant with the ALARP principles, considered for the evaluation criteria of the assessment.

3.4.1.1 Strengths and limitations of ALARP criteria

Benefits / Strengths	Limitations /Weakness
Allow for non-prescriptive goal setting	The interpretation might be challenging because it requires
Allow continuous improvement towards the goal of minimising risk	With new technologies risks and possible treatments, might not be known or fully understood.
Provide a transparent an objective methodology for discussing and determining acceptable or tolerable risk through stakeholder consultation	Might set a common standard of care that may not be financially affordable for small organisations.

Table 18. Strengths and limitations of ALARP. Adapted IEC31010:2017

3.4.1.2 ALARP for CCS-HoD®

The results of the assessment are implicitly included in the development of the risk identification, the risk matrix utilised to perform this assessment is in compliance with the ALARP specifications and codes.

4 - Results of the Assessment

4.1 Results of What if? Analysis

The record of the What if Analysis Worksheets is found on the **Annex I**.

The work made, was taken as a first approach to the continuous circulation device HoD and the common problems that happen during the drilling operations.

This assessment was made in order to identify the common problems that might appear during the normal operation of the tool. The value of the assessment it is that it was made from the point of view of the well. Therefore, is not only an assessment that will uncover the tool usage, but also the surrounding activities that might cause harm if performed in a wrong way.

Therefore, the analysis had been carried on three different levels in order to identify the risks that had been added to the drilling operation by the utilization of CCS-HoD®. The first level is to identify the risk that arise from the wellbore, and the ones that are accompanied with the normal drilling operations.

The second level is concerned about the identification of risks colligated to the installation and utilisation of the continuous circulation system HoD while drilling on the rig.

The third and last level was made to identify the effect of the human errors from the HoD staff.

The second and third level are made as an introductory way to understand how the HoD might affect the normal drilling operation, and to assess its negative impacts on the normal drilling operation on a qualitative approach.

The worksheets are referred to:

- Natural and conventional risks during drilling operation
- Continuous Circulation Device – HoD
- Human Errors

Table 19 presents a summary of the ALARP evaluation performed on the What if? Worksheets.

	What if											
ANALYSIS	UNACCEPTABLE RISK				ALARP				BROADLY ACCEPTABLE RISK			
	People	Envi	Econ	Rep	People	Envi	Econ	Rep	People	Envi	Econ	Rep
Normal & Conventional	11	13	6	6	9	14	15	11	14	7	13	17
Human Factors	2	0	0	0	6	4	5	23	16	20	19	2
CCS-HOD	0	0	0	0	5	1	3	1	20	24	22	24

Table 19. ALARP results of what if analysis

The ALARP evaluation technique allows to have a visual representation of the risk, red for unacceptable risk, yellow for risks that might need to be "As Low As Reasonably Possible (ALARP)" and finally the kind of risk that is within a category where all activities do not need any further mitigation to lower down the frequency or the damage caused by them. This last category on the ALARP evaluation technique is found coloured on green.

The analysis of that table shows that:

- The majority of the risks during normal drilling operations arise from well control and well integrity issues (e.g., Kick, Blow Out, Hole Collapse…etc.).

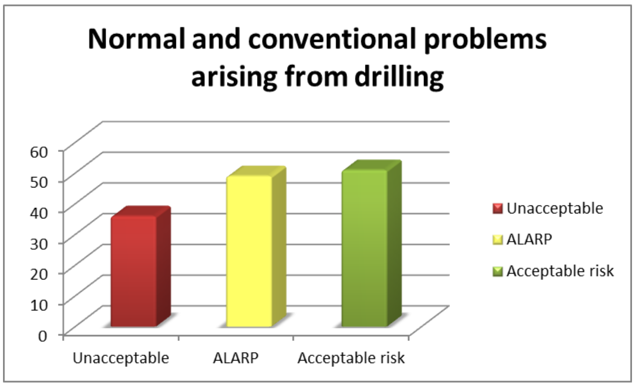


Figure 37. Results of what if analysis on Normal & Conventional Problems on Drilling

- The addition of HoD Continuous Circulation System will not add any major risks to the drilling operation. On the contrary, the addition of it can help in the minimization or elimination of normal drilling operational risks.
- In General, most of the risks added by the CCS-HoD® are in the category of Acceptable Risks with no intolerable ones.

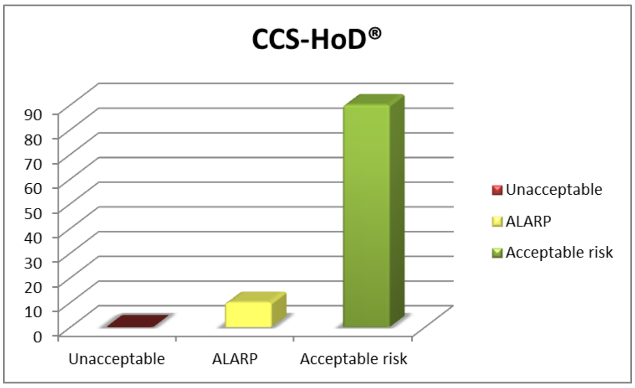


Figure 38. Results of what if CCS-HoD®

- Risks that arise by the human factors, can be mitigated by proper training of the personnel and a correct labour size.

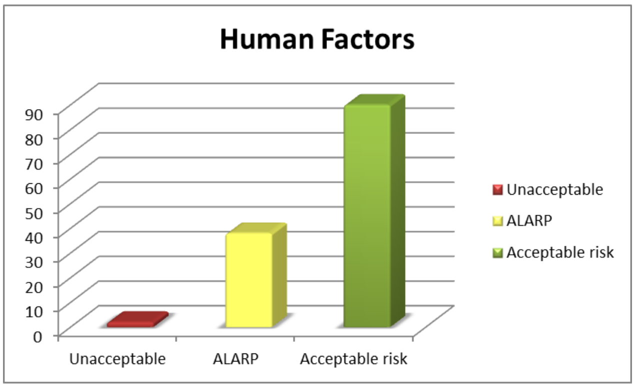


Figure 39. Results of what if analysis on Human Factors

4.2 Results of HAZID and HAZOP Analysis of CCS-HoD®

As an initial screening of the functionality of the CCS-HoD®, the functionality analysis was performed as showed in chapter 3 subsection 3.2.3.2, on the development of the analysis.

It was possible to identify the most critical functional deviations for the four categories of risk studied:

- Risk for people
- Risk for environment
- Risk for assets
- Risk for company reputation

Specifically for people, table 19 and figure 40, shows the distribution of the functional deviations according to is specific level of risk, calculated through the risk matrix and categorised by the ALARP methodology.

		Frequency Index				
		A	B	C	D	E
Consequences	0					
	1	1.4.3.a	1.11.3.1.a 1.3.1.b 1.3.1.c2b	1.1.3 1.1.4 1.2.1 1.2.3 1.2.5 1.2.6 1.3.4.b.a 1.3.6 1.4.2.a 1.4.2.b 1.4.3.b		
	2	1.3.3d 1.4.5	1.1.3 1.1.4 1.2.1 1.2.3 1.2.5 1.2.6 1.3.4.b.a 1.3.6 1.4.2.a 1.4.2.b 1.4.3.b	1.3.4.b.b		
	3			1.3.7 1.4.4 1.5.1.1 1.5.2.1 1.5.3.1		
	4	1.4.1.a 1.4.1b				
	5	1.1.1.c 1.2.2 1.2.4.c 1.3.1d 1.3.2b	1.3.2.c 1.3.3.b 1.3.3.c 1.4.1.C			

Table 20. Functional deviations on Risk Matrix for People

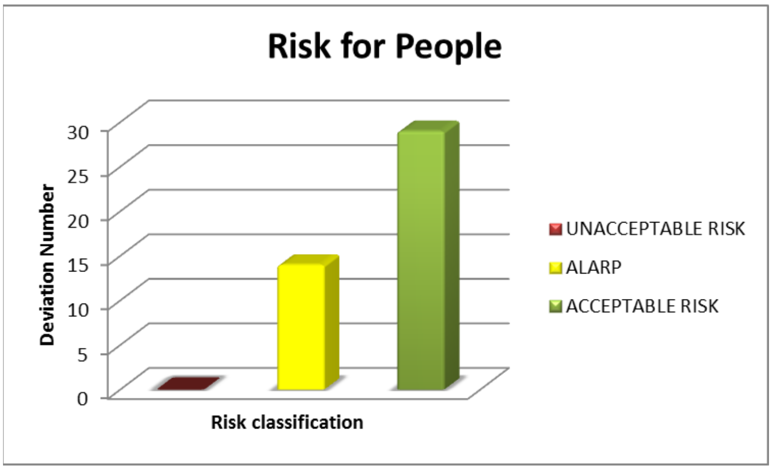


Figure 40. Functional Deviations on Risk Matrix for People

The utilisation of the tool, holds mainly acceptable risks, the ones failing into the ALARP section will be categorised as critical functional deviations as there are no unacceptable risks for people.

For environment, table 20 and figure 41, shows the distribution of the functional deviations according to is specific level of risk, calculated through the risk matrix and categorised by the ALARP methodology.

The utilisation of the tool, holds mainly acceptable risks, the ones failing into the ALARP section will be categorised as critical functional deviations as there are no unacceptable risks for environment.

Consequences		Frequency Index				
		A	B	C	D	E
	0					
	1	1.4.1.b 1.4.3.a 1.4.5	1.3.1.a 1.3.1.b 1.3.1.c 1.4.2.b 1.4.3.b	1.1.1.a 1.1.1.b 1.1.2.a 1.2.4.a 1.2.4.b 1.3.2.a 1.3.2.d 1.3.3.a 1.3.4.a		
	2		1.2.1 1.2.3 1.2.5 1.2.6 1.3.4.b 1.3.6 1.4.2.a	1.3.7		
	3	1.3.3.d 1.4.1.a	1.1.2.b 1.1.3 1.1.4 1.3.2.c 1.3.3.b 1.4.4	1.5.1.1 1.5.2.1 1.5.3.1		
	4		1.3.3.c 1.4.1.C			
	5	1.1.1.c 1.2.2 1.2.4.c 1.3.1.d 1.3.2.b				

Table 21. Functional deviations on Risk Matrix for Environment

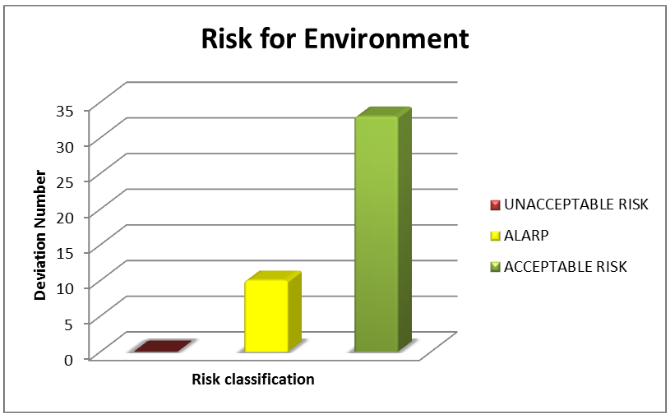


Figure 41. Functional Deviations on Risk Matrix for Environment

For assets, table 21 and figure 42, shows the distribution of the functional deviations according to is specific level of risk, calculated through the risk matrix and categorised by the ALARP methodology.

Consequences		Frequency Index				
		A	B	C	D	E
	0					
	1	1.4.3.a 1.4.5	1.1.3 1.2.3 1.2.5 1.2.6 1.3.1.a 1.3.1b 1.3.1.c 1.3.6 1.4.2.a 1.4.2b 1.4.3b	1.1.1.a 1.1.1b 1.1.2.a 1.2.4.a 1.2.4b 1.3.2.a 1.3.2.d 1.3.3.a 1.3.4.a 1.3.7		
	2	1.4.1.a	1.1.4 1.2.1 1.3.4b			
	3	1.4.1b	1.1.2b 1.3.2.c 1.3.3b 1.3.3.c 1.4.1.c 1.4.4	1.5.1.1 1.5.2.1 1.5.3.1		
	4	1.1.1.c 1.2.2 1.2.4.c 1.3.1.d 1.3.2b 1.3.3.d				
	5					

Table 22. Functional deviations on Risk Matrix for Assets / Economy

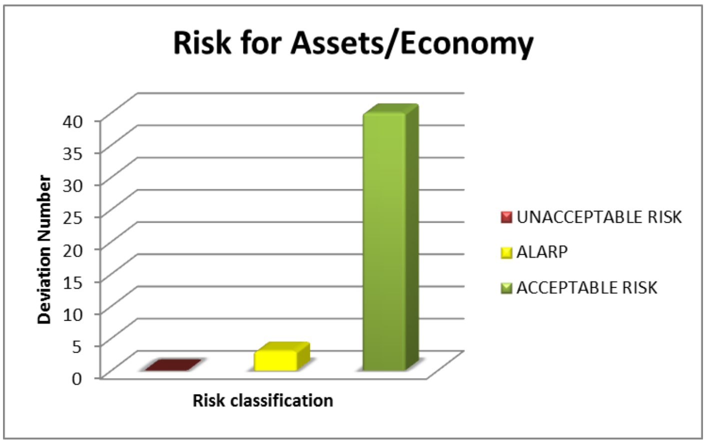


Figure 42. Functional Deviations on Risk Matrix for Assets / Economy

The utilisation of the tool, holds mainly acceptable risks, the ones failing into the ALARP section will be categorised as critical functional deviations as there are no unacceptable risks for assets.

For company's reputation, table 22 and figure 43, shows the distribution of the functional deviations according to is specific level of risk, calculated through the risk matrix and categorised by the ALARP methodology.

		Frequency Index				
		A	B	C	D	E
Consequences	0		1.4.2.a			
	1	1.4.1.a 1.4.3.a 1.4.5	1.1.2.b 1.1.3 1.2.3 1.2.5 1.2.6 1.3.1.a 1.3.1.b 1.3.1.c 1.3.6 1.4.2.b 1.4.3.b	1.1.1.a 1.1.1.b 1.1.2.a 1.2.4.a 1.2.4.b 1.3.2.a 1.3.2.d 1.3.3.a 1.3.4.a 1.3.7		
	2	1.4.1.b	1.2.1 1.3.4.b			
	3		1.1.4 1.4.4	1.5.1.1 1.5.2.1 1.5.3.1		
	4	1.1.1.c 1.2.2 1.2.4.c 1.3.1.d 1.3.2.b 1.3.3.d	1.3.2.c 1.3.3.b 1.3.3.c 1.4.1.c			
	5					

Table 23. Functional deviations on Risk Matrix for Company's Reputation

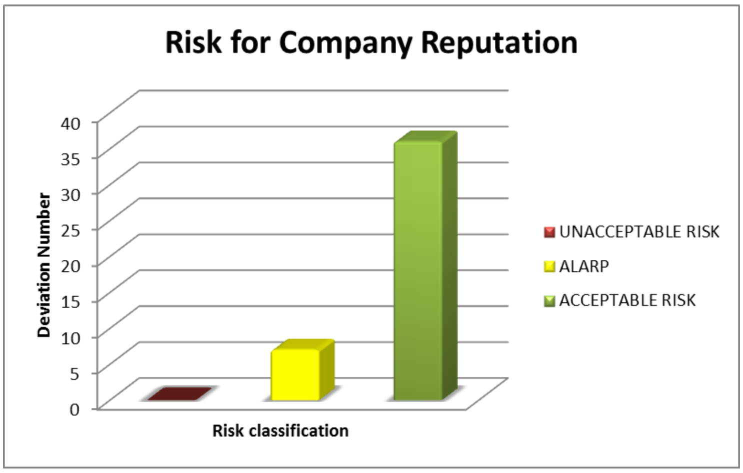


Figure 43. Functional deviations on Risk Matrix for Company's Reputation

The utilisation of the tool, holds mainly acceptable risks, the ones failing into the ALARP section will be categorised as critical functional deviations as there are no unacceptable risks for assets.

The record of the Hazard Identification Analysis is found on Annex II.

So far the results from the What if analysis regarding the CCS-HoD® and the HAZID coincide somehow, nevertheless in order to be able to deepen the knowledge about the risk factors that might affect the operation of the equipment, and having as a base case, the functional deviations obtained from the Hazard Identification Analysis, the Hazard an Operability Analysis was further developed.

It is important to mention, that due to the extension of the analysis (HAZOP), the worksheets are divided by operational phase, and subdivided per node.

The analysis of the worksheets, shows that:

- One of the most common occurrences in all the operative phases, that might be marked as an initiating event, and if further developed can create a major risk, is the failure of the control system or one of the components that ensure its proper function.

- The control system needs to be always available while the HoD is used on the rig. Any failure of this part of the equipment will provoke non-productive time, as well as economical losses.

- By analysing the worksheets, it is noticeable that another failure that might compromise the integrity of the tool while operating is the loss energy supply, which comes from the Electrical Power Unit.

- By losing the EPU, we lose the ability to control the equipment remotely, because the control system, the Hydraulic Power Unit, and so, the manifold, the clamp, and also the double filler pump are electrical operated.

- situation alongside with the loss of electricity can represent a high risk to the people working in the rig.

- During drilling phase, one of the most dangerous deviations that can occur, is to have an overpressure either on the manifold or in the sub. This can be due to a blockage inside the equipment, a malfunction of the pressure sensors, and also a malfunction of the control system.

- Bypass drilling phase, is somehow similar to the drilling phase; the objective is the same, to deviate the mud, by means of the manifold, to the mud standpipe manifold and to the top drive. Again, the riskier conditions is overpressure or a malfunction of the control system.

- During drill pipe connection, the riskier part of the operation is the fact that there will be workers on the rig floor, handling equipment (HoD clamp), and connecting it to the sub in order to continue the circulation. Although the XHoD control system works as a safety system that will not allow to have any uncontrolled flux if some parameter out of place, it represents a risk to have workers where high pressures are used.

- New stand filling operational phase is one of the most critical phases of the equipment, as all the equipment is in use at the same time including the double filler pump which is not used in other operational phases.

- A failure in any equipment during the new stand filling phase, will have potential consequences starting from delayed operations, until more serious ones depending the equipment failure.

- As the phase of drillpipe connection this phase has human interaction with the machinery, because it will need to remove the connection of the clamp to the sub, to continue with the drilling phase, nevertheless the working pressures in the zone of the connection are high.

The record of the Hazard and Operability Analysis Worksheets is found on the Annex IV.

From this deviations found on HAZID and HAZOP, the Risk Analysis was developed through the Fault Tree Analysis methodology.

4.3 Results of the Fault Tree Analysis of CCS-HoD®

The analysis presented with this methodology is quantitative, so it presents the results in an objective way. As stated in the development of the risk analysis, two scenarios were developed for the FTA. In both scenarios all the components of the equipment were taken as unrepairable, but the human error probability, which was kept constant (for scenario 1), for the scenario 2, the FTA was developed cutting all the human interaction with the machine, this is to see the impact that the human activities have on the equipment of the CCS-HoD®.

Individually for each operational phase, the top event is total failure of the equipment. Which is described as the worst-case scenario founded by the risk identification phase.

As all the components for both cases were considered unrepairable, the top event probability is related to the unreliability of the system to perform the operative phase from t=0 hour to t=24 hour, as well as for the unavailability of the system to perform at t=24 hour.

It is important to mention that, in the case where the Human Error Probability was taken into consideration, the value of Unreliability will vary from the one of Unavailability due to the fact that the probability of human error was not following the law for "unrepairable" components, but kept constant during the time, on the other hand, when the human error probability was omitted from the calculations, unavailability and unreliability have to coincide.

Due to these assumptions, it is obvious that this analysis will require to be updated in the future, by adding the maintenance time, for each component, as well as getting more reliable data referred to this kind of technology about the failure modes, and failure rates for each one. However, this is a good approximation that will allow to prioritise the improvements that the CCS-HoD® might require before is put on the market.

All the fault tree analysis and the results were computed with the software Arbre Analyste.

<u>FTA results: Drilling Phase</u>

FTA considering Human Error probability

Results	
Probability:	0.0202
System unreliability:	0.00594
Lambda system:	0.00025
Number of failures:	0.00585
System MTTR	83.53

FTA without considering Human Error probability

Results	
Probability:	0.00588
System unreliability:	0.00585
Lambda system:	0.000246
Number of failures:	0.00585
System MTTR	24.12

Table 24. FTA main results for Drilling Phase

Considering Human Error

- The unavailability of the entire CCS-HoD® at time t=24 hour, is **0.0202** this means that there is a probability of 0.0202 that the system will not be able to function properly on demand.
- The unreliability of the system to perform from t=0 hour to t=24 hour is 0.00594.
- The failure rate of the equipment is given with a value of λ=0.00025 failure/hour.
- System mean time to repair rises up to **83.53 hours** (**3.5 days**).

- The criticality index were calculated by means of Fussel Vesely Index for the Unavailability of the system. (The entire report is found on Annex VII).

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E028	HPU fails	1	0.00033	1	0.017
E303	Human Failure HPU	1	0.003	1	0.15
E012	Radial Valve Failure	1	3.6e-05	1	0.0018
E013	Sub Body Failure	1	1.6e-06	1	8.2e-05
E014	Axial Valve Failure	1	3.6e-05	1	0.0018
E305	Electronic Power Unit Failure	1	0.00029	1	0.014

Table 25. Criticality Index Results Drilling Phase considering Human Error

- The most critical component that might affect the performance of the equipment is the Electronic Power Unit followed by failure of the HoD-Sub because of its components, and the Hydraulic Power Unit.
- The human factor is also a big contributor of the failure of the equipment, nevertheless the probability of failure can be decreased if the personnel on the rig have a proper training and an adequate planning of the operations.

Without considering Human Error

- The unavailability of the entire CCS-HoD® at time t=24 hour, is 0.0059 this means that there is a probability of 0.0059 that the system will not be able to function properly on demand.
- The unreliability of the system to perform from t=0 hour to t=24 hour is 0.00594.
- The failure rate of the equipment is given with a value of λ=0.000246 failure/hour.
- System mean time to repair rises up to **24.1 hours** (**1 day**).
- The criticality index were calculated by means of Fussel Vesely Index for the Unavailability of the system. (The entire report is found on Annex VIII).

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E028	HPU fails	1	0.00033	1	0.057
E014	Axial Valve Failure	1	3.6e-05	1	0.0061
E013	Sub Body Failure	1	1.6e-06	1	0.00028
E012	Radial Valve Failure	1	3.6e-05	1	0.0061
E305	Electronic Power Unit Failure	1	0.00029	1	0.049
E262	Master Control Unit Failure	1	0.0044	1	0.74

Table 26. Criticality Index Results Drilling Phase without considering Human Error

- The most critical component that might affect the performance of the equipment is the Master control unit, of the XHoD Control Panel, the HoD-Sub because of its components, and the Electronic Power Unit.

General Considerations for Drilling Phase

- The human factors increase the MTTR of the system from 1 day to 3.5 approximately.
- The unavailability value decrease when there are no human interaction with the machine.
- The reliability of the system keeps more or less constant, it is not affected by the human interaction with the system.
- The key equipment that needs to be highlighted in this operational phase:
    - Master Control Unit Failure (XHoD Control System)
    - Electronic Power Unit
    - Hydraulic Power Unit
    - HoD-Sub
- For the human factor that is part of the normal functioning of the equipment, training must be provided in order to decrease the error probability.

FTA results: By-pass Drilling Phase

FTA considering Human Error probability

Results	
Probability:	0.0203
System unreliability:	0.00598
Lambda system:	0.000251
Number of failures:	0.00589
System MTTR	83.13

FTA without considering Human Error probability

Results	
Probability:	0.00591
System unreliability:	0.00589
Lambda system:	0.000248
Number of failures:	0.00589
System MTTR	24.12

Table 27. FTA main results for Bypass Drilling Phase

Considering Human Error

- The unavailability of the entire CCS-HoD® at time t=24 hour, is **0.0203** this means that there is a probability of 0.0203 that the system will not be able to function properly on demand.
- The unreliability of the system to perform from t=0 hour to t=24 hour is 0.00598.
- The failure rate of the equipment is given with a value of λ=0.000251 failure/hour.
- System mean time to repair rises up to **83.13 hours** (**3.46 days**).
- The criticality index was calculated by means of Fussel Vesely Index for the Unavailability of the system. (The entire report is found on Annex VII).

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E028	HPU fails	1	0.00033	1	0.017
E303	Human Failure HPU	1	0.003	1	0.15
E012	Radial Valve Failure	1	3.6e-05	1	0.0018
E013	Sub Body Failure	1	1.6e-06	1	8.2e-05
E014	Axial Valve Failure	1	3.6e-05	1	0.0018
E305	Electronic Power Unit Failure	1	0.00029	1	0.014
E306	Human Failure EPU	1	0.003	1	0.15

Table 28. Criticality Index Results Bypass Drilling Phase considering Human Error

- The most critical component that might affect the performance of the equipment is the Hydraulic Power Unit, the Electronic Power Unit and the HoD-Sub because of its components.
- The human factor is also a big contributor of the failure of the equipment, as it is seem on the failure of HPU due to Human Error.

Without considering Human Error

- The unavailability of the entire CCS-HoD® at time t=24 hour, is 0.0059 this means that there is a probability of 0.0059 that the system will not be able to function properly on demand.
- The unreliability of the system to perform from t=0 hour to t=24 hour is 0.00589.
- The failure rate of the equipment is given with a value of λ=0.000248 failure/hour.
- System mean time to repair rises up to **24.12 hours** (**1 day**).
- The criticality index were calculated by means of Fussel Vesely Index for the Unavailability of the system. (The entire report is found on Annex VIII).

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E262	Master Control Unit Failure	1	0.0044	1	0.74
E028	HPU fails	1	0.00033	1	0.057

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E305	Electronic Power Unit Failure	1	0.00029	1	0.049
E095	Filter is blocked	1	1.8e-06	1	0.00031
E083	PV8 leaking	1	3.4e-06	1	0.00057
E082	PV8 fail to open	1	9.1e-05	1	0.016

Table 29. Criticality Index Results Bypass Drilling Phase without considering Human Error

- The most critical component that might affect the performance of the equipment is the Master control unit, of the XHoD Control Panel, the HPU, the Electronic Power Unit, and in this case also the HoD-Manifold might contribute to the unavailability of the equipment, if no human interaction is needed.

General Considerations for Bypass Drilling Phase

- The human factors increase the MTTR of the system from 1 day to 3.46 approximately.
- The unavailability value decrease when there are no human interaction with the machine.
- The reliability of the system keeps more or less constant, it is not affected by the human interaction with the system.
- The key equipment that needs to be highlighted in this operational phase:
    - Master Control Unit Failure (XHoD Control System)
    - Electronic Power Unit
    - Hydraulic Power Unit
    - HoD-Sub
    - HoD-Manifold
- For the human factor that is part of the normal functioning of the equipment, training must be provided in order to decrease the error probability.

FTA results: Drill Pipe connection phase

FTA considering Human Error probability

Results	
Probability:	0.0261
System unreliability:	0.00637
Lambda system:	0.000268
Number of failures:	0.00624
System MTTR	101.6

FTA without considering Human Error probability

Results	
Probability:	0.00627
System unreliability:	0.00624
Lambda system:	0.000263
Number of failures:	0.00624
System MTTR	24.12

Table 30. FTA main results for Drill Pipe Connection Phase

Considering Human Error

- The unavailability of the entire CCS-HoD® at time t=24 hour, is **0.0261** this means that there is a probability of 0.0203 that the system will not be able to function properly on demand.
- The unreliability of the system to perform from t=0 hour to t=24 hour is 0.0063.
- The failure rate of the equipment is given with a value of λ=0.000268 failure/hour.
- System mean time to repair rises up to **101.6 hours** (**4.2 days**).
- The criticality index was calculated by means of Fussel Vesely Index for the Unavailability of the system. (The entire report is found on Annex VII).

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E009	Radial Valve Failure	1	3.6e-05	0.0014	0.0014
E010	Sub Body Leaks	1	1.6e-06	6.2e-05	6.3e-05
E006	Flapper Valve	1	3.6e-05	0.0014	0.0014
E005	Excesive Loading	1	1e-05	0.00039	0.0004
E004	Insufficient Make up torque	1	8.2e-07	3.1e-05	3.2e-05
E002	Manufacturing Tolerances	1	1.4e-08	5.2e-07	5.3e-07
E262	Master Control Unit Failure	1	0.0044	0.16	0.17
E305	Electronic Power Unit Failure	1	0.00029	0.011	0.011
E306	Human Failure EPU	1	0.003	0.11	0.12

Table 31. Criticality Index Results Drill Pipe Connection Phase considering Human Error

- The most critical component that might affect the performance of the equipment is the Master control unit, of the XHoD Control Panel, the HPU, the Electronic Power Unit, and the HoD sub, by failure on the flapper valves.

Without considering Human Error

- The unavailability of the entire CCS-HoD® at time t=24 hour, is 0.00627 this means that there is a probability of 0.00627 that the system will not be able to function properly on demand.
- The unreliability of the system to perform from t=0 hour to t=24 hour is 0.00624.
- The failure rate of the equipment is given with a value of λ=0.000263failure/hour.
- System mean time to repair rises up to **24.12 hours** (**1 day**).
- The criticality index were calculated by means of Fussel Vesely Index for the Unavailability of the system. (The entire report is found on Annex VIII).

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E028	HPU fails	1	0.00033	1	0.053
E141	Filter obstructed	1	1.8e-06	1	0.00029
E137	Internal Pipes Leaking to outside	1	2.9e-05	1	0.0046
E138	Internal pipes Blocked	1	4.3e-06	1	0.00069
E116	PV2 Fail to close	2	9.1e-05	7.6e-05	9.3e-05
E262	Master Control Unit Failure	1	0.0044	1	0.7

Table 32. Criticality Index Results Drill Pipe Connection Phase without considering Human Error

- The most critical component that might affect the performance of the equipment is the Master control unit, of the XHoD Control Panel, the HPU, and in this case also the HoD-Manifold due to internal failures might contribute to the unavailability of the equipment, if no human interaction is needed.

General Considerations for Bypass Drilling Phase

- The human factors increase the MTTR of the system from 1 day to 4.2 approximately.
- The unavailability value decrease when there are no human interaction with the machine.
- The reliability of the system keeps more or less constant, it is not affected by the human interaction with the system.
- The key equipment that needs to be highlighted in this operational phase:
    - Master Control Unit Failure (XHoD Control System)
    - Hydraulic Power Unit
    - HoD-Sub
    - HoD-Manifold
- It is important to notice that the Drillpipe conection phase adds another piece of equipment to be used, this is the reason the MTTR increases.
- For the human factor that is part of the normal functioning of the equipment, training must be provided in order to decrease the error probability.

FTA results: New Stand Filling Phase

From all the operational phases, this is the one that might cause more problems due to the fact that the entire equipment is operational during the phase; the Double Filler Pump, HoD-Manifold, HoD-Clamp and HoD-Sub.

FTA considering Human Error probability

Results	
Probability:	0.0297
System unreliability:	0.00707
Lambda system:	0.000298
Number of failures:	0.0069
System MTTR	104.6

FTA without considering Human Error probability

Results	
Probability:	0.00692
System unreliability:	0.0069
Lambda system:	0.000291
Number of failures:	0.0069
System MTTR	24.12

Table 33. FTA main results for New Stand Filling Phase

Considering Human Error

- The unavailability of the entire CCS-HoD® at time t=24 hour, is **0.0297** this means that there is a probability of 0.0297that the system will not be able to function properly on demand.
- The unreliability of the system to perform from t=0 hour to t=24 hour is 0.00693.
- The failure rate of the equipment is given with a value of λ=0.000298 failure/hour.
- System mean time to repair rises up to **104.6 hours** (**4.3 days**).
- The criticality index was calculated by means of Fussel Vesely Index for the Unavailability of the system. (The entire report is found on Annex VII).

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E302	Human Error Manifold Operation	1	0.0083	1	0.28
E250	Filter	1	1.8e-06	1	6.2e-05
E217	PV2 External Leakage	2	3.4e-06	7.6e-05	3.4e-06
E216	PV2 Fail to close	2	7.3e-05	7.6e-05	7.3e-05
E219	PV1 Fail to close	2	7.3e-05	7.6e-05	7.3e-05
E218	PV1 External Leakage	2	3.4e-06	7.6e-05	3.4e-06
E204	PV8 External Leakage	1	3.4e-06	1	0.00012
E309	Human Error Control System	1	0.00021	1	0.0071
E262	Master Control Unit Failure	1	0.0044	1	0.15

Table 34. Criticality Index Results New Stand Filling Phase considering Human Error

- The most critical component that might affect the performance of the equipment is the Master control unit, of the XHoD Control Panel, and failure of the HoD-Manifold due to internal failures.

Without considering Human Error

- The unavailability of the entire CCS-HoD® at time t=24 hour, is 0.00692 this means that there is a probability of 0.00692 that the system will not be able to function properly on demand.
- The unreliability of the system to perform from t=0 hour to t=24 hour is 0.0069.
- The failure rate of the equipment is given with a value of λ=0.000291 failure/hour.
- System mean time to repair rises up to **24.12 hours** (**1 day**).
- The criticality index were calculated by means of Fussel Vesely Index for the Unavailability of the system. (The entire report is found on Annex VIII).

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E305	Electronic Power Unit Failure	1	0.00029	1	0.042
E010	Sub Body Leaks	1	1.6e-06	1	0.00024
E009	Radial Valve Failure	1	3.6e-05	1	0.0052
E006	Flapper Valve	1	3.6e-05	1	0.0052
E003	Critical	1	8.2e-07	1	0.00012
E005	Excesive Loading	1	1e-05	1	0.0015
E002	Manufacturing Tolerances	1	1.4e-08	1	2e-06
E004	Insufficient Make up torque	1	8.2e-07	1	0.00012
E262	Master Control Unit Failure	1	0.0044	1	0.63
E270	Internal Actuator failure	1	0.00015	1	0.022
E271	Clamping Actuator Failure	1	2.4e-05	1	0.0035

Table 35. Criticality Index Results New Stand Filling Phase without considering Human Error

- The most critical component that might affect the performance of the equipment is the Master control unit, of the XHoD Control Panel, the HoD Clamp, and in this case also the HoD-Sub due to internal failures might contribute to the unavailability of the equipment, if no human interaction is needed.

General Considerations for Bypass Drilling Phase

- The human factors increase the MTTR of the system from 1 day to 4.3 approximately.
- The unavailability value decrease when there are no human interaction with the machine.
- The reliability of the system keeps more or less constant, it is not affected by the human interaction with the system.
- The key equipment that needs to be highlighted in this operational phase:
    - Master Control Unit Failure (XHoD Control System)
    - HoD-Sub
    - HoD-Clamp
    - HoD-Manifold
- For the human factor that is part of the normal functioning of the equipment, training must be provided in order to decrease the error probability.

5 - Conclusions and Recommendations

HoD is a continuous circulation system used for drilling that allows a great control of the well while drilling a hole, with the addition of additional equipment (to the equipment originally in place in a rig). HoD technology, is usually applied to drill wells in hard conditions with narrow pressure windows (between the formation pressure and the fracture pressure), that are difficult to drill conventionally

The risk identification studies performed allow to identify the hazards and consequences associated with normal drilling, but also the ones directly associated to the equipment HoD, and actually, it is seen in the analysis of this thesis, that the addition of HoD to the equipment of the rig, did not incremented the risks, but decreased the frequency of the normal problems to develop into a hazardous situation.

The risk analysis study performed allowed to see, not only in a quantitative way the failures of the equipment. But also studied the impact of human errors within the operation of the equipment.

- The most automatized the equipment is, will allow a higher availability and reliability on the system.

- The human error increase the mean time to repair from 1 up to 4.5 days depending on the operational phase. Thus, more training to the personnel should be provided.

Some improvements on the tool will need to be done in order to decrease the probability of total failure of the CCS-HoD; the list of required improvements in order to increase the availability and its reliability are:

1. **X-HoD Control System.**

   a) Add a rechargeable battery to the system, so if there is any variation on the energy supply on the rig, the system will be on.
   b) To have a back-up for the control panel on the rig.
   c) Perform periodical updates on the software system.

2. **Electrical Power Unit.**

   a) It is important to have a backup for the system, or a battery that allow to have electricity on the system for around 30 minutes after a loss of electrical power on the rig.
   b) In order to increase the security of the system, add an Uninterruptable power supply, to provide energy for a short period of time in case of a rig blackout.

3. **Hydraulic Power Unit.**

   a) Provide a backup system.

4. **HoD Clamp**

   a) Study for the feasibility to have the clamp to move and perform the connection automatically without the necessity of the operators to be near the dangerous (high pressure) zones. This will reduce the risk on people as all the connections will be from a safe zone.

5. **HoD Sub**

   a) Concentrate on the possibility of utilizing the sub with just one flapper valve, that will decrease the probability of failure of the equipment as the axial valve and all the components will be removed.

6. **HoD-Manifold**

   a) Study the possibility to add a relief valve on the manifold on the line utilized for low pressure on the New Stand Filling line, in case there is an event of overpressure on this line, there is the possibility to release the pressure.

For all the methodologies performed on this assessment, the general assumptions were:

- Reservoir conditions are "normal", which implies that, no High Pressure, High Temperature conditions are considered.
- The BOP stack arrangement is suitable for the drilling well, fully compliant with the relevant Codes and Standards.
- The equipment that is considered for the identification is belonging to the CCS- HoD® system, all the rig equipment, is considered to be suitable for the operation in the rig, also it is considered to be fully compliant with codes and standards.
- There are two safety barriers present during the operation (mud, and BOP).

It is quite possible that the results of the assessment made might change if we consider, for example, that the conditions of the well are high pressure, high temperature, due to the fact that more precautions will need to be taken.

It is also possible that if the equipment rig is not in "perfect" conditions, an external failure of the rig equipment might affect the functionality of the CCS-HoD®.

Specifically for the Fault Tree Analysis,

- All components are considered unrepairable on the time of mission
- The CCF's are defined as probabilities of independent failure of an utility component.
- The CCF's are introduced explicitly on the FTA.
- Two different simulations of the FTA were performed:
  - III. One considering the human error on each equipment
    - c. The probability of error of the operators is calculated per operator (per equipment), through the HEART methodology
    - d. The probability of error of the operators in the development of FTA is kept constant.
  - IV. One considering the equipment as independent of the human error,

The results presented on this assessment, are denoted as a first approach to the quantitative risk analysis for the equipment, ergo, there will be several variations that might arise from changing the initial assumptions of the analysis.

For instance, changing the type of components, to tested or repairable, will need the inclusion of more data, like the test schedule of the component , or the mean time to repair. And the unreliability and unavailability will vary accordingly.

By considering in the human error probability, calculated though HEART methodology, the training for personnel, the value obtained will be less, but also it will be considered that there are not one person controlling an equipment only, but one person controlling several parts of the equipment.

In general, the HoD, represents an improvement to the drilling rigs, it helps with maintaining the well bottom hole pressure while performing a connection, decreasing considerably the positive and negative surges inside the well. All of this without adding any considerable risk to the operation.

5.1 Further work

HoD works as an open loop system, regardless of this, the implementation of an annular back pressure equipment to the functioning will allow the companies to reach new limits on drilling operations, in situations where, for example, Pressurised Mud Cap Drilling is needed.

The inclusion of an annular back pressure equipment into the CCS-HoD might bring positive impacts on the drilling operation, among those are find:

- Lowering of the Non-Productive Time
- Increased well control
- Common drilling problems overcome
- Deeper range of depths are reached.

Nevertheless, there are some negative impacts found on the inclusion of a backpressure equipment:

- Modification of the rig is unavoidable.
- Requires more expertise
- Well barriers need to be redefined
- Increase the hazards on the operations if not proper care is taken.

Further work on the development of a close loop system should be made in order to update the HoD system, though, the implementation of safety measures in all the phases of the design should be performed, and also the study of the need of an open or closed loop system should be studied and developed on the well planning process.

The Hazard Identification and the Hazard an Operability analysis are complete for the present version of the HoD; however subsequent updates to this work might be required. The risk assessment should always reflect the actual present design of the system.

In order to have a probability of failure for the equipment more reliable, aside of the pressure tests that are periodically performed on the equipment, tests that allow to have the frequency of failure of the equipment should be done specifically for the Heart of Drilling components and equipment.

Aside from the tests that need to be done, the risk analysis of this tool was made assuming unrepairable components for the time of mission set on 24 hours. However, the reality is that, there are components that are tested, and repairable ones, also the mission does not endure for 24 hours straight. So, making the FTA analysis considering the components as repairable or tested will vary the result to a one closer to the reality.

Maintain a periodic maintenance programme that will ensure that the controls and equipment are working properly, and they are all in place.

HoD, like any other continuous circulation system requires for its proper performance that the personnel working with it have a proper training in order to bring its full advantages to work.

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ANNEX I - *What if Analysis*

Natural & conventional risks during drilling operations

System	Well	**What if? Number:**	1
		Prepared By:	Magdalena Vera Chena
		Date:	23/10/2019
Mode	Natural & Conventional Risks	**Revision Date:**	02/11/2019

What if?	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
High Equivalent Circulating Density	Increased flow of mud pump; as this increases the annular pressure. Increased mud density Insufficient hole cleaning during drilling Mud rheological properties	Lost circulation	Apply Continuous Circulation techniques		B	3	4	3	3	B3	B4	B3	B3
		Stuck pipe / Drill string			B	3	3	4	2	B3	B3	B4	B2
		Breakdown of formation			C	4	4	4	2	C4	C4	C4	C2
		Kick - Well control Incident			D	4	4	3	2	D4	D4	D3	D2
		Blowout - Well control Incident			C	5	5	5	5	C5	C5	C5	C5
Hole instability	High Pressure formation	Hole collapse	Maintain the mud density to keep the hole open		C	3	4	3	2	C3	C4	C3	C2
		Stuck pipe / Drill string			D	2	2	2	2	D2	D2	D2	D2
		Kick - Well control Incident			D	4	4	3	2	D4	D4	D3	D2
		Blowout - Well control Incident			C	5	5	5	5	C5	C5	C5	C5
Insufficient cutting removal during drilling	Insufficient annular velocity Wellbore geometry	Lost circulation	Apply Continuous Circulation techniques Apply well control methods	If mud window is too narrow, consider change the CCS open loop, to a closed one, as it can control the back pressure generated	C	2	4	3	2	C2	C4	C3	C2
		Tight hole			D	2	2	2	2	D2	D2	D2	D2
		Pack off hole			C	2	2	2	1	C2	C2	C2	C1
		High ECD			C	2	2	2	1	C2	C2	C2	C1
		Stuck pipe / Drill string			D	2	2	2	2	D2	D2	D2	D2
High BHP	Lack of information Underbalanced hydrostatic column	Hole collapse			C	2	3	3	3	C2	C3	C3	C3
		Kick - Well control Incident			D	4	4	3	2	D4	D4	D3	D2
		Blowout - Well control Incident			C	5	5	5	5	C5	C5	C5	C5
Unsuccessfull well control	Lost circulation	Kick - Well control Incident			D	4	4	3	2	D4	D4	D3	D2
		Blowout - Well control Incident			C	5	5	5	5	C5	C5	C5	C5
Lost circulation	Inadequate mud properties Inadequate geological /	Loss of mud volume	Modify pupming rate to alter the flow regime Mantain the annular		C	2	3	2	1	C2	C3	C2	C1
		Loss of hydrostatic pressure			C	2	2	1	1	C2	C2	C1	C1

System	Well	**What if? Number:**	1
		Prepared By:	Magdalena Vera Chena
		Date:	23/10/2019
Mode	Natural & Conventional Risks	**Revision Date:**	02/11/2019

What if?	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
	geophysical data High porosity formation High permeability formation High ECD Insufficient cutting removal Fractured formation Overpressured mud pump Pressure surge Leakage on rig equipment	Kick - Well control Incident	fluid volume and the density to be similar to the BHP		D	2	2	2	2	D2	D2	D2	D2
		Fluid loss during dynamic conditions			C	2	3	2	1	C2	C3	C2	C1
		Stuck pipe / Drill string			C	2	2	2	1	C2	C2	C2	C1
		Unsuccessfull well control			C	3	3	3	2	C3	C3	C3	C2
		Loss in mud pit level			C	2	3	1	1	C2	C3	C1	C1
		Blowout - Well control Incident			D	5	5	5	5	D5	D5	D5	D5
		Loss of hole			C	2	2	4	2	C2	C2	C4	C2
Wellbore influx	Incidental Wellbore influx Unexpected gas to surface Drill Stem Test High BHP	Kick - Well control Incident	Increase mud density BOP Kill well	Consider change the CCS open loop, to a closed one, as it can control the back pressure generated, control the well more efficiently instead of killing the well	D	4	4	3	2	D4	D4	D3	D2
		Blowout - Well control Incident			C	5	5	5	5	C5	C5	C5	C5
Surge	Tripping in drillpipe	Fracture of formation	Control the velocity for tripping in the DP		C	2	3	2	1	C2	C3	C2	C1
		Lost circulation			C	2	3	2	1	C2	C3	C2	C1
		Underground blowout			C	4	5	4	4	C4	C5	C4	C4
		Stuck pipe / Drill string			C	2	2	2	1	C2	C2	C2	C1
		Kick - Well control Incident			D	4	4	3	2	D4	D4	D3	D2
		Blowout - Well control Incident			C	5	5	5	5	C5	C5	C5	C5
Fracture of formation	Overbalanced mud column Surge	Lost circulation	Apply Continuous Circulation techniques		C	2	3	2	1	C2	C3	C2	C1

System	Well	**What if? Number:**	1
		Prepared By:	Magdalena Vera Chena
		Date:	23/10/2019
Mode	Natural & Conventional Risks	**Revision Date:**	02/11/2019

What if?	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
		Underground blowout			C	4	5	4	4	C4	C5	C4	C4
		Stuck pipe / Drill string			C	2	2	2	1	C2	C2	C2	C1
		Kick - Well control Incident			D	4	4	3	2	D4	D4	D3	D2
		Blowout - Well control Incident			C	5	5	5	5	C5	C5	C5	C5
Kick - Well Control Incident	Continuous Influx High BHP Inadequate mud properties Lost circulation Gain in mud pit level High ECD Inhability to manage loss situations Unsuccessfull well control Fracture of formation Change of mud properties Gas in riser Unexpected gas to surface Loss of pressure control Hole collapse Hole Instability Flowline rupture Overpressured mud pump Surge No kill weight mud available	Blowout - Well control Incident	Shut in well Kill well Training to shut well in based on increased flow at surface Slow pump rate	Personnel is prepared to calculate flow, and inputs. Kill sheet is necessary	C	3	3	2	2	C3	C3	C2	C2
Blowout - Well Control Incident	Continuous Influx High BHP Inadequate mud	Gain in mud pit level	Lifeboats Remote choke manifold control	Have a defined evacuation plan. Personnel training	C	5	5	5	5	C5	C5	C5	C5

System	Well	**What if? Number:**	1
		Prepared By:	Magdalena Vera Chena
		Date:	23/10/2019
Mode	Natural & Conventional Risks	**Revision Date:**	02/11/2019

What if?	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
	properties Lost circulation Gain in mud pit level High ECD Inhability to manage loss situations Unsuccessfull well control Fracture of formation Change of mud properties Gas in riser Unexpected gas to surface Loss of pressure control Hole collapse Hole Instability Flowline rupture Overpressured mud pump Surge No kill weight mud available	Produced fluid to the surface	Remote BOP controls		C	5	5	5	5	C5	C5	C5	C5
		Life threatening			C	5	5	5	5	C5	C5	C5	C5
		Asset threathening			C	5	5	5	5	C5	C5	C5	C5
		Environment threatening			C	5	5	5	5	C5	C5	C5	C5

Continuous Circulation Device – HoD

System	HoD	**What if Number:**	2
		Prepared By:	Magdalena Vera Chena
		Date:	23/10/2019
Mode	CCS-HoD	**Revision Date:**	02/11/2019

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
High environment temperature of the Bottom Hole Assembly while installing the CCS-HoD	High BT static temperature Problems collegated to the instalation of the CCS-HoD Lack of clear instructions and procedures for instalation	Electronic damage to BHA	Installation of CCS-HoD before tripping in The BOP is installed on the righ and ready to perform.	Verification that instructions and procedures are clear. Personnel is trained to perform the installation of the CCS-HoD and to solve any problem collegated to the operation.	B	1	1	1	1	B1	B1	B1	B1
		Damage of BHA			B	1	2	3	3	B1	B2	B3	B3
		Tripping operations			B	2	2	2	2	B2	B2	B2	B2
		Non-Productive Time			B	1	1	2	2	B1	B1	B2	B2
Problems collegated to the installation of CCS-HoD	Lack of clear instructions and procedures for the instalation. Lack of trained personnel	Non-Productive Time	Installation of CCS-HoD before tripping in. The BOP is installed on the rig and ready to perform. Personnel trainning Review of procedures before start of drilling operation Documentation review with HoD operators	Trainning courses Safety meetings Intensive supervison Simulation of operations	B	1	2	3	3	B1	B2	B3	B3
		CCS-HoD unplanned and unwanted events			B	3	3	4	4	B3	B3	B4	B4
Unplanned event originated because of the CCS-HoD	Lack of clear instructions and procedures for the instalation. Lack of trained personnel	Non-Productive Time	Review of procedures before start of drilling operation. Documentation review with HoD operators	Trainning courses Safety meetings Intensive supervison Simulation of operations	B	2	2	4	3	B2	B2	B4	B3
Damage to equipment	Lack of clear instructions and procedures for the instalation. Lack of trained personnel	Non-Productive Time	Installation of CCS-HoD before tripping in. The BOP is installed on the rig and ready to perform. Personnel trainning Review of procedures before start of drilling operation Documentation review with HoD operators		B	2	2	2	2	B2	B2	B2	B2
		CCS-HoD unplanned and unwanted events			B	3	1	2	2	B3	B1	B2	B2

System	HoD	**What if Number:**	2
		Prepared By:	Magdalena Vera Chena
		Date:	23/10/2019
Mode	CCS-HoD	**Revision Date:**	02/11/2019

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
Lack of containment fluids	Incorrect conection. Leaking hoses	Environmental damage on site	Plug drains. Plug hoses prior to removal Rig up or rig down procedures		B	4	4	4	3	B4	B4	B4	B3
System not operational	Computer hardware or software malfunction	Conections should be performed manually.	Troubleshooting procedures must be clear	Trainning courses Safety meetings Intensive supervison Simulation of operations Troubleshooting procedures must be clear	B	1	1	3	2	B1	B1	B3	B2
Loss of electrical power	Lighting strike Overload Transformer fire	Conections should be performed manually; personnel close to the pressurised equipment	Alternative power source Emergency shutdown and switchover procedures Redundant power generation equipment Manual application	Trainning courses Safety meetings Intensive supervison Simulation of operations Troubleshooting procedures must be clear	C	3	1	2	1	C3	C1	C2	C1
		Non-Productive Time			C	2	1	3	1	C2	C1	C3	C1
		Control System non operational			C	3	1	2	1	C3	C1	C2	C1
Loss of hydraulics	Lighting strike Overload Transformer fire Loss of electrical power	Conections should be performed manually.	Alternative power source Emergency shutdown and switchover procedures Redundant power generation equipment Manual application	Trainning courses Safety meetings Intensive supervison Simulation of operations Troubleshooting procedures must be clear	B	3	1	2	1	B3	B1	B2	B1
		Non-Productive Time			B	2	1	3	1	B2	B1	B3	B1
Loss of mud in the system	Mechanical breakdown Loss of electric power	Stop drilling	Redundant pump to provide mud. BOP should be in place and ready to perform.		B	1	3	2	2	B1	B3	B2	B2

System	HoD	**What if Number:**	2
		Prepared By:	Magdalena Vera Chena
		Date:	23/10/2019
Mode	CCS-HoD	**Revision Date:**	02/11/2019

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
Exceeding pressure limits of equipment	Inadequate planning or design phase Relief valves does not activate	Bursting hoses, conections, pipes	Pressure relief valves	Discharge pressure of the valves should be at half of the maximum pressure allowed from the equipment. The pumping capacity should be at least 2 times the maximum rate expected.	B	4	3	3	2	B4	B3	B3	B2
		Rig floor personnel injuries			B	4	3	3	2	B4	B3	B3	B2
		Stop drilling			B	1	1	2	1	B1	B1	B2	B1
		Non-Productive Time			B	1	1	2	1	B1	B1	B2	B1
Pressure relief valves activate but undettected	Inadequate trainning Unadequate personnel Understaff operation Unclear definition of job duties Mechanical failure of the valve Spurious operation	Decreased pressure on the components of the CCS-HoD	Flow sensor alarm on pressure relief valve visual and auditive X-HoD control pannel	Install flow sensor alarms on the pressure relief valves	B	3	1	3	1	B3	B1	B3	B1
		Increased flow from pumps			B	3	1	3	1	B3	B1	B3	B1
Pressure relief valves do not activate and undettected	Mechanical malfunction Leakage Incorrect setting Blockage	Increased ECD	Perform pressure test on the valve before the drilling operation	Install flow sensor alarms (visual and auditive) on the pressure relief valves	B	3	2	2	2	B3	B2	B2	B2
		Pressure surge			B	3	2	2	2	B3	B2	B2	B2
		Lost circulation			B	3	3	3	2	B3	B3	B3	B2
		Fracture formation			B	3	3	3	2	B3	B3	B3	B2

Human Factors

System	HoD	**What if Number:**	3
		Prepared By:	Magdalena Vera Chena
		Date:	23/10/2019
Mode	Human Factors	**Revision Date:**	02/11/2019

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
Untrained personnel Lack of experience from the personnel	Not enough staff for the project Competency assumed	NPT Unplanned events	Trainning courses on the planning phase Safety meetings Job Safety courses Intensive supervison	Rig personnel organisation chart Establishment of chain of command Determination of personnel competency (training) Discussion of deficiencies found out with the training with the operator manager	C	1	1	1	0	C1	C1	C1	C0
		Incorrect measurements (like mud weight calculations)			B	1	2	1	0	B1	B2	B1	B0
		Personnel injury			C	3	1	1	1	C3	C1	C1	C1
		Failure to follow a schedule plan			C	1	1	1	1	C1	C1	C1	C1
		Job duties unclear			C	1	1	1	1	C1	C1	C1	C1
		Personnel not familiar with the equipment			C	1	1	1	1	C1	C1	C1	C1
		Non detected operational problems in time			C	3	3	2	2	C3	C3	C2	C2
Work plan not followed	Inadequate training Best practices and "lessons learned not implemented" Inexperienced/untrained personnel	CCS unplanned and unwanted events	Trainning courses on the planning phase Safety meetings Job Safety courses Intensive supervison Know- How shared and applied by experienced personnel	Contingency plan creation and evaluation Implementation of lessons learned and best practices	C	3	3	2	2	C3	C3	C2	C2
		Unclear definition of job duties			C	1	1	1	1	C1	C1	C1	C1
Injuries	Personnel unfamiliar with the CCS equipment Unclear definition of duties Personnel understaffed Mechanical failure / rupture of equipment or presurised equipment	Comisioning problems after the instalation of CCS- HoD	Comisioning and reviewing procedures prior to start operations Personnel training Continuous training and supervision during the operations	Training of personnel	B	2	1	2	1	B2	B1	B2	B1
		Non-productive Time			C	1	1	2	1	C1	C1	C2	C1
CCS-HoD understaffed	Inadequate trainning Unadequate personnel	Fatigue	Definition of shifts of maximum 12 hours	Adequate staff hired to perform the duties	E	3	1	1	1	E3	E1	E1	E1

System	HoD	**What if Number:**	3
		Prepared By:	Magdalena Vera Chena
		Date:	23/10/2019
Mode	Human Factors	**Revision Date:**	02/11/2019

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
		Injuries			E	3	1	1	1	E3	E1	E1	E1
		Unplanned events			D	3	3	3	2	D3	D3	D3	D2
		Unclear definition of job duties			B	3	2	1	1	B3	B2	B1	B1
		Non detected operational problems in time			B	3	2	2	2	B3	B2	B2	B2
Unclear definition of duties	Personnel unfamiliar with the CCS equipment Unclear definition of duties Personnel understaffed Mechanical failure / rupture of equipment or presurised equipment	Project implementation failure	Trainning courses on the planning phase Safety meetings Job Safety courses Intensive supervision Know- How shared and applied by experienced personnel Simulation of operations	Rig personnel organisation chart Establishment of chain of command Determination of personnel competency (training) Discussion of deficiencies found out with the training with the operator manager	B	1	2	3	2	B1	B2	B3	B2
		Slow operation			D	1	1	2	1	D1	D1	D2	D1
		Equipment damage			D	2	2	2	1	D2	D2	D2	D1
		Injuries			C	3	1	2	1	C3	C1	C2	C1
		Non detected operational problems in time			C	3	2	2	2	C3	C2	C2	C2
Overstaffed CCS-HoD operations	Specialized services needed, interns	Injuries	Offduty personnel outside the working areas	Prior information to manager and to workers about the extra personnel on the rigside. Provide trainning to the extra-staff	C	2	1	2	1	C2	C1	C2	C1
		Time shift arrangements			C	2	1	2	1	C2	C1	C2	C1
		Evacuation capacity consideration			C	2	1	2	1	C2	C1	C2	C1
Untrained personal / not familiar with equipment	Inexperienced personnel	Project implementation failure	Trainning courses on the planning phase Safety meetings Job Safety courses Intensive supervision Know- How shared and applied by	Discussion of deficiencies found out with the training with the operator manager Training implementation and continuous improvement	C	3	3	2	2	C3	C3	C2	C2
		Slow operation			D	1	1	2	1	D1	D1	D2	D1
		Injuries			D	3	1	2	2	D3	D1	D2	D2

System	HoD	**What if Number:**	3
		Prepared By:	Magdalena Vera Chena
		Date:	23/10/2019
Mode	Human Factors	**Revision Date:**	02/11/2019

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	MITIGATION	Freq. Index	DAMAGE				RISK			
						People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
		Equipment damage	experienced personnel Simulation of operations		D	3	3	3	2	D3	D3	D3	D2
Communication issues	Innexperienced personnel Language barriers Communication equipment failure	Slow operation	Trainning courses on the planning phase Safety meetings Job Safety courses Intensive supervison Know- How shared and applied by experienced personnel	Common language must be used while performing any operation Training courses Team work Discussion of deficiencies found out with the training with the operator manager Maintenance of communication equipment before perform any operation on the rigside. Adequate staff hired to perform the duties	D	1	1	2	1	D1	D1	D2	D1
		Non-productive Time			D	1	1	2	1	D1	D1	D2	D1
		Unclear definition of job duties			D	2	2	1	1	D2	D2	D1	D1
		Equipment damage			C	2	2	3	1	C2	C2	C3	C1
		Injuries			D	3	1	2	1	D3	D1	D2	D1

ANNEX II - *Hazard Identification (HAZID) Analysis - Worksheets*

System	HoD	**HAZID Number:**	1
Subsystem	HoD Operation	**Prepared By:**	Magdalena Vera Chena
		Date:	04/11/2019
		Revision Date:	14/11/2019

CODE	FUNCTION	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	Freq. Index	DAMAGE				RISK			
								People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
1	HoD Continuous Circulation System To Maintain Circulation to the well in all phases of operation														
1.1	Drilling & Bypass Drilling Phase : To keep the flow inside the drillstring from the Top Drive while drilling														
1.1.1.a		Less Flow	Valves inside the manifold can be partially blocked, pipeline blocked, filter obstructed	The reduction of bottom hole pressure, affecting well safety Increase the pressure in the surface network	Periodic Maintenance Monitoring from XHOD System	To have a cleaning liquid in the field ready to be injected in case of need	C	1	1	1	1	C1	C1	C1	C1
1.1.1.b	Manifold divert the flow to the mud standpipe manifold	No Flow	Valves in the manifold can be closed, internal pipes obstructed, fillter dirty.	Loss of Circulation in the well, Loss of the dynamic pressure downhole The pressure increase in the surface netwrok affecting the safety of personal aroudn the equipment	Relief Valve Pressure Sensors and Monitoring from the X HoD control panel		C	1	1	1	1	C1	C1	C1	C1
1.1.1.c			Break on the Manifold Piping	Loss of Circulation in the well, Loss of the dynamic pressure downhole Affecting the Safety of Personal working around the tool Leakage to the Environment	Relief Valve XHOD Monitoring system	Periodic hourly Visual inspection while the manifold in operation	A	5	5	4	4	A5	A5	A4	A4
1.1.2.a	HoD Sub mantain the axial valve open	Incomplete Opening	Failure of the valve	Loss of BHP Shearing of the valve due to the effect of fluid flow	Make sure the subs will not operate more than 400 hrs	Maintenance of the subs and valves once they are available in the surface	C	1	1	1	1	C1	C1	C1	C1

System	HoD	HAZID Number:	1
Subsystem	HoD Operation	Prepared By:	Magdalena Vera Chena
		Date:	04/11/2019
		Revision Date:	14/11/2019

CODE	FUNCTION	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	Freq. Index	DAMAGE				RISK			
								People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
1.1.2.b		No opening, No Flow	Failure of the valve or failure of the pin after downhole pressure fluctuations	Loss of Circulation in the wellbore		Ensure no downhole rate of pressure fluctuations to happen in the drilling operation	B	1	3	3	1	B1	B3	B3	B1
1.1.3	HoD Sub mantain the radial valve closed	Valve Leakage	Failure of the Valve seal	Loss of Circulation, Washout effect	Plug is the second barrier from the annulus		B	2	3	1	1	B2	B3	B1	B1
1.1.4	The Plug on the Radial Valve to maintain Seal	Lose of the plug or the Seal	Failure of the Plug seal	Loss of plug on the hole Fishing Job NPT	Spring in the plug		B	2	3	2	3	B2	B3	B2	B3
1.2	Drillpipe connection Phase: To Maintain Circulation while top drive is disconnected														
1.2.1	Clamp Attaching in the right position to the sub	Fail to Attach	Human error to attach the clamp. Wrong direction of the Sub Manufacturing error	The mud will spill in the rig floor High Pressure in the rig floor Deformation of the Sub	XHOD system will not permit the fluid diversion if theres a seal failure, and correct operation	Clear and efficient procedure to be followed by the workers	B	2	2	2	2	B2	B2	B2	B2
1.2.2	Clamp Make Pressure Seal Around the Sub Radial Valve	Pressure Leak on the Rig Floor	Lack of maintenance, failure of the seal.				A	5	5	4	4	A5	A5	A4	A4
1.2.3	Clamp removes the plug of the radial valve of the sub	Failure of Plug retrieval	Failure of the clamp, failure of the plug, manufacturing defect	Failure of flow diverison Clean line in the clamp	Special Attaching mechanism between plug and piston in the clamp Diverion by manual operation		B	2	2	1	1	B2	B2	B1	B1

System	HoD	**HAZID Number:**	1
Subsystem	HoD Operation	**Prepared By:**	Magdalena Vera Chena
		Date:	04/11/2019
		Revision Date:	14/11/2019

CODE	FUNCTION	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	Freq. Index	DAMAGE				RISK			
								People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
1.2.4.a	Manifold divert the flow to the clamp	Less Flow to the Clamp	Inlet hose to the clamp is damaged (leaking), manifold is partially blocked, internal pipelines are blocked, filter obstructed.	The reduction of bottom hole pressure, affecting well safety Increase the pressure in the surface network	Periodic Maintenance Monitoring from XHOD System	To have a cleaning liquid in the field ready to be injected in case of need	C	1	1	1	1	C1	C1	C1	C1
1.2.4.b		No Flow to the Clamp	Valves in the manifold can be closed, internal pipes obstructed, filter dirty. The outlet of the manifold can be obstructed (clamp hose)	Loss of Circulation in the well, Loss of the dynamic pressure downhole The pressure increase in the surface network affecting the safety of personal around the equipment	Relief Valve Pressure Sensors and Monitoring from the X HoD control panel		C	1	1	1	1	C1	C1	C1	C1
1.2.4.c			Break on the Manifold Piping	Loss of Circulation in the well, Loss of the dynamic pressure downhole Affecting the Safety of Personal working around the tool Leakage to the Environment	Relief Valve XHOD Monitoring system	Periodic hourly Visual inspection while the manifold in operation	A	5	5	4	4	A5	A5	A4	A4
1.2.5	Radial Valve of the sub opens	Fail to open the Valve	Failure of the valve	Failure of keeping circulation in the wellbore	Make sure the subs will not operate more than 400 hrs	Maintenance of the subs and valves once they are available in the surface	B	2	2	1	1	B2	B2	B1	B1

System	HoD	HAZID Number:	1
Subsystem	HoD Operation	Prepared By:	Magdalena Vera Chena
		Date:	04/11/2019
		Revision Date:	14/11/2019

CODE	FUNCTION	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	Freq. Index	DAMAGE				RISK			
								People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
1.2.6	Axial Valve of the Sub closes	Fail to close	Failure of the valve	Failure of keeping circulation in the wellbore	Make sure the subs will not operate more than 400 hrs	Maintenance of the subs and valves once they are available in the surface	B	2	2	1	1	B2	B2	B1	B1
1.3	New Stand Filing Phase: To fill the new stand with the mud from the Top drive Side, while keeping the circulation from the Sub Side Valve														
1.3.1.a	Double filler pump delivers mud to manifold (low pressure line)	More Flow	Error of the control system, error of operator. Pumps malfunction	Increase of the pressure in the surface network	Relief Valve The pressure rating of the pipes and connections is higher than the max. pump delivery pressure	Periodic Maintenance, and monitoring of the system Make sure correct procedures are followed by adequate training of the personal	B	1	1	1	1	B1	B1	B1	B1
1.3.1.b		Less Flow	Error of the control system, error of operator. Pumps malfunction, one pump is not working, obstruction inside the pump	Pipe filling in more time, which adds more NPT to the drilling operation			B	1	1	1	1	B1	B1	B1	B1
1.3.1.c		No Flow	Error of the control system, error of operator. Pumps malfunction, one pump is not working, obstruction inside pipeline of the pump.	Pipe filling operation failure, leads to pressure fluctuation downhole			B	1	1	1	1	B1	B1	B1	B1

System	HoD	HAZID Number:	1
Subsystem	HoD Operation	Prepared By:	Magdalena Vera Chena
		Date:	04/11/2019
		Revision Date:	14/11/2019

CODE	FUNCTION	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	Freq. Index	DAMAGE				RISK			
								People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
1.3.1.d			Break on the Manifold Piping	Pipe filling operation failure, leads to pressure fluctuation downhole Leakage of mud to the environment Risk for the people around the equipment of high pressure			A	5	5	4	4	A5	A5	A4	A4
1.3.2.a	Manifold delivers mud to the mud standpipe manifold (through low pressure line)	Less Flow	manifold is partially blocked, internal pipelines are blocked. Leakage of Connections Fracture of Manifold Pipes	Pipe filling in more time, which adds more NPT to the drilling operation			C	1	1	1	1	C1	C1	C1	C1
1.3.2.b		No Flow	Valves in the manifold can be closed, internal pipes obstructed, Fracture in the manifold piping	Pipe filling operation failure, leads to pressure fluctuation downhole			A	5	5	4	4	A5	A5	A4	A4
1.3.2.c			Break on the Manifold Piping	Pipe filling operation failure, leads to pressure fluctuation downhole Leakage of mud to the environment Risk for the people around the equipment of high pressure		Periodic hourly Visual inspection while the manifold in operation	B	5	3	3	4	B5	B3	B3	B4

System	HoD	**HAZID Number:**	1
Subsystem	HoD Operation	**Prepared By:**	Magdalena Vera Chena
		Date:	04/11/2019
		Revision Date:	14/11/2019

CODE	FUNCTION	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	Freq. Index	DAMAGE				RISK			
								People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
1.3.2.d		High Pressure	Failure of the Valve Sealing between the high pressure and low pressure lines	Pressure Fluctuation downhole The radial Valve might open causing faulty operation	XHOD system will alarm if there is any anomaly detection	add extra valve to work as a barrier between the high and low pressures	C	1	1	1	1	C1	C1	C1	C1
1.3.3.a	Manifold delivers high pressure mud to the clamp	Less Flow	manifold is partially blocked, internal pipelines are blocked, filter obstructed. Leakage of Connections	The reduction of bottom hole pressure, affecting well safety Increase the pressure in the surface network	Periodic Maintenance Monitoring from XHOD System	To have a cleaning liquid in the field ready to be injected in case of need	C	1	1	1	1	C1	C1	C1	C1
1.3.3.b		No Flow	Valves in the manifold can be closed, internal pipes obstructed, filter dirty.	Loss of Circulation in the well, Loss of the dynamic pressure downhole The pressure increase in the surface network affecting the safety of personal around the equipment	Relief Valve Pressure Sensors and Monitoring from the X HoD control panel		B	5	3	3	4	B5	B3	B3	B4
1.3.3.c			Break on the Manifold Piping	Loss of Circulation in the well, Loss of the dynamic pressure downhole Affecting the Safety of Personal working around the tool Leakage to the Environment	Relief Valve XHOD Monitoring system	Periodic hourly Visual inspection while the manifold in operation	B	5	4	3	4	B5	B4	B3	B4

System	HoD	**HAZID Number:**	1
Subsystem	HoD Operation	**Prepared By:**	Magdalena Vera Chena
		Date:	04/11/2019
		Revision Date:	14/11/2019

CODE	FUNCTION	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	Freq. Index	DAMAGE				RISK			
								People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
1.3.3.d		Low Pressure	Failure of the Valve Sealing between the high pressure and low pressure lines	Pressure Fluctuation downholeThe radial Valve might open causing faulty operation	XHOD system will alarm if there is any anomaly detection	add extra vlave to work as a barrier between the high and low pressures	A	2	3	4	4	A2	A3	A4	A4
1.3.4.a		Less Flow	Obstruction on the Clamp Hose, Failure of the Seal with the Sub	The reduction of bottom hole pressure, affecting well safety Increase the pressure in the surface network	Relief Valve in the manifold		C	1	1	1	1	C1	C1	C1	C1
	Clamp mantains circulation	No Flow	Total Failure of Seal Around the Sub.	Loss of Circulation in the well, Loss of the dynamic pressure downhole	XHOD system to assure and monitor the seal and the pressure data all the time		B	1	2	2	2	B1	B2	B2	B2
1.3.4.b			Loss of Clamp Arms hydraulic power	Loss of the Circulation in the Wellbore High pressure in the rig floor Leakage to the environment	The Arms has a looking mechanism, that in case of lose of hydraulic power, the arms stay intact		B	2	2	2	2	B2	B2	B2	B2
1.3.6	Sub maintains radial valve open	Incomplete Opening	Obstruction of the Valve due to internal deformation in the sub	Shearing and failure of the valve by the effect of mud flow Failure to continue in circulation , and loss of downhole dynamic pressure.	XHOD Monitoring system Make sure the subs will not operate more than 400 hrs		B	2	2	1	1	B2	B2	B1	B1
1.3.7	Sub maintains axial valve closed	Axial Valve Leak	Metal to Metal Seal Failure	The high pressure transmits to the manifold low	Periodic inspection of the sub on the		C	3	2	1	1	C3	C2	C1	C1

System	HoD	HAZID Number:	1
Subsystem	HoD Operation	Prepared By:	Magdalena Vera Chena
		Date:	04/11/2019
		Revision Date:	14/11/2019

CODE	FUNCTION	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	Freq. Index	DAMAGE				RISK			
								People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
				pressure line making safety issue on the rig floor	surface										
1.4	Continue Drilling Phase: To Divert the Flow to the Top Drive Side and Prepare to continue Drilling														
1.4.1.a	Manifold to Divert the Flow to the Standpipe manifold and top drive	Less flow to the Top Drive	manifold is partially blocked, internal pipelines are blocked, filter obstructed. Leakage of Connections Fracture of Manifold Pipes	The reduction of bottom hole pressure, affecting well safety Increase the pressure in the surface network	Periodic Maintenance Monitoring from XHOD System	To have a cleaning liquid in the field ready to be injected in case of need	A	4	3	2	1	A4	A3	A2	A1
1.4.1.b		No Flow to the Top Drive	Valves in the manifold can be closed, internal pipes obstructed, filter dirty. Fracture in the manifold piping	Loss of Circulation in the well, Loss of the dynamic pressure downhole The pressure increase in the surface network affecting the safety of personal around the equipment	Relief Valve Pressure Sensors and Monitoring from the X HoD control panel		A	4	1	3	2	A4	A1	A3	A2
1.4.1.C			Break on the Manifold Piping	Loss of Circulation in the well, Loss of the dynamic pressure downhole Affecting the Safety of Personal working around the tool Leakage to the Environment	Relief Valve XHOD Monitoring system	Periodic hourly Visual inspection while the manifold in operation	B	5	4	3	4	B5	B4	B3	B4

System	HoD	HAZID Number:	1
Subsystem	HoD Operation	Prepared By:	Magdalena Vera Chena
		Date:	04/11/2019
		Revision Date:	14/11/2019

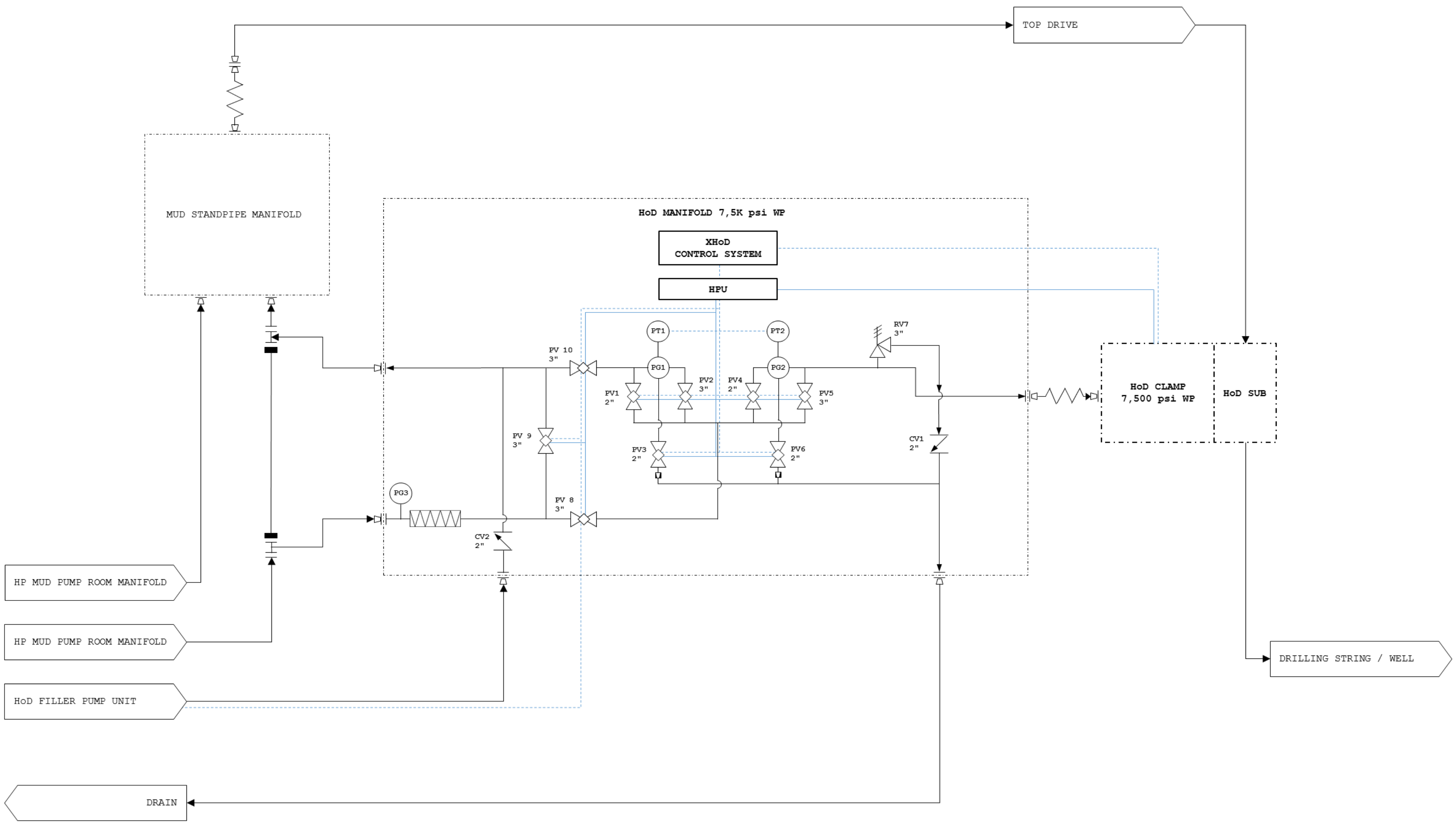
CODE	FUNCTION	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	Freq. Index	DAMAGE				RISK			
								People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
1.4.2.a	Subs Axial Valve To open Completely	Fail to Open	Valve Failed and Stuck in position	Shearing and failure of the valve by the effect of mud flow Failure to continue in circulation , and loss of downhole dynamic pressure	XHOD Monitoring system Make sure the subs will not operate more than 400 hrs Periodic inspection of the sub on the surface		B	1	2	1	0	B1	B2	B1	B0
1.4.2.b		Incomplete Opening	Mud Deposits on the Valve.				B	1	1	1	1	B1	B1	B1	B1
1.4.3.a	Sub Radial Valve to close	Not Closing	Valve Sheared. Valve Stuck in position				A	1	1	1	1	A1	A1	A1	A1
1.4.3.b		No Pressure Seal	Mud Deposits on the Valve.				B	1	1	1	1	B1	B1	B1	B1
1.4.4	Clamp to put the Plug and Securing it	Fail to Secure the Plug in Place	Plug Deformation Mud Deposits on the threads between plug and sub	Risky situation of one pressure barrier	Locking Mechanism in the plug XHoD to ensure correct operation cleaning system in the clamp to remove any deposits	To put a troubleshooting plan, that can be done without the operator in the high pressure zone around the sub with one barrier	B	4	3	3	3	B4	B3	B3	B3
1.4.5	Clamp detach from the Sub	Clamp Hydraulic Arms Fail to Open	Internal Malfunction of the Hydraulic system Malfunction of the Control System	NPT	The clamp can be operated manually The operator should be able to troubleshoot the system completely		A	2	1	1	1	A2	A1	A1	A1
1.5	Auxiliary Services														
1.5.1	Electrical Power Unit														

System	HoD	**HAZID Number:**	1
Subsystem	HoD Operation	**Prepared By:**	Magdalena Vera Chena
		Date:	04/11/2019
		Revision Date:	14/11/2019

CODE	FUNCTION	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	Freq. Index	DAMAGE				RISK			
								People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.
1.5.1.1	Provide energy to the Control System, Manifold, Clamp, and Double filler pump	No or Less Energy	Black Out on the Rig Loss of the connection to the rig power system	Loss of Continuous Circulation service in the Wellbore Increase the probability of having a risky situation with high pressure	system can be operated manually	Addition of Extra battery package to the system	C	3	3	3	3	C3	C3	C3	C3
1.5.2	Hydraulic Power Unit														
1.5.2.1	Provide hydraulic power to Manifold, Clamp, and Double filler pump	No or Less Power	Internal Failure of the system Leakage in the Hydraulic Connections Human Error	Loss of Continuous Circulation service in the Wellbore Increase the probability of having a risky situation with high pressure	system can be operated manually		C	3	3	3	3	C3	C3	C3	C3
1.5.3	XHoD Control System														
1.5.3.1	Control and Monitor of the system during all phases	Malfunction	Internal Error of the system Human Error	Miss indications, that will lead to incorrect decsions Loss of Continuous Circulation service in the Wellbore Increase the probability of having a risky situation with high pressure	system can be operated manually	To have a contniuous improvment and updates on the current system, with after job review. For the operator to be well trained to troubelshoot the system completely	C	3	3	3	3	C3	C3	C3	C3

ANNEX III - *Node Definition - Hazard and Operability Analysis (HAZOP)*

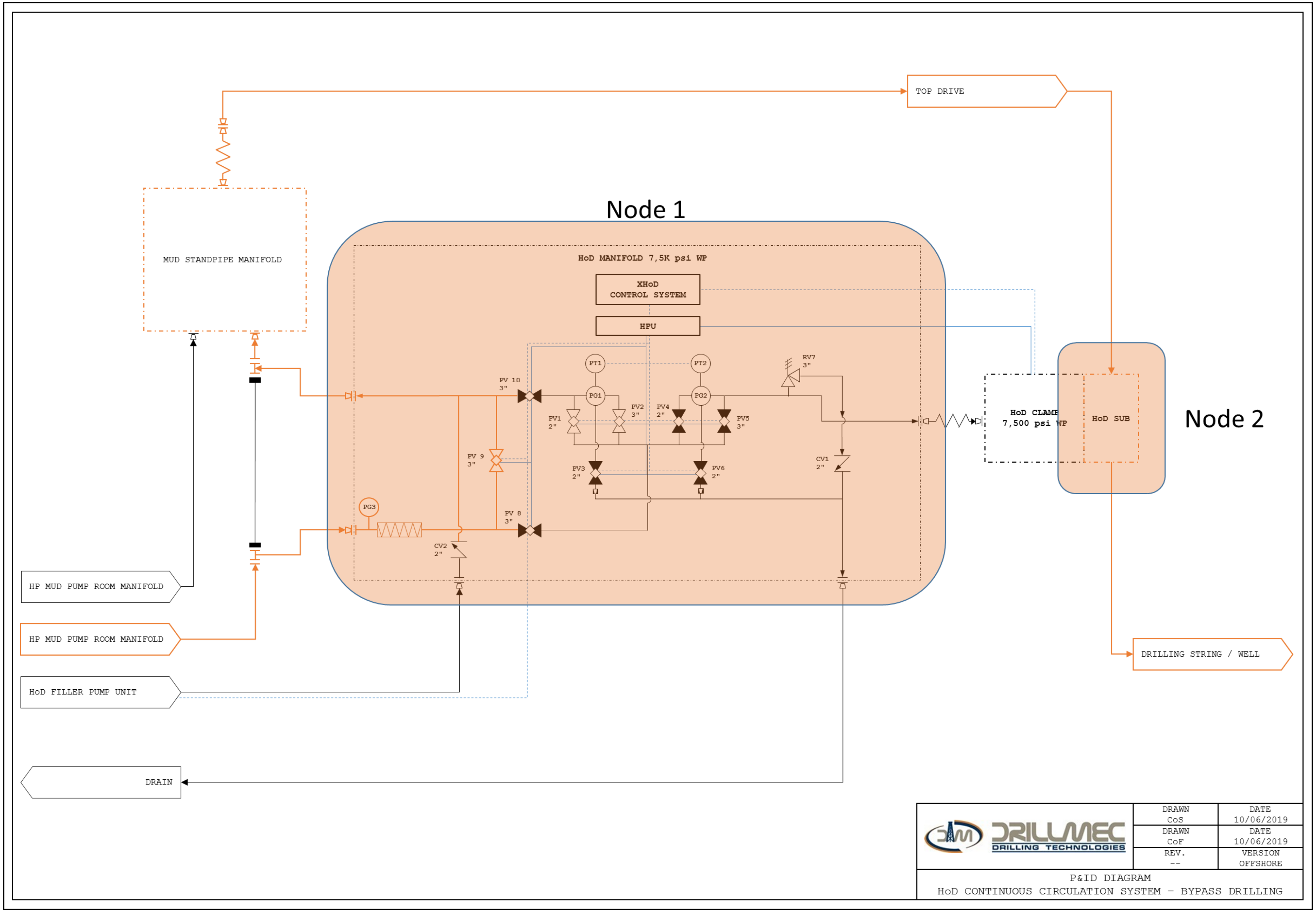
General P&ID of the System



	DRAWN CoS	DATE 10/06/2019
DRILLMEC DRILLING TECHNOLOGIES	DRAWN CoF	DATE 10/06/2019
	REV. --	VERSION OFFSHORE

P&ID DIAGRAM
HoD CONTINUOUS CIRCULATION SYSTEM - GENERAL

Drilling Phase


TOP DRIVE
Node 1
MUD STANDPIPE MANIFOLD
HoD MANIFOLD 7,5K psi WP
XHoD
CONTROL SYSTEM
HPU
PT1
PT2
RV7
3"
PV 10
3"
PG1
PG2
PV1
2"
PV2
3"
PV4
2"
PV5
3"
HoD CLAMP
7,500 psi WP
HoD SUB
Node 2
CV1
2"
PV 9
3"
PV3
2"
PV6
2"
PG3
PV 8
3"
CV2
2"
HP MUD PUMP ROOM MANIFOLD
HP MUD PUMP ROOM MANIFOLD
HoD FILLER PUMP UNIT
DRILLING STRING / WELL
DRAIN
DRAWN
CoS
DATE
10/06/2019
DRAWN
CoF
DATE
10/06/2019
REV.
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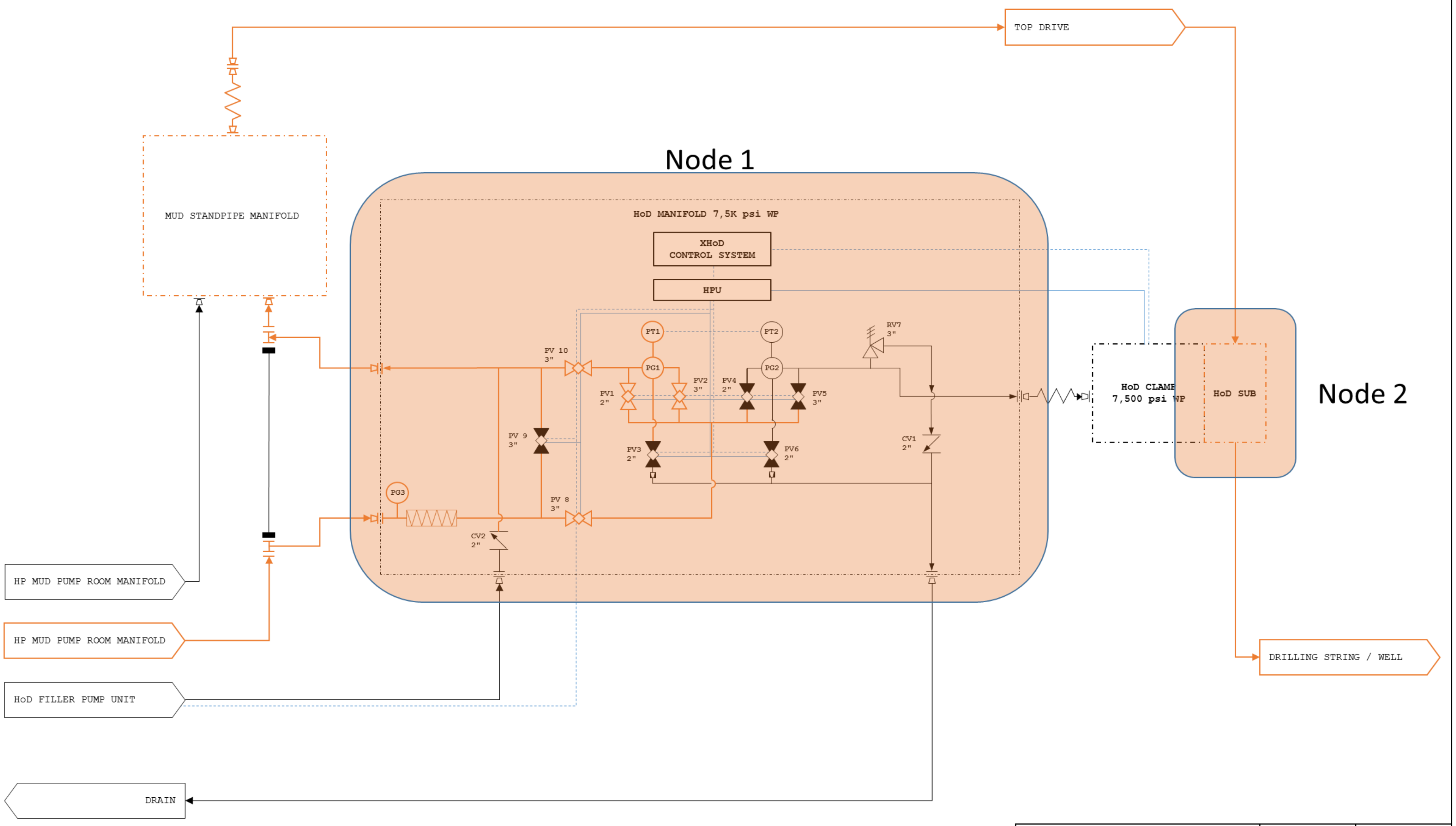
VERSION
OFFSHORE
DRILLING TECHNOLOGIES
P&ID DIAGRAM
HoD CONTINUOUS CIRCULATION SYSTEM - BYPASS DRILLING

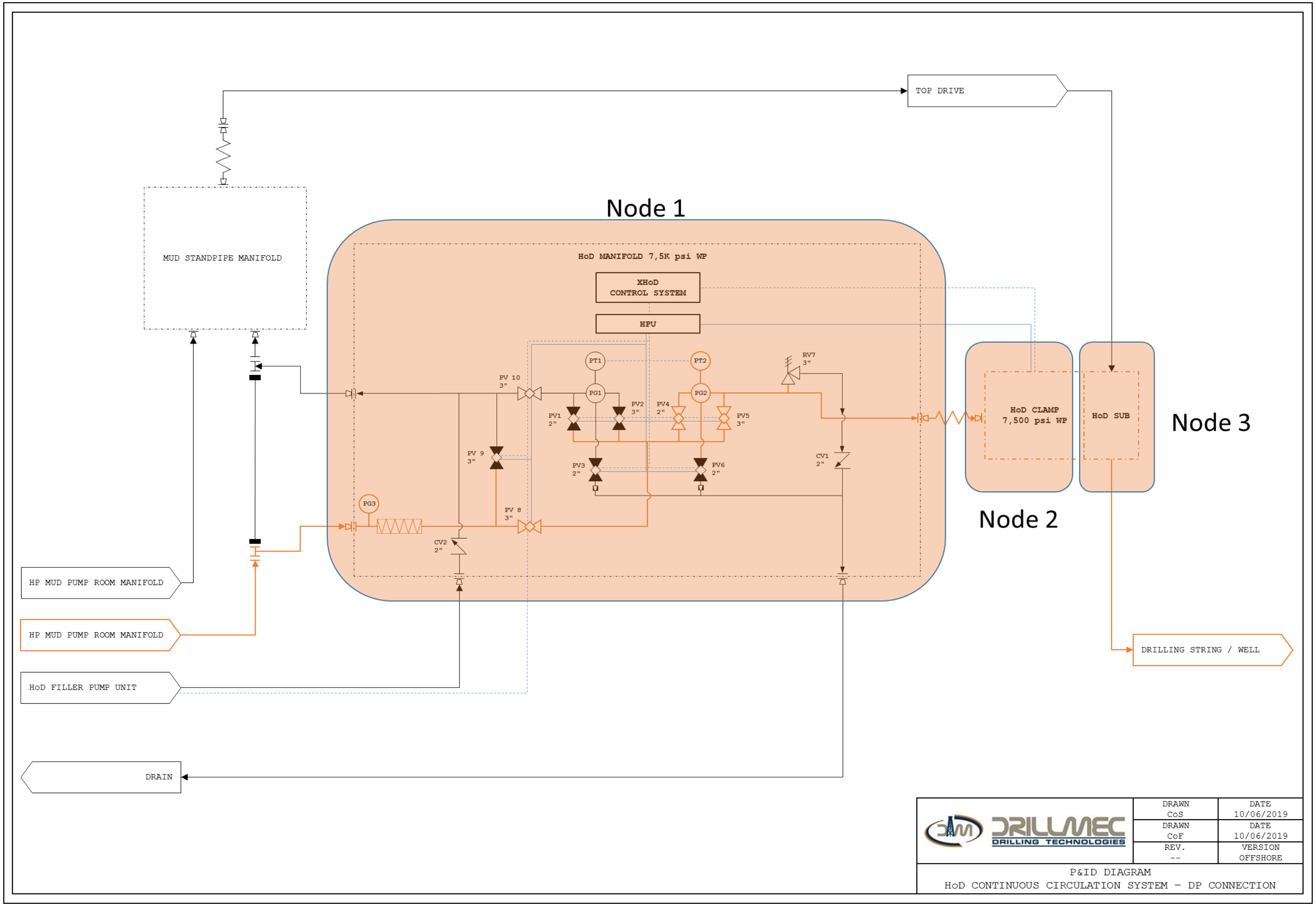
By-Pass Drilling Phase



	DRAWN CoS	DATE 10/06/2019
DRILLMEC DRILLING TECHNOLOGIES	DRAWN CoF	DATE 10/06/2019
	REV. --	VERSION OFFSHORE

P&ID DIAGRAM
HoD CONTINUOUS CIRCULATION SYSTEM – DRILLING PHASE

Drill Pipe Connection Phase



TOP DRIVE
MUD STANDPIPE MANIFOLD
Node 1
HoD MANIFOLD 7,5K psi WP
XHoD
CONTROL SYSTEM
HPU
PT1
PT2
PG1
PG2
PG3
RV7
3"
PV 10
3"
PV1
2"
PV2
3"
PV4
2"
PV5
3"
PV 9
3"
PV3
2"
PV6
2"
CV1
2"
PV 8
3"
CV2
2"
HoD CLAMP
7,500 psi WP
HoD SUB
Node 3
Node 2
HP MUD PUMP ROOM MANIFOLD
HP MUD PUMP ROOM MANIFOLD
HoD FILLER PUMP UNIT
DRAIN
DRILLING STRING / WELL
DRILLMEC
DRILLING TECHNOLOGIES
DRAWN
CoS
DATE
10/06/2019
DRAWN
CoF
DATE
10/06/2019
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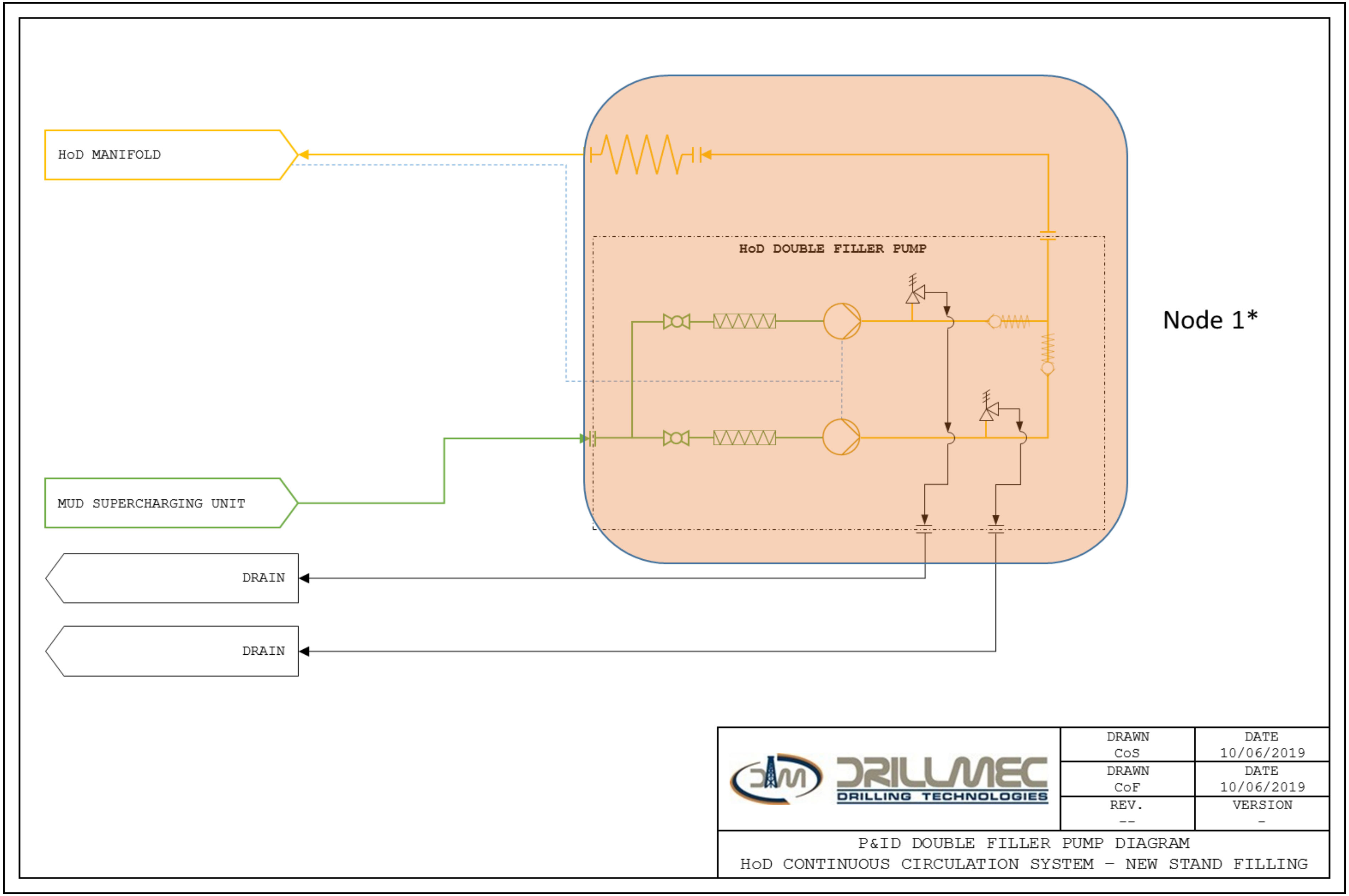
VERSION
OFFSHORE
P&ID DIAGRAM
HoD CONTINUOUS CIRCULATION SYSTEM - DP CONNECTION

New Stand Filling Phase


HoD MANIFOLD
HoD DOUBLE FILLER PUMP
Node 1*
MUD SUPERCHARGING UNIT
DRAIN
DRAIN
DRILLMEC
DRILLING TECHNOLOGIES
DRAWN
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DATE
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DRAWN
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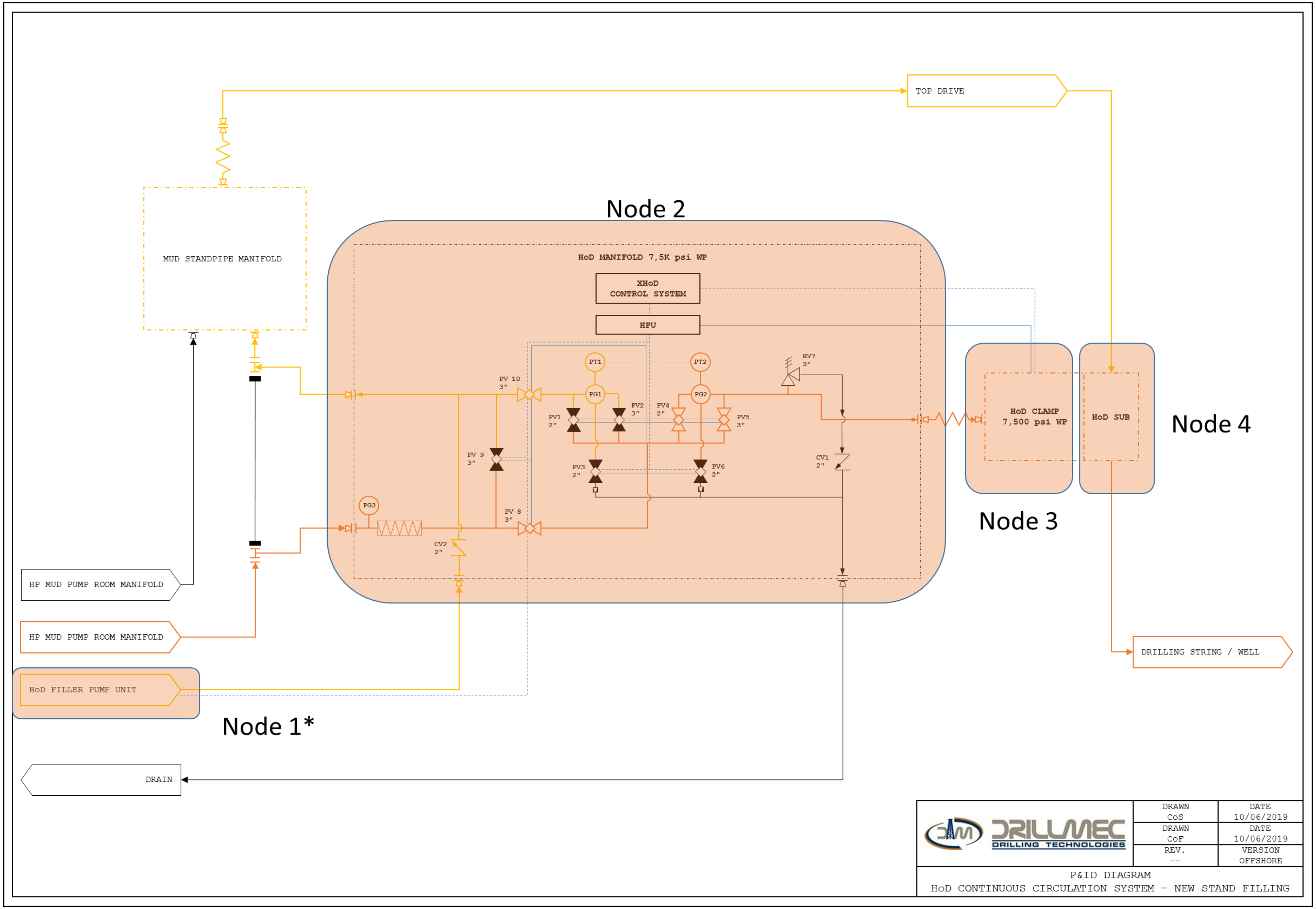
P&ID DOUBLE FILLER PUMP DIAGRAM
HoD CONTINUOUS CIRCULATION SYSTEM – NEW STAND FILLING



TOP DRIVE
MUD STANDPIPE MANIFOLD
Node 2
HoD MANIFOLD 7,5K psi WP
XHoD
CONTROL SYSTEM
HPU
PT1
PT2
RV7
3"
PV 10
3"
PG1
PG2
PV1
2"
PV2
3"
PV4
2"
PV5
3"
PV 9
3"
PV3
2"
PV6
2"
CV1
2"
PG3
PV 8
3"
CV2
2"
HoD CLAMP
7,500 psi WP
HoD SUB
Node 4
Node 3
HP MUD PUMP ROOM MANIFOLD
HP MUD PUMP ROOM MANIFOLD
HoD FILLER PUMP UNIT
Node 1*
DRILLING STRING / WELL
DRAIN
DRILLMEC
DRILLING TECHNOLOGIES
DRAWN
CoS
DATE
10/06/2019
DRAWN
CoF
DATE
10/06/2019
REV.
--
VERSION
OFFSHORE
P&ID DIAGRAM
HoD CONTINUOUS CIRCULATION SYSTEM - NEW STAND FILLING

ANNEX IV - *Hazard and Operability Analysis (HAZOP) - Worksheets*

HAZOP HoD Sub – Diverting the Flow by the Clamp

System HoD **NODE** DP-2

Subsystem HoD Sub

Operational Phase **DRILLING PHASE**

Mission To allow the connection of the top drive or the clamp according to the phase

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Flow	No	No	Blockage of the sub due to structural deformation of the sub	Non productive time. Lack of mud inside the drillpipe. Loss of Circulation in the wellbore.		A	4	4	4	4	A4	A4	A4	A4	
			No feed from the top drive			A	2	4	2	2	A2	A4	A2	A2	
	Less	Low	Partially obstructed sub or drillpipe.	Less amount of mud will enter into the well.		A	2	4	2	2	A2	A4	A2	A2	
			Radial valve is leaking in closed position	Mud spill in the rig floor.	Tested and installed plug above the radial Valve Periodical maintenance and revision of the subs before and after every operation.	A	2	4	2	2	A2	A4	A2	A2	
			Radial valve opens		Tested and installed plug above the radial Valve	A	2	4	2	2	A2	A4	A2	A2	
			Mud is not filtered and precipitation inside the Sub	The reduction and restriction of flow. Non productive time to discover the faulty Sub.	The Sub is designed to have minimum diameter changes and the minimum ability of having precipitation surfaces. Periodic maintenance according on working hours of the tool	B	1	2	1	1	B1	B2	B1	B1	

System	HoD	**NODE**	DP-2
Subsystem	HoD Sub		
Operational Phase	**DRILLING PHASE**		
Mission	To allow the connection of the top drive or the clamp according to the phase		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
	More	High	High flow coming from the top drive side.	Erosional Deformation of the sub interior and the valves, affecting the functionality of the sub.	The operator to know the optimum and maximum operating limits of the sub.	B	1	3	1	1	B1	B3	B1	B1	
Pressure	More	High	Blockage of the sub or drillpipe	Non productive time.	Decrease the flow rate.	B	1	3	1	1	B1	B3	B1	B1	
	Less	Low	Not enough flow is arriving to the sub from the top drive side	Non productive time.	Increase pressure on clamp side.	C	1	0	1	1	C1	C0	C1	C1	
Position	More	The release of the plug and lose in hole	The Plug is not well installed.	Non Prodcutive Time Failure on the sub Safety issue in the rig floor Stop Circulation		C	1	1	1	1	C1	C1	C1	C1	Add a locking mechanism to the plug that can only be released and unlocked by the clamp. Addition by a locking Mechanism in the Clamp making sure that the plug won't be wrongly released.
Weather	More	Above limitations	Temperature beneath the 0 °C	Valve Mechanism Failure to work as designed.	N/A	A	1	1	1	1	A1	A1	A1	A1	

HAZOP HoD Manifold – By-Pass Drilling Phase

System	HoD	**NODE**	BPD-1
Subsystem	Manifold (High pressure line)		
Operational Phase	**BY PASS DRILLING**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	No	No	Inlet pipeline coming from the HP Mud Pump Room Manifold is blocked	Increase in pressure inside the inlet line, which might result in rupture of the pipeline connections.	No pressure measurement will be read on PG3	A	3	3	2	1	A3	A3	A2	A1	
			HP Mud Pump Room Manifold is not functioning correctly	No mud will arrive to the Mud Standpipe Manifold Lack of mud in the well which might induce a kick	PG3 will show up an increase in pressure	A	0	0	0	0	A0	A0	A0	A0	
			Filter is blocked			B	1	1	1	1	B1	B1	B1	B1	
			Outlet line after PV9 is blocked			B	1	1	1	1	B1	B1	B1	B1	
			HPU not functioning		X-HoD control system shows whether the HPU is working or not	A	1	1	1	2	A1	A1	A1	A2	
			X-HoD Control System malfunction		May have to stop circulation and secure the well using primary well control to reboot the system.	B	1	1	2	3	B1	B1	B2	B3	Provide a backup system, and a battery in case of loss of power.
Pressure	Less	Low	Inlet pipeline is damaged	Rupture of the pipeline connections at the inlet	Increase of pressure in PG3	B	3	4	4	3	B3	B4	B4	B3	
			Filter is dirty	Increase in pressure inside the inlet line, which might result in rupture of the pipeline connections.		B	1	1	1	1	B1	B1	B1	B1	
			PV9 is not fully open	Less amount of mud will go out from the manifold to the mudstandpipe manifold.		B	1	1	1	1	B1	B1	B1	B1	

System	HoD	**NODE**	BPD-1
Subsystem	Manifold (High pressure line)		
Operational Phase	**BY PASS DRILLING**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			PV8 or PV10 are open	Deviation of the mud to the standpipe manifold, which will cause an increase in the pressure of the PT1 PG1	Increase in pressure will be detected by PG1 / PT1 and so the X-HoD control system. X-HoD system can control the valves. If operator notices the variation in pressure on the system. Specially on PG1/PT1	B	1	1	1	1	B1	B1	B1	B1	
			Pipeline inside the manifold is partially blocked	Increase in pressure inside the manifold. Eventual rupture of line connections.	It will show up as an increase in the values of PT2 and PG2 but the pressure at the outlet (connection with the clamp is low). All the valves are working normally	A	3	1	2	1	A3	A1	A2	A1	
Pressure	More	High	Human Error to measure the flow rate coming from the HP Mud pump room manifold	Malfunction of the system. Stop operations	It will be noticed as the pressure read at PG3 will be greater than the one expected. Also the flowrate will be big	A	5	5	5	5	A5	A5	A5	A5	
Pressure	Reverse	Reverse	Pressure in the mudstandpipe manifold is greater than the pressure in the HP Mud pump room manifold	Malfunction of the system. Stop operations	Unlikely to happen but all pressure variations are monitored by X-HoD Control System in real time.	A	5	5	5	5	A5	A5	A5	A5	
Flow	No	No	Inlet line to the manifold is obstructed	No mud will arrive to the Mud Standpipe Manifold Lack of mud in the well which might induce a kick	Routine maintenance	B	1	1	1	0	B1	B1	B1	B0	
			Filter is blocked			B	1	1	1	0	B1	B1	B1	B0	

System HoD **NODE** BPD-1

Subsystem Manifold (High pressure line)

Operational Phase **BY PASS DRILLING**

Mission Deviate the mud flow where is required

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			PV9 is closed		Increase in pressure in PG3 indicating a problem with the flow line	A	4	2	3	2	A4	A2	A3	A2	
			Outlet line of manifold is blocked	Will cause overpressure on the line. Which might cause rupture of the pipe connections		A	4	2	3	2	A4	A2	A3	A2	
Flow	Less	Low	Filter is partially obstructed.	Increase in the value of pressure on PG3, Decrease in the flow that gets out from the HoD manifold to the Mud Standpipe Manifold,	Increase in pressure in the PG3. Routine maintenance.	B	1	1	1	0	B1	B1	B1	B0	
			PV9 is not fully open		Increase in the value of pressure on PG3, increase in the flow that enters the Mud standpipe manifold.	A	1	1	1	0	A1	A1	A1	A0	
			Inlet line of manifold ispartially blocked.			A	1	1	1	0	A1	A1	A1	A0	
			PV8 or PV10 are open		Increase in the value of pressure read on PT1/PG1, Decrease of the value of pressure read in PG3	A	1	1	1	0	A1	A1	A1	A0	
Flow	Reverse	Reverse	Pressure in the well is higher than the pressure in the manifold	Kick entering inside the drillpipe	The sub will work as one way valve not allowing the reverse of the flow.	A	5	5	5	5	A5	A5	A5	A5	
Flow	More	High	Problem with the HP mud pump room manifold	Increase of the flow inside the mud stand pipe value, sub and subsequently well. Increase the ECD which might cause fracture of formation and eventual loss of mud to the formation.	Increase in the value of PG3 The Mud standpipe manifold also has its own controls to detect if the entering flow is too big	A	3	4	5	5	A3	A4	A5	A5	

System	HoD	**NODE**	BPD-1
Subsystem	Manifold (High pressure line)		
Operational Phase	**BY PASS DRILLING**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Power	Less	Partly lost	Short circuit on the rig. Failure of the HPU	X-HoD Control System might not work properly.	The valves will stay in location. But the operator will have the ability to control each of them manually. The cable that connects the control panel with the manifold is located on the rig floor, but it is covered in order to avoid being damaged.	A	1	0	2	1	A1	A0	A2	A1	Have a backup battery for the X-HoD Control System, Standpipe Manifold can be filled directly with the HP Mud pump room manifold
	No	Complete loss	Blackout on the rig	X-HoD Control System might not work properly.		B	2	1	3	1	B2	B1	B3	B1	

HAZOP HoD Sub – By-Pass Drilling Phase

System	HoD	NODE	BPD-2
Subsystem	HoD Sub		
Operational Phase	BY PASS DRILLING		
Mission	To allow the connection of the top drive or the clamp according to the phase		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Flow	No	No	Blockage of the sub due to structural deformation of the sub	Failure to keep the circulation inside the wellbore.		A	4	4	4	4	A4	A4	A4	A4	Addition of a locking mechanism for the valves.
	Less	Low	Partially obstructed sub or drillpipe.	Less amount of mud will enter into the well.		A	2	4	2	2	A2	A4	A2	A2	
			Radial valve is leaking in closed position	Mud spill in the rig floor. Loss of continuous circulation inside the wellbore.	Periodical maintenance and revision of the subs before and after every operation.	A	2	4	2	2	A2	A4	A2	A2	Addition of a locking mechanism for the valves.
			Radial valve opens		As the clamp is connected to the sub, the axial valve will remain closed due to the pressure difference inside the sub body.	A	2	4	2	2	A2	A4	A2	A2	Addition of a locking mechanism for the valves.
			Mud was not filtered and precipitation inside the sub surfaces	Non productive time.	The reduction of surfaces change inside the sub. Periodic maintenance according on working hours of the tool	B	1	2	1	1	B1	B2	B1	B1	Check of the drift Diameter with each installation.
	More	High	High flow coming from the top drive side. Wrong input on the software	High influx in the well. Increase of ECD which might lead to fracturing the formation	Software prevents from the influx to increase without a specific command	B	1	3	1	1	B1	B3	B1	B1	

System	HoD	**NODE**	BPD-2
Subsystem	HoD Sub		
Operational Phase	**BY PASS DRILLING**		
Mission	To allow the connection of the top drive or the clamp according to the phase		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	More	High	Blockage of the sub or drillpipe	The loss of circulation inside the wellbore. Non productive time.	Decrease the flow rate.	B	1	3	1	1	B1	B3	B1	B1	
	Less	Low	Washout of the sub	The loss of circulation inside the wellbore. Non productive time.		C	1	0	1	1	C1	C0	C1	C1	
Position	More	The loss of the plug inside the wellbore.	The plug is not well installed.	Failure on the sub. Lost Fish in the wellbore. non Productive time.	Make sure that the plug is in the right position while performing the previous operation.	C	1	1	1	1	C1	C1	C1	C1	Add a plug locking mechanism before running in hole. The locking mechanism to be activated and deactivated by the clamp.
Weather	More	Above limitations	Temperature beneath the 0 °C	Failure of the sub valves working mechanisms.	N/A	A	1	1	1	1	A1	A1	A1	A1	

HAZOP HoD Manifold – Drill Pipe Connection Phase

System	HoD	**NODE**	DPC-3
Subsystem	Manifold (High pressure line)		
Operational Phase	**DRILL PIPE CONNECTION**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	No	No	Inlet pipeline coming from the HP Mud Pump Room Manifold is blocked	Increase in pressure inside the inlet line, which might result in rupture of the pipeline connections.	No pressure measurement will be read on PG3	A	5	3	2	1	A3	A3	A2	A1	
			HP Mud Pump Room Manifold is not functioning correctly	No mud will arrive to the HoD Clamp Lack of mud in the well which might induce a kick	PG3 will show up an increase in pressure while PT2 and PG2 will remain invariant	A	0	0	0	0	A0	A0	A0	A0	
			Filter is blocked		PG3 will show up an increase in pressure while PT2 and PG2 will remain invariant	B	1	1	1	1	B1	B1	B1	B1	
			PV8 is closed		X-HoD Control System shows the valves that are closed and open. It can control the opening or closure. Valves can be activated manually	B	1	1	1	1	B1	B1	B1	B1	
			PV4 and PV5 are closed			B	1	1	1	1	B1	B1	B1	B1	
			Pipeline after the connection with RV7 is obstructed.		Pressure gauges PT2 PG2 will show an increase in pressure while at the outlet of the manifold will not be any.	B	2	3	1	1	B2	B3	B1	B1	
			HPU not functioning		X-HoD control system shows whether the HPU is working or not	A	1	1	1	2	A1	A1	A1	A2	
			X-HoD Control System malfunction		May have to stop circulation and secure the well using primary well control to reboot the system.	B	1	1	2	3	B1	B1	B2	B3	Provide a backup system, and a battery in case of loss of power.

System	HoD	NODE	DPC-3
Subsystem	Manifold (High pressure line)		
Operational Phase	**DRILL PIPE CONNECTION**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	Less	Low	Inlet pipeline is damaged	Rupture of the pipeline connections at the inlet	Increase of pressure in PG3	B	3	4	4	3	B3	B4	B4	B3	
			Filter is dirty	Increase in pressure inside the inlet line, which might result in rupture of the pipeline connections.		B	1	1	1	1	B1	B1	B1	B1	
			PV8 is not fully open	Less amount of mud will go out from the manifold to the clamp.		B	1	1	1	1	B1	B1	B1	B1	
			PV9 is open	Deviation of the mud to the standpipe manifold, which will cause an increase in the pressure of the PT1 PG1	Increase in pressure will be detected by PG1 / PT1 and so the X-HoD control system. X-HoD system can control the valves. If operator notices the variation in pressure on the system. Specially on PG1/PT1	B	1	1	1	1	B1	B1	B1	B1	
			PV1 or PV2 are open			B	1	1	1	1	B1	B1	B1	B1	
			PV6 is open	Loss of mud to the drain	Loss of pressure that can be noticed by PT2 or PG2	B	1	1	1	1	B1	B1	B1	B1	
			RV7 is open or leaking	Less amount of mud will go out from the manifold to the clamp. Pressure build up inside the manifold		B	1	4	1	1	B1	B4	B1	B1	
			Pipeline inside the manifold is partially blocked		It will show up as an increase in the values of PT2 and PG2 but the pressure at the outlet (connection with the clamp is low). All the valves are working normally	A	3	1	2	1	A3	A1	A2	A1	

System	HoD	**NODE**	DPC-3
Subsystem	Manifold (High pressure line)		
Operational Phase	**DRILL PIPE CONNECTION**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	More	High	RV7 does not open on command of PT2/PG2	Rupture of pipe connections. Pressure might damage the hose connection with the clamp or the clamp itself.	Pressure gauges are monitored by X-HoD Control System	A	5	5	5	5	A5	A5	A5	A5	
Flow	No	No	Filter is blocked	No mud will arrive to the HoD Clamp Lack of mud in the well which might induce a kick	Routine maintenance	B	1	1	1	0	B1	B1	B1	B0	
			PV8 is closed and PV9 is open		No pressure read on PT2/PG2, may be an indicator that something is blocking the path of flow	A	1	1	1	0	A1	A1	A1	A0	
			PV 4 and PV5 are closed		No Presure value will be read on PT2/PG2, and an increase on the pressure at PG3 will be shown.	A	1	1	1	0	A1	A1	A1	A0	
			RV7 is open		Decrease of pressure at PT2/PG2 and no flow coming out from the clamp.	A	1	1	1	0	A1	A1	A1	A0	
			Outlet line of manifold is blocked	Will cause overpressure on the line. Which might cause rupture of the pipe connections	Increase in pressure will be detected by PG2 / PT2 and so the X-HoD control system.	A	1	1	1	0	A1	A1	A1	A0	
Flow	Less	Low	Filter is dirty (partially obstructed)	Decrease in the value of pressure on PT2/PG2, increase in the flow that enters the Mud standpipe manifold. Decrease	Increase in pressure in the PG3. Routine maintenance.	B	1	1	1	0	B1	B1	B1	B0	

System	HoD	**NODE**	DPC-3
Subsystem	Manifold (High pressure line)		
Operational Phase	**DRILL PIPE CONNECTION**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			PV8 is not fully open	in the flow that gets out from the HoD manifold to the clamp, sub and well. Lack of mud inside the well might allow the entrance of formation fluids.	Decrease in pressure will be detected by PG2 / PT2, increase in pressure at PT3, X-HoD control system will detect this variations in pressure. Routine maintenance	A	1	1	1	0	A1	A1	A1	A0	
			PV9 is open	Increase in the value of pressure on PT1/PG1, increase in the flow that enters the Mud standpipe manifold. Decrease of the value of pressure read in PT2/PG2, also decrease in the flow that gets out from the HoD manifold to the clamp, sub and well. Lack of mud inside the well might allow the entrance of formation fluids.		A	1	1	1	0	A1	A1	A1	A0	
			PV1 or PV2 are open			A	1	1	1	0	A1	A1	A1	A0	
			PV1 and PV3 are open			A	1	1	1	0	A1	A1	A1	A0	
			PV2 and PV3 are open			A	1	1	1	0	A1	A1	A1	A0	
			PV4 is closed	Decrease in the value of pressure on PT2/PG2, increase in the flow that enters the Mud standpipe manifold. Decrease in the flow that gets out from the HoD manifold to the clamp, sub and well. Lack of mud inside		A	1	1	1	0	A1	A1	A1	A0	
			PV5 is closed			A	1	1	1	0	A1	A1	A1	A0	
			PV6 is open			A	1	1	1	0	A1	A1	A1	A0	

System	HoD	**NODE**	DPC-3
Subsystem	Manifold (High pressure line)		
Operational Phase	**DRILL PIPE CONNECTION**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			RV7 is open	the well might allow the entrance of formation fluids.		A	1	1	1	0	A1	A1	A1	A0	
Flow	Reverse	Reverse	Pressure in the well is bigger than the pressure in the manifold	Kick entering inside the drillpipe	Initiate well control procedures	A	5	5	5	5	A5	A5	A5	A5	
Flow	More	High	Problem with the HP mud pump room manifold	Increase of the flow inside the clamp, sub and subsequently well. Increase the ECD which might cause fracture of formation and eventual loss of mud to the formation.	Increase in the value of PG3, as well as the value of PT2 / PG2.	A	3	4	5	5	A3	A4	A5	A5	
Power	Less	Partly lost	Short circuit on the rig. Failure of the HPU	X-HoD Control System might not work properly.	The cable that connects the control pannel with the manifold is located on the rigfloor, but it is covered in order to avoid being damaged.	A	1	0	2	1	A1	A0	A2	A1	Have a backup battery for the X-HoD Control System, Standpipe Manifold can be filled directly with the HP Mud pump room manifold
	No	Complete loss	Blackout on the rig	X-HoD Control System might not work properly.		B	2	1	3	1	B2	B1	B3	B1	

HAZOP HoD Clamp – Drill Pipe Connection Phase

System	HoD	**NODE**	DPC-2
Subsystem	CLAMP		
Operational Phase	**DRILL PIPE CONECTION**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	Less	Low	Hose is partially obstructed	Flow might not reach the outlet of the clamp	Preventive maintenance and onsite programmes to ensure the right functioning of the tool.	A	1	0	1	1	A1	A0	A1	A1	
			Clamping actuator, mud conduct is partially obstructed	The pressure is not enough to divert the flow and open the radial valve.		B	1	0	1	1	B1	B0	B1	B1	
Pressure	No	No	Clamp actuator malfunction. Mud conduct can be obstructed.	Inability to divert the flow.	Pressure build up in manifold PT2/PG2	B	3	1	1	1	B3	B1	B1	B1	
			Internal actuator is blocked			C	1	1	1	1	C1	C1	C1	C1	
			Hydraulic component not working			B	1	1	1	1	B1	B1	B1	B1	
			Electric component damaged			B	3	1	1	1	B3	B1	B1	B1	
			No flow coming from the manifold	xHoD System to identity the problem directly.	Troubleshooting sequence of the manifold										Check the HAZOP table for the Manifold HP line
Pressure	More	High	Inlet hose of the clamp is blocked	Pressure build-up inside the hose. Rupture of hose and connections	The hose and pipelines utilised are designed to have a bursting pressure above the working pressure	B	1	0	1	1	B1	B0	B1	B1	

System	HoD	**NODE**	DPC-2
Subsystem	CLAMP		
Operational Phase	**DRILL PIPE CONECTION**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			Human error	More flow into the sub and well. Increase the ECD, it is possible to break formation if pressure too high	Training course	B	2	1	2	1	B2	B1	B2	B1	
Flow	No	No	Clamping actuators failure	No mud is entering to the well. Non-productive time.	Venturi system will detect the lack of mud at the outlet. And will send a signal to the X-HoD control panel. Routine Maintenance	B	1	0	1	1	B1	B0	B1	B1	
			Electrical actuator failure			B	1	0	2	1	B1	B0	B2	B1	
			Internal actuator is blocked			B	2	1	3	1	B2	B1	B3	B1	
			Hose is obstructed			C	2	3	3	2	C2	C3	C3	C2	
			No flow coming from the manifold	Check the HAZOP table for the Manifold HP line											Check the HAZOP table for the Manifold HP line
Flow	Less	Low	Clamping actuators failure	Less mud than required is entering into the well.	Venturi system will detect the lack of mud at the outlet. And will send a signal to the X-HoD control panel. Routine Maintenance	B	2	3	3	2	B2	B3	B3	B2	
			Electrical actuator failure			B	3	3	3	3	B3	B3	B3	B3	
			Internal actuator is blocked			B	3	3	3	3	B3	B3	B3	B3	
Flow	More	High	Human error	Mud spill in the rig floor. Increase ECD as	Venturi system will detect the increase of mud at the outlet.	C	2	3	3	2	C2	C3	C3	C2	

System	HoD	**NODE**	DPC-2
Subsystem	CLAMP		
Operational Phase	DRILL PIPE CONECTION		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			Calibration Error	mud is going to the well which might fracture formation	And will send a signal to the X-HoD control panel. Routine Maintenance	A	3	3	3	3	A3	A3	A3	A3	
			High flow coming from manifold	Troubleshooting of the Manifold HP line.											Troubleshooting of the Manifold HP line.
Personnel	No	Lack of competence	Lack of trainning	Damage of the system. Personal Injuries. Mud spill.	Training course	B	3	3	3	3	B3	B3	B3	B3	
	Less	Too few	Lack of organisation and planning	Clamp might fall while trying to Personal Injuries.	Clear procedures and personnel should be defined ahead	B	3	3	4	3	B3	B3	B4	B3	
	More	Too many	Lack of organisation and planning	Clamp might fall while trying to remove (heavy) People might get hurt.	Clear procedures and personnel should be defined ahead	B	3	3	4	3	B3	B3	B4	B3	
	No	Complete loss	Electrical Connections problem. Blackout on the rig.	X-HoD Control System might not work properly. Mud Spill in the rig floor.	The cable that connects the control panel with the manifold is located on the rig floor, but it is covered in order to avoid being damaged.	B	2	1	3	1	B2	B1	B3	B1	

HAZOP HoD Sub – Drill Pipe Connection Phase

System HoD **NODE** DPC-1

Subsystem HoD Sub

Operational Phase DRILL PIPE CONNECTION

Mission To allow the connection of the top drive or the clamp according to the phase

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Flow	No	No	Blockage of the sub due to structural deformation of the sub	Non productive time. Lack of mud inside the drillpipe, prevent the benefits of continuous circulation		A	4	4	4	4	A4	A4	A4	A4	
			Radial valve is not open			A	2	4	2	2	A2	A4	A2	A2	
			No feed from the clamp			A	2	4	2	2	A2	A4	A2	A2	
	Less	Low	Partially obstructed sub or drillpipe.	Less amount of mud will enter into the well.		A	2	4	2	2	A2	A4	A2	A2	
			Axial valve is leaking in closed position	Mud spill in the rig floor.	Periodical maintenance and revision of the subs before and after every operation.	A	2	4	2	2	A2	A4	A2	A2	
			Axial valve opens		As the clamp is connected to the sub, the axial valve will remain closed due to the pressure difference inside the sub body.	A	2	4	2	2	A2	A4	A2	A2	

System	HoD	**NODE**	DPC-1
Subsystem	HoD Sub		
Operational Phase	**DRILL PIPE CONNECTION**		
Mission	To allow the connection of the top drive or the clamp according to the phase		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			Mud was not filtered	Non productive time.	Pressure can be increased in the clamp. Periodic maintenance according on working hours of the tool	B	1	2	1	1	B1	B2	B1	B1	
	More	High	High flow coming from the clamp. Wrong input on the software	High influx in the well. Increase of ECD which might lead to fracturing the formation	Software prevents from the influx to increase without a specific command	B	1	3	1	1	B1	B3	B1	B1	
Pressure	More	High	Blockage of the sub or drillpipe	Non productive time.	Decrease the flow rate.	B	1	3	1	1	B1	B3	B1	B1	
	Less	Low	Not enough flow is arriving to the sub from the clamp	Non productive time.	Increase pressure on clamp side.	C	1	0	1	1	C1	C0	C1	C1	
Position	More	Movement exceeding tolerances	Sub is not well positioned on the drillpipe. Human error	Failure on the sub	Make sure that the sub is in the right position while performing the previous operation.	C	1	1	1	1	C1	C1	C1	C1	
Weather	More	Above limitations	Temperature beneath the 0 °C	Mud might freeze inside the sub.	N/A	A	1	1	1	1	A1	A1	A1	A1	

HAZOP HoD Double Filler Pump – New Stand Filling Phase

System	HoD	**NODE**	NSF-1
Subsystem	Double Filler Pump		
Operational Phase	**NEW STAND FILLING**		
Mission	Allow the stand filling before removing the clamp off the system		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	Less	Low	Inadequate suction	Low flow to the manifold. The system won't function properly as the new standpipe will not be filled. Non-Productive-Time while repairing the pump. Cavitation of the pump.	Installation procedures	A	1	1	1	1	A1	A1	A1	A1	Maintain the short suction line, maximum 3m
			Low flow			B	1	1	1	1	B1	B1	B1	B1	Check suction line
			Gaskets worn out		Maintenance of the pump after having accomplished an amount of working hours	C	2	1	2	1	C2	C1	C2	C1	Replace gaskets when any worn signs appear.
			Valves struck (due to dirt)			C	2	1	2	1	C2	C1	C2	C1	Disassemble, check and clean the valves
			Pump malfunction		Pumps can work together or separately, nevertheless the stand filling will take more time if using just one pump	B	2	1	2	1	B2	B1	B2	B1	
			Relief valve open or leakage		Maintenance every 1000 working hours	A	2	1	2	1	A2	A1	A2	A1	
			Air sucked into the system		N/A	B	1	1	1	1	B1	B1	B1	B1	Check that suction line is not empty
			Motor of the pump is damaged		There are two pumps. And the system can work with one only, but with more time.	A	1	1	1	1	A1	A1	A1	A1	Maintenance of the pump after having accomplished an amount of working hours
			Check valves leaking or damaged			A	1	1	1	1	A1	A1	A1	A1	
			No electricity on the motor		N/A	C	1	1	1	1	C1	C1	C1	C1	Consider installing a backup battery to the electrical motors, or making that one motor can sustain the two pumps

System	HoD	**NODE**	NSF-1
Subsystem	Double Filler Pump		
Operational Phase	NEW STAND FILLING		
Mission	Allow the stand filling before removing the clamp off the system		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			Serious wear of the suction or delivery valves		Maintenance of the pump after having accomplished an amount of working hours	A	2	1	2	1	A2	A1	A2	A1	Replace the valves
	More	High	Blockage in the pipeline after the pump	Rupture of the connection pipes	There's a relief valve that opens before the pump reaches its maximum pressure. The relief valve opens at 600 psi.	B	4	3	4	3	B4	B3	B4	B3	The pipelines after the pump should be ensured that can hold a yield point higher than the maximum delivery pressure of the pump.
Flow	Less	Low	Filter is dirty.	More time to fill the stand	Maintenance of the pump after having accomplished an amount of working hours	C	1	1	1	1	C1	C1	C1	C1	
			Valves are closed	Cavitation of the pump	XHoD Control System, shows which valves are open and which ones are closed	B	1	1	1	1	B1	B1	B1	B1	Add a visual signal in the pump to know if the valves are open or closed
			One of the pumps is lost	More time to fill the stand	Pumps can work together or separately, neverthelesss the stand filling will take more time if using just one pump	B	1	1	1	1	B1	B1	B1	B1	
			Wrong sequence performed	Cavitation of the pump	XHoD Control System ensures the correct sequence of the HoD	B	2	1	1	2	B2	B1	B1	B2	

System	HoD	**NODE**	NSF-1
Subsystem	Double Filler Pump		
Operational Phase	**NEW STAND FILLING**		
Mission	Allow the stand filling before removing the clamp off the system		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Temperature	Less	Low	Mud temperature is low	If temperature is lower than 0°C, mudrheological properties might change causing ump failure	Coating suction and delivery hoses (normally with rock wool or glass wool), to avoid the mud freeze inside the hoses (of course if using WBM - no problem while using OBM).	A	1	1	1	0	A1	A1	A1	A0	With temperatures below 0° Celsius (in all cases WBM or OBM), it is recommended run the pump at least every half hour for about 3/4 minutes.
	More	High	Excessive belt tension	Noise Cavitation of the pump Failure of the pump	Maintenance on the pump according to schedule	A	2	1	2	1	A2	A1	A2	A1	Reduce and calibrate the belt tension
			Irregular pulley alignment		Maintenance on the pump according to schedule	B	1	1	1	1	B1	B1	B1	B1	Recalibrate Proper alignment
			Pump operating at maximum pressure limit		X-HoD Control System can limits the pump	B	2	1	2	0	B2	B1	B2	B0	Reduce the limits of functioning of the pump
Power	Less	Partly lost	Short circuit on the rig.	Motors cannot work properly after. Delayed operation.	N/A	B	2	1	1	0	B2	B1	B1	B0	To have a backup power generator for the electrical motors of the Double Filler Pump
			One of the motors does not work	Delayed operation. More time to fill up a stand pipe	N/A	B	1	1	1	0	B1	B1	B1	B0	Work with the other pump. Migth be beneficial to be able to use one motor for both pumps
	No	Complete loss	Rig blackout	Standpipe won't be filled. Delayed operation	N/A	B	1	1	1	0	B1	B1	B1	B0	To have a backup power generator for the electrical motors of the Double Filler Pump

HAZOP HoD Manifold Low Pressure Line – New Stand Filling Phase

System	HoD	**NODE**	NSF-2A
Subsystem	Manifold (low pressure line)		
Operational Phase	NEW STAND FILLING		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	No	No	Inlet pipeline is blocked.	No mud will arrive to the standpipe manifold	Routine maintenance every 24 working hours	A	1	0	1	1	A1	A0	A1	A1	
			Pipeline after the CV2 is blocked			A	1	0	1	1	A1	A0	A1	A1	
			CV2 is damaged, dirty or blocked			A	1	0	1	1	A1	A0	A1	A1	
			Double Filler pump is damaged		The standpipe manifold can be used without the double filler pump.										Check the HAZOP table for double filler pump
	Less	Low	Inlet pipeline is damaged	Loss of pressure on the PG1 /PT1 and mud flow delayed to the standpipe manifold	Routine maintenance after 24 working hours	A	0	0	1	1	A0	A0	A1	A1	
			Pipeline after the CV2 is partially blocked			A	1	0	1	1	A1	A0	A1	A1	
			CV2 is damaged, dirty or blocked			A	1	0	1	1	A1	A0	A1	A1	
			PV1 or PV2 are open		X-HoD system can control the valves. If operator notices the low pressure, it can be detected that they are open	A	1	0	1	1	A1	A0	A1	A1	
			PV3 is open			A	1	0	1	1	A1	A0	A1	A1	
			PV9 is open	Mud will go to the clamp side outlet. PT1 and PG1 will show a lower pressure		B	1	0	1	1	B1	B0	B1	B1	
			Double Filler pump is damaged	Check the HAZOP table for the Double Filler pump	The mud standpipe manifold can be used without the double filler pump.										Check the HAZOP table for double filler pump

System	HoD	**NODE**	NSF-2A
Subsystem	Manifold (low pressure line)		
Operational Phase	**NEW STAND FILLING**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
	More	High	Blockage on the pipeline after the check valve	Rupture of pipe connections	The pipe connections yielding pressure rating is higher than pump max delivery pressure. Pressure gauges are monitored by X-HoD Control System	B	5	3	5	5	B5	B3	B5	B5	Release pressure valve needed after CV2
Flow	No	No	No flow coming from the HoD double Filler Pump	No mud will arrive to the mud standpipe manifold	Use the HP Mud Pump Room Manifold to fill the mud standpipe manifold	A	1	0	1	2	A1	A0	A1	A2	
			Outlet line of manifold is blocked	Will cause overpressure on the line. Which might cause rupture of the pipe connections	Increase in pressure will be detected by PG1 / PT1 and so the X-HoD control system.	A	1	0	1	2	A1	A0	A1	A2	
	Less	Low	CV2 is damaged or is partially blocked	The required quantity of mud will not arrive to the mud standpipe manifold	Increase in pressure will be detected by PG1 / PT1 and so the X-HoD control system.	B	1	0	1	1	B1	B0	B1	B1	
			Pipeline is obstructed	Pressure build up inside the manifold, rupture of pipeline connections if not detected on time		B	4	3	4	3	B4	B3	B4	B3	
			PV3 is open	Loss of pressure due to the loss of mud to the drain.	X-HoD system can control the valves. If operator notices the low pressure, it can be detected that they are open	B	1	0	1	1	B1	B0	B1	B1	

System	HoD	NODE	NSF-2A
Subsystem	Manifold (low pressure line)		
Operational Phase	**NEW STAND FILLING**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			PV2 or PV3 are open	Loss of pressure in PG1 / PT1, increase of pressure on PT2 /PG2. Less mud will arrive to the standpipe manifold		B	1	0	1	1	B1	B0	B1	B1	
			Mud flow coming from the HoD Double Filler pump is low.	Check the HAZOP table for the Double Filler pump	N/A										Check the HAZOP table for double filler pump
	Reverse	Reverse	Blockage on the pipeline or hose that connects with the mud standpipe manifold	Rupture of pipe connections if the amount of flow is too high	Variations in the PG1/PT1 will appear. CV2 will prevent the flow to go backwards	A	5	3	5	5	A5	A3	A5	A5	
	More	High	PV9 is open and the mud coming from the HP Mud Pump room manifold its entering into the Mud standpipe circuit	Less mud will enter to the clamp side. Increase in the flowrate that will enter to the mud standpipe manifold.	X-HoD system can control the valves. If operator notices variations on pressure. Close manually	B	3	0	3	2	B3	B0	B3	B2	

System	HoD	**NODE**	NSF-2A
Subsystem	Manifold (low pressure line)		
Operational Phase	**NEW STAND FILLING**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			HoD Double Filler Pump is not calibrated and it is delivering more mud than necessary	Check the HAZOP table for the Double Filler pump	N/A										Check the HAZOP table for double filler pump
Power	Less	Partly lost	Short circuit on the rig. Failure of the HPU	X-HoD Control System might not work properly.	The cable that connects the control panel with the manifold is located on the rig floor, but it is covered in order to avoid being damaged.	A	1	0	2	1	A1	A0	A2	A1	Have a backup battery for the X-HoD Control System, Standpipe Manifold can be filled directly with the HP Mud pump room manifold
	No	Complete loss	Blackout on the rig	X-HoD Control System might not work properly.		B	2	1	3	1	B2	B1	B3	B1	

HAZOP HoD Manifold High Pressure Line – New Stand Filling Phase

System	HoD	**NODE**	NSF-2B
Subsystem	Manifold (High pressure line)		
Operational Phase	**NEW STAND FILLING**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	No	No	Inlet pipeline coming from the HP Mud Pump Room Manifold is blocked	Increase in pressure inside the inlet line, which might result in rupture of the pipeline connections.	No pressure measurement will be read on PG3	A	3	3	2	1	A3	A3	A2	A1	
			HP Mud Pump Room Manifold is not functioning correctly	No mud will arrive to the HoD Clamp Lack of mud in the well which might induce a kick	PG3 will show up an increase in pressure while PT2 and PG2 will remain invariant	A	0	0	0	0	A0	A0	A0	A0	
			Filter is blocked		PG3 will show up an increase in pressure while PT2 and PG2 will remain invariant	B	1	1	1	1	B1	B1	B1	B1	
			PV8 is closed		X-HoD Control System shows the valves that are closed and open. It can control the opening or closure. Valves can be activated manually	B	1	1	1	1	B1	B1	B1	B1	
			PV4 and PV5 are closed			B	1	1	1	1	B1	B1	B1	B1	
			Pipeline after the connection with RV7 is obstructed.		Pressure gauges PT2 PG2 will show an increase in pressure while at the outlet of the manifold will not be any.	B	2	3	1	1	B2	B3	B1	B1	
			HPU not functioning		X-HoD control system shows whether the HPU is working or not	A	1	1	1	2	A1	A1	A1	A2	
			X-HoD Control System malfunction		May have to stop circulation and secure the well using primary well control to reboot the system.	B	1	1	2	3	B1	B1	B2	B3	Provide a backup system, and a battery in case of loss of power.

System	HoD	NODE	NSF-2B
Subsystem	Manifold (High pressure line)		
Operational Phase	NEW STAND FILLING		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	Less	Low	Inlet pipeline is damaged	Rupture of the pipeline connections at the inlet	Increase of pressure in PG3	B	3	4	4	3	B3	B4	B4	B3	
			Filter is dirty	Increase in pressure inside the inlet line, which might result in rupture of the pipeline connections.		B	1	1	1	1	B1	B1	B1	B1	
			PV8 is not fully open	Less amount of mud will go out from the manifold to the clamp.		B	1	1	1	1	B1	B1	B1	B1	
			PV9 is open	Deviation of the mud to the standpipe manifold, which will cause an increase in the pressure of the PT1 PG1	Increase in pressure will be detected by PG1 / PT1 and so the X-HoD control system. X-HoD system can control the valves. If operator notices the variation in pressure on the system. Specially on PG1/PT1	B	1	1	1	1	B1	B1	B1	B1	
			PV1 or PV2 are open			B	1	1	1	1	B1	B1	B1	B1	
			PV6 is open	Loss of mud to the drain	Loss of pressure that can be noticed by PT2 or PG2	B	1	1	1	1	B1	B1	B1	B1	
			RV7 is open or leaking	Less amount of mud will go out from the manifold to the clamp. Pressure build up inside the manifold		B	1	4	1	1	B1	B4	B1	B1	
			Pipeline inside the manifold is partially blocked		It will show up as an increase in the values of PT2 and PG2 but the pressure at the outlet (connection with the clamp is low). All the valves are working normally	A	3	1	2	1	A3	A1	A2	A1	

System	HoD	**NODE**	NSF-2B
Subsystem	Manifold (High pressure line)		
Operational Phase	**NEW STAND FILLING**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	More	High	RV7 does not open on command of PT2/PG2	Rupture of pipe connections. Pressure might damage the hose connection with the clamp or the clamp itself.	Pressure gauges are monitored by X-HoD Control System	A	5	5	5	5	A5	A5	A5	A5	
Flow	No	No	Filter is blocked	No mud will arrive to the HoD Clamp Lack of mud in the well which might induce a kick	Routine maintenance	B	1	1	1	0	B1	B1	B1	B0	
			PV8 is closed and PV9 is open		No pressure read on PT2/PG2, may be an indicator that something is blocking the path of flow	A	1	1	1	0	A1	A1	A1	A0	
			PV 4 and PV5 are closed		No Pressure value will be read on PT2/PG2, and an increase on the pressure at PG3 will be shown.	A	1	1	1	0	A1	A1	A1	A0	
			RV7 is open		Decrease of pressure at PT2/PG2 and no flow coming out from the clamp.	A	1	1	1	0	A1	A1	A1	A0	
			Outlet line of manifold is blocked	Will cause overpressure on the line. Which might cause rupture of the pipe connections	Increase in pressure will be detected by PG2 / PT2 and so the X-HoD control system.	A	1	1	1	0	A1	A1	A1	A0	
Flow	Less	Low	Filter is dirty (partially obstructed)	Decrease in the value of pressure on PT2/PG2, increase in the flow that enters	Increase in pressure in the PG3. Routine maintenance.	B	1	1	1	0	B1	B1	B1	B0	

System	HoD	**NODE**	NSF-2B
Subsystem	Manifold (High pressure line)		
Operational Phase	**NEW STAND FILLING**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			PV8 is not fully open	the Mud standpipe manifold. Decrease in the flow that gets out from the HoD manifold to the clamp, sub and well. Lack of mud inside the well might allow the entrance of formation fluids.	Decrease in pressure will be detected by PG2 / PT2, increase in pressure at PT3, X-HoD control system will detect this variations in pressure. Routine maintenance	A	1	1	1	0	A1	A1	A1	A0	
			PV9 is open	Increase in the value of pressure on PT1/PG1, increase in the flow that enters the Mud standpipe manifold. Decrease of the value of pressure read in PT2/PG2, also decrease in the flow that gets out from the HoD manifold to the clamp, sub and well. Lack of mud inside the well might allow the entrance of formation fluids.		A	1	1	1	0	A1	A1	A1	A0	
			PV1 or PV2 are open			A	1	1	1	0	A1	A1	A1	A0	
			PV1 and PV3 are open			A	1	1	1	0	A1	A1	A1	A0	
			PV2 and PV3 are open			A	1	1	1	0	A1	A1	A1	A0	
			PV4 is closed	Decrease in the value of pressure on PT2/PG2, increase in the flow that enters the Mud standpipe manifold. Decrease in the flow that gets out from the HoD manifold to the		A	1	1	1	0	A1	A1	A1	A0	
			PV5 is closed			A	1	1	1	0	A1	A1	A1	A0	
			PV6 is open			A	1	1	1	0	A1	A1	A1	A0	

System	HoD	NODE	NSF-2B
Subsystem	Manifold (High pressure line)		
Operational Phase	NEW STAND FILLING		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			RV7 is open	clamp, sub and well. Lack of mud inside the well might allow the entrance of formation fluids.		A	1	1	1	0	A1	A1	A1	A0	
Flow	Reverse	Reverse	Pressure in the well is bigger than the pressure in the manifold	Kick entering inside the drillpipe	The Sub will act as one way valve not allowing the mud the flow to be reversed.	A	5	5	5	5	A5	A5	A5	A5	
Flow	More	High	Problem with the HP mud pump room manifold	Increase of the flow inside the clamp, sub and subsequently well. Increase the ECD which might cause fracture of formation and eventual loss of mud to the formation.	Increase in the value of PG3, as well as the value of PT2 / PG2.	A	3	4	5	5	A3	A4	A5	A5	
Power	Less	Partly lost	Short circuit on the rig. Failure of the HPU	X-HoD Control System might not work properly.	The cable that connects the control panel with the manifold is located on the rig floor, but it is covered in order to avoid being damaged.	A	1	0	2	1	A1	A0	A2	A1	Have a backup battery for the X-HoD Control System, Standpipe Manifold can be filled directly with the HP Mud pump room manifold
	No	Complete loss	Blackout on the rig	X-HoD Control System might not work properly.		B	2	1	3	1	B2	B1	B3	B1	

HAZOP HoD Clamp – New Stand Filling Phase

System	HoD	**NODE**	NSF-3
Subsystem	CLAMP		
Operational Phase	**NEW STAND FILLING**		
Mission	Deviate the mud flow where is required		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Pressure	Less	Low	Hose is partially obstructed	Flow might not reach the outlet of the clamp	Preventive maintenance and onsite programmes to ensure the right functioning of the tool.	A	1	0	1	1	A1	A0	A1	A1	
			Clamping actuator, mud conduct is partially obstructed	Not enough to have flow inside the sub and drillpipe. All the advantages of continuous circulation drilling will be vanished.		B	1	0	1	1	B1	B0	B1	B1	
Pressure	No	No	Clamp actuator malfunction. Mud conduct can be obstructed.	Lack of mud inside the drillpipe. Might allow the entrance of a kick.	Pressure build up in manifold PT2/PG2	B	3	1	1	1	B3	B1	B1	B1	
			Internal actuator is blocked			C	1	1	1	1	C1	C1	C1	C1	
			Hydraulic component not working			B	1	1	1	1	B1	B1	B1	B1	
			Electric component damaged			B	3	1	1	1	B3	B1	B1	B1	
			No flow coming from the manifold	Clear Troubleshooting scheme for the Manifold HP line.											
Pressure	More	High	Inlet hose of the clamp is blocked	Pressure build-up inside the hose. Rupture of hose and connections	The hose and pipelines utilised are designed to have a bursting pressure above the working pressure	B	1	0	1	1	B1	B0	B1	B1	

System HoD **NODE** NSF-3

Subsystem CLAMP

Operational Phase NEW STAND FILLING

Mission Deviate the mud flow where is required

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			The clamping actuator could not open the radial valve of the sub	Mud spillage	X-HoD system will not allow flow to pass if the radial valve of the sub is not correctly open	B	2	2	2	2	B2	B2	B2	B2	
			Human error	More flow into the sub and well. Increase the ECD, it is possible to break formation if pressure too high	Training course	B	2	1	2	1	B2	B1	B2	B1	
Flow	No	No	Clamping actuators failure	No mud is entering to the well. Non-productive time.	Venturi system will detect the lack of mud at the outlet. And will send a signal to the X-HoD control panel. Routine Maintenance	B	1	0	1	1	B1	B0	B1	B1	
			Electrical actuator failure			B	1	0	2	1	B1	B0	B2	B1	
			Internal actuator is blocked			B	2	1	3	1	B2	B1	B3	B1	
			Hose is obstructed			C	2	1	3	1	C2	C1	C3	C1	
			No flow coming from the manifold	Check the HAZOP table for the Manifold HP line											Check the HAZOP table for the Manifold HP line
	Less	Low	Clamping actuators failure	Less mud than required is entering into the well. Kick	Venturi system will detect the lack of mud at the outlet. And will send a signal to the X-HoD control panel. Routine Maintenance	B	1	0	1	1	B1	B0	B1	B1	
			Electrical actuator failure			B	1	0	2	1	B1	B0	B2	B1	
			Internal actuator is blocked			B	2	1	3	1	B2	B1	B3	B1	
	More	High	Human error	Mud spill. Increase ECD as mud is going to the	Venturi system will detect the increase of mud at the outlet.	C	2	3	3	2	C2	C3	C3	C2	

System HoD **NODE** NSF-3

Subsystem CLAMP

Operational Phase NEW STAND FILLING

Mission Deviate the mud flow where is required

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
			Calibration Error	well which might fracture formation	And will send a signal to the X-HoD control panel. Routine Maintenance	A	3	3	3	3	A3	A3	A3	A3	
			High flow coming from manifold	Check the HAZOP table for the Manifold HP line											Check the HAZOP table for the Manifold HP line
Personnel	No	Lack of competence	Lack of trainning	Damage of the system. People might get hurt. Environmental damage if clamp is not well connected and mud is spilled	Training course	B	3	3	3	3	B3	B3	B3	B3	
	Less	Too few	Lack of organisation and planning	Clamp might fall while trying to remove (heavy) People might get hurt.	Clear procedures and personnel should be defined ahead	B	3	3	4	3	B3	B3	B4	B3	
	More	Too many	Lack of organisation and planning	Clamp might fall while trying to remove (heavy) People might get hurt.	Clear procedures and personnel should be defined ahead	B	3	3	4	3	B3	B3	B4	B3	
Power	Less	Partly lost	Short circuit on the rig. Failure of the HPU	X-HoD Control System might not work properly.	The cable that connects the control panel with the manifold is located on the rig floor, but it is covered in order to avoid being damaged.	A	1	0	2	1	A1	A0	A2	A1	Have a backup battery for the X-HoD Control System, Standpipe Manifold can be filled directly with the HP Mud pump room manifold
	No	Complete loss	Blackout on the rig	X-HoD Control System might not work properly.		B	2	1	3	1	B2	B1	B3	B1	

HAZOP HoD Sub – New Stand Filling Phase

System	HoD	NODE	NSF-4
Subsystem	HoD Sub		
Operational Phase	**NEW STAND FILLING**		
Mission	To allow the connection of the top drive or the clamp according to the phase		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
Flow	No	No	Blockage of the sub due to structural deformation of the sub	Non productive time. Loss of Circulation		A	4	4	4	4	A4	A4	A4	A4	
			Radial valve is not open			A	2	4	2	2	A2	A4	A2	A2	
			No feed from the clamp			A	2	4	2	2	A2	A4	A2	A2	
	Less	Low	Partially obstructed sub or drillpipe.	Less amount of mud will enter into the well.		A	2	4	2	2	A2	A4	A2	A2	
			Axial valve is leaking in closed position	Mud spill in the rig floor.	Periodical maintenance and revision of the subs before and after every operation.	A	2	4	2	2	A2	A4	A2	A2	
			Axial valve opens		As the clamp is connected to the sub, the axial valve will remain closed due to the pressure difference inside the sub body.	A	2	4	2	2	A2	A4	A2	A2	
			Mud was not filtered	Non productive time.	Pressure can be increased in the clamp. Periodic maintenance according on working hours of the tool	B	1	2	1	1	B1	B2	B1	B1	

System	HoD	**NODE**	NSF-4
Subsystem	HoD Sub		
Operational Phase	**NEW STAND FILLING**		
Mission	To allow the connection of the top drive or the clamp according to the phase		

PROCESS PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	Freq. Index	DAMAGE				RISK				RECOMMENDATIONS
							People	Envir.	Econ,	Rep.	People	Envi	Econ.	Rep.	
	More	High	High flow coming from the clamp. Wrong input on the software	High influx in the well. Increase of ECD which might lead to fracturing the formation	Software prevents from the influx to increase without a specific command	B	1	3	1	1	B1	B3	B1	B1	
Pressure	More	High	Blockage of the sub or drillpipe	Non productive time.	Decrease the flow rate.	B	1	3	1	1	B1	B3	B1	B1	
	Less	Low	Not enough flow is arriving to the sub from the clamp	Non productive time.	Increase pressure on clamp side.	C	1	0	1	1	C1	C0	C1	C1	
Position	More	Movement exceeding tolerances	Sub is not well positioned on the drillpipe. Human error	Failure on the sub	Make sure that the sub is in the right position while performing the previous operation.	C	1	1	1	1	C1	C1	C1	C1	
Weather	More	Above limitations	Temperature beneath the 0 °C	Mud might freeze inside the sub.	N/A	A	1	1	1	1	A1	A1	A1	A1	

ANNEX V – *Heart Methodology*

HEART Methodology

The HEART technique was developed by Williams and it is based on human performance. (Williams, 1986)

In order to estimate the probability of failure for a specific task the steps to follow are:

1. Nominal human unreliability probability.- Classify the task to develop in terms of the generic task found in table XX
2. Multiplier.- Identify the relevant error producing conditions from table XX.
3. Proportion Effect.- Estimate the impact of each Error Producing Condition on task. The value is given depending the person performing the assessment and varies between 0 and 1.
4. Assessed impact value .- Calculate the impact following the formula:

   (Multiplier – 1) Assessed proportion of effect) +1 = Impact

5. Human Error Probability.- Calculate the final probability following the formula:

   *Nominal human reliability * Assessed Impact 1 * Assessed impact n… = Human Error Probability*

	Generic Task	Proposed nominal human unreliability	5th - 95th percentile boundaries	
A	Totally unfamiliar, performed at speed with not real idea of likely consequences	0,55	0,35	0,97
B	Shift or restore system to a new original state on a single attempt without supervision or procedures	0,26	0,14	0,42
C	complex task requiring high level of comprehension and skill	0,16	0,12	0,28
D	Fairly simple task performed rapidly or given scant attention	0,09	0,06	0,13
E	Routine, highly practised, rapid task involving relatively low level of skill	0,02	0,007	0,045
F	Restore or shift a system to original or new state following procedures with some checking	0,003	0,008	0,007
G	Completely familiar, well-designed, highly practiced routine task occurring several times per hour, performed to highest possible standards by highly motivated, highly trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids.	0,0004	0,00008	0,009
H	Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system stage	0,00002	0,000006	0,00009
M	Miscellaneous task for which no description can be found (Nominal 5th to 95th percentile data spreads were chosen on the basis of experience suggesting log-normality)	0,03	0,008	0,11

Table 36. Generic Task HEART methodology

	Error Producing Condition	Maximum predicted nominal amount by which unreliability might change going from good conditions to bad
1	Unfamiliarity with a situation which is potentially importan but which only occurs infrequently or which is novel	17
2	A shortage of time available for error detection and correction	11
3	A low signal-to-noise ratio	10
4	A means of suppresing or overriding information or features which is too easily accesible	9
5	No means of conveying spatial and functional information to operators in a form which they can readily assimilate	8
6	A mismatch between an operator's model of the world and that imagined by the designer	8
7	No obvious means of reversing an unintended action	8
8	A channel capacity overload, particularly one caused by simultaneous presentation of non redundant information	6
9	A need to unlearn a technique and apply one which requires the application of an opposing philosophy	6
10	The need to transfer specific knowledge from task to task without loss	5,5
11	Ambiguity in the required performance standards	5
12	A mismatch between perceived and real risk	4
13	Poor, ambiguos or ill-matched system feedback	4
14	No clear direct and timely confirmation of an intended action from the portion of the system over which control is to be excerted	3
15	Operator inexperienced	3
16	An impoverished quality of information conveyed by procedures and person-person interaction	3
17	Little or no independent checking or testing of output	3
18	A conflict between immediate and long term objectives	2,5
19	No diversity of information input for veracity checks	2,5
20	A mismatch between the educational achievement level of an individual and the requirements of the task	2
21	An incentive to use other more dangerous procedures	2
22	Little opportunity to exercise mind and body outside the immediate confines of the job	1,8
23	Unreliable instrumentation (enough that it is noticed)	1,6
24	A need for absolute judgements which are beyond the capabilities or experience of an operator	1,6
25	Unclear allocation of function and responsibility	1,4

	Error Producing Condition	Maximum predicted nominal amount by which unreliability might change going from good conditions to bad
26	No obvious way to keep track of progress during an activity	1,4
27	A danger that finite physical capabilities will be exceeded	1,4
28	Little or no intrinsic meaning in a task	1,3
29	High-level emotional stress	1,2
30	Evidence of ill-health amongst operatives, especially fever	1,2
31	Low workforce morale	1,2
32	Inconsistency of meaning of displays and procedures	1,15
33	A poor or hostile environment (below 75% or health or life-threatening severity)	1,1
34	Prolongued inactivity or highly repetitious cycling of low mental workload tasks	1,05
35	Disruption of normal work-sleep cycles	1,1
36	Task pacing caused by the intervention of others	1,06
37	Additional team members over and above those necessary to perform task normally and satisfactorily	1,03
38	Age of personnel performing perceptual tasks	1,02

Table 37. Error Producing Condition. Heart Methodology.

Human Error probabilities estimation for CCS-HoD

Task	Generic Task Unreliability	Error Producing Condition	Multiplier	Assessed Proportion of Effect	Assessed Impact Value	Human Error probability
Decision Error / Delayed intervention MANIFOLD utilisation	0,0004	Shortage of time available for error	11	0,5	6	**8,32E-03**
		Low signal to noise ratio	10	0,2	2,8	
		Operator inexperienced	3	0,05	1,1	
		Unreliable instrumentation	1,6	0,2	1,12	
		Disruption of normal work-sleep cycles	1,1	0,05	1,005	
Decision Error / Delayed intervention CONTROL PANNEL utilisation	0,00002	A shortage of time available for error detection and correction	11	0,25	3,5	**2,08E-04**
		Operator inexperienced	3	0,3	1,6	
		An impoverished quality of information conveyed by procedures and person-person interaction	3	0,2	1,4	
		Little or no independent checking or testing of output	3	0,15	1,3	
		No obvious way to keep track of progress during an activity	1,4	0,05	1,02	
Wrong action / Delayed	0,0004	A mismatch between perceived and real risk	4	0,5	2,5	**5,66E-03**

Task	Generic Task Unreliability	Error Producing Condition	Multiplier	Assessed Proportion of Effect	Assessed Impact Value	Human Error probability
intervention CLAMP utilisation		A shortage of time available for error detection and correction	11	0,2	3	
		No clear direct and timely confirmation of an intended action from the portion of the system over which control is to be excreted	3	0,05	1,1	
		Operator inexperienced	3	0,2	1,4	
		A conflict between immediate and long term objectives	2,5	0,15	1,225	
Wrong action / Delayed intervention DOUBLE FILLER PUMP utilisation	0,0004	Operator inexperienced	3	0,1	1,2	**2,98E-03**
		Little or no independent checking or testing of output	3	0,2	1,4	
		A conflict between immediate and long term objectives	2,5	0,05	1,075	
		A shortage of time available for error detection and correction	11	0,25	3,5	
		Unreliable instrumentation (enough that it is noticed)	1,6	0,3	1,18	
Wrong action / Delayed intervention HPU utilisation	0,0004	Operator inexperienced	3	0,1	1,2	**2,98E-03**
		Little or no independent checking or testing of output	3	0,2	1,4	
		A conflict between immediate and long term objectives	2,5	0,05	1,075	
		A shortage of time available for error detection and correction	11	0,25	3,5	
		Unreliable instrumentation (enough that it is noticed)	1,6	0,3	1,18	
Wrong action / Delayed intervention EPU utilisation	0,0004	Operator inexperienced	3	0,1	1,2	**2,98E-03**
		Little or no independent checking or testing of output	3	0,2	1,4	
		A conflict between immediate and long term objectives	2,5	0,05	1,075	
		A shortage of time available for error detection and correction	11	0,25	3,5	
		Unreliable instrumentation (enough that it is noticed)	1,6	0,3	1,18	

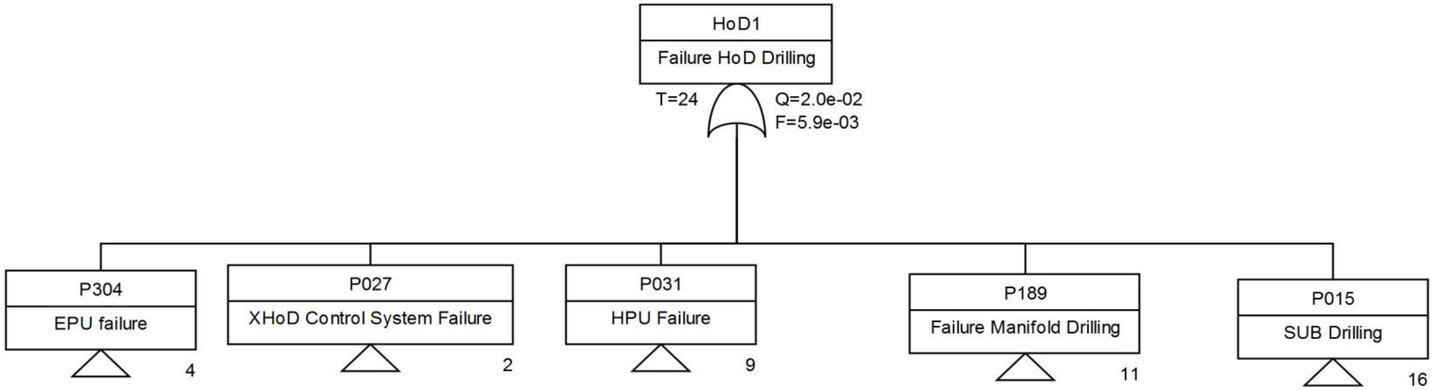
Table 38. Human Error Probabilities estimation utilised on this study.

ANNEX VI - *Fault Tree Analysis Schemes (considering human error)*

Fault Tree Analysis – ***HoD® - Drilling Phase***

Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: Failure HoD while Drilliing	Page 8/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06

Arbre Analyste - version 2.3.2 - 2014-19



Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: Manifold Drilling	Page 11/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06

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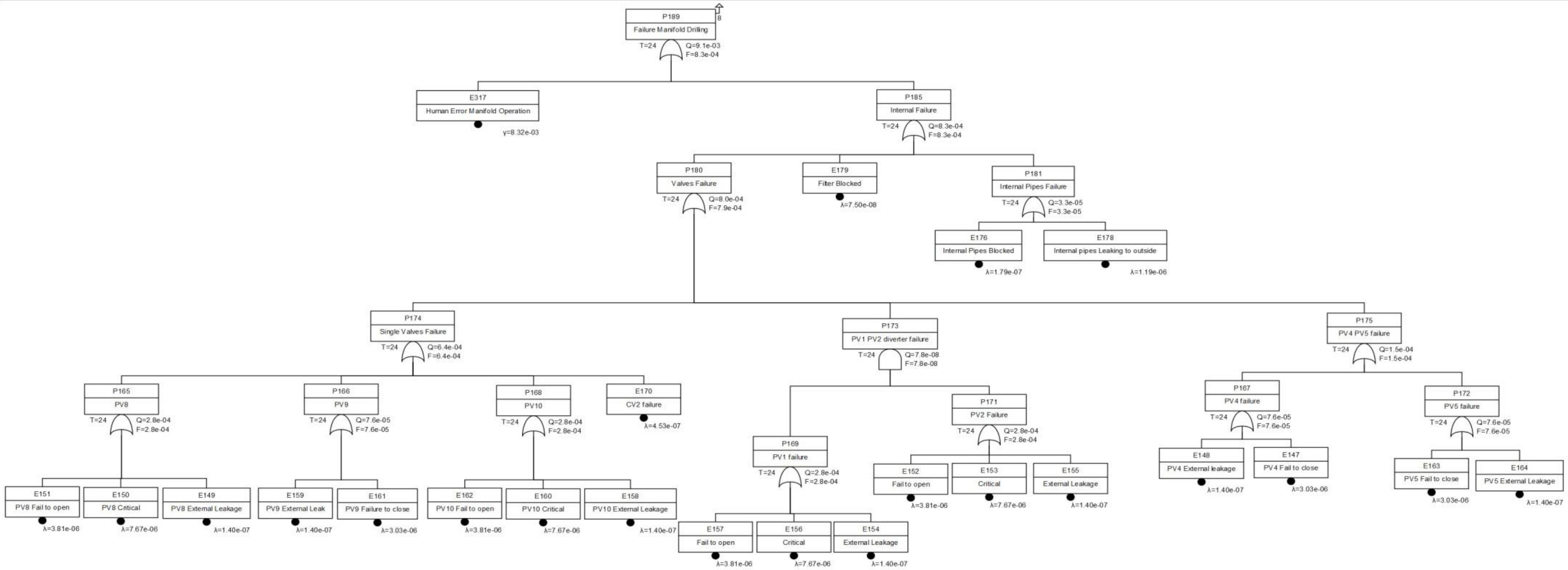

Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: SUB Drilling	Page 16/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06

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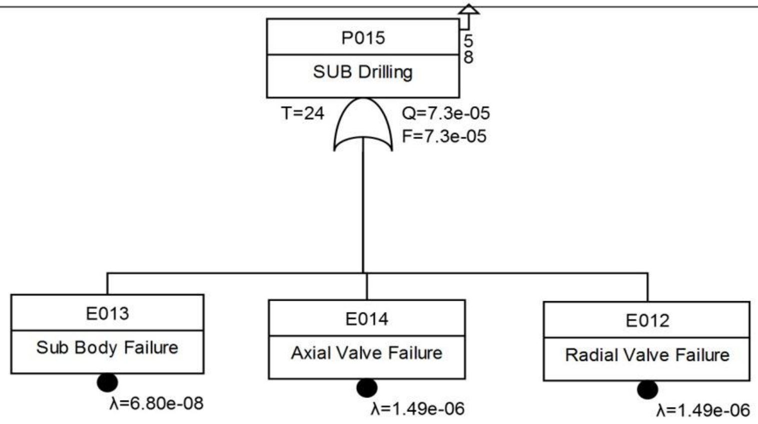
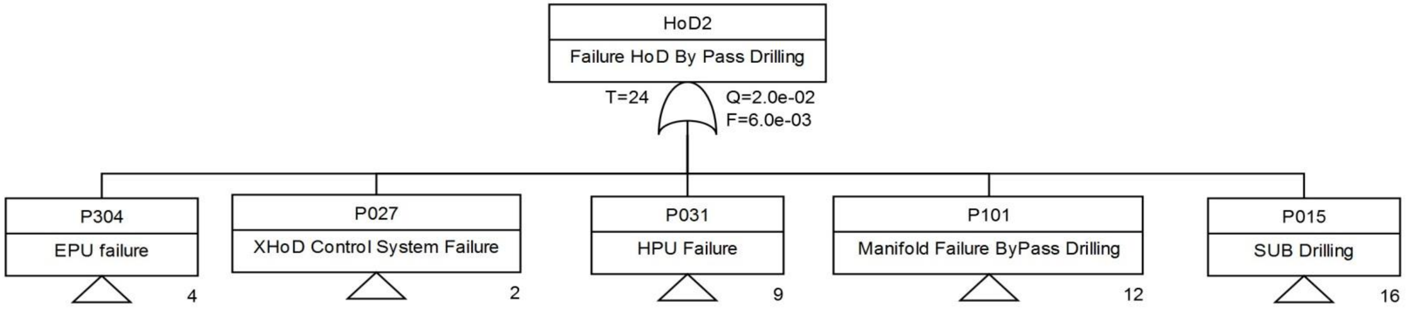


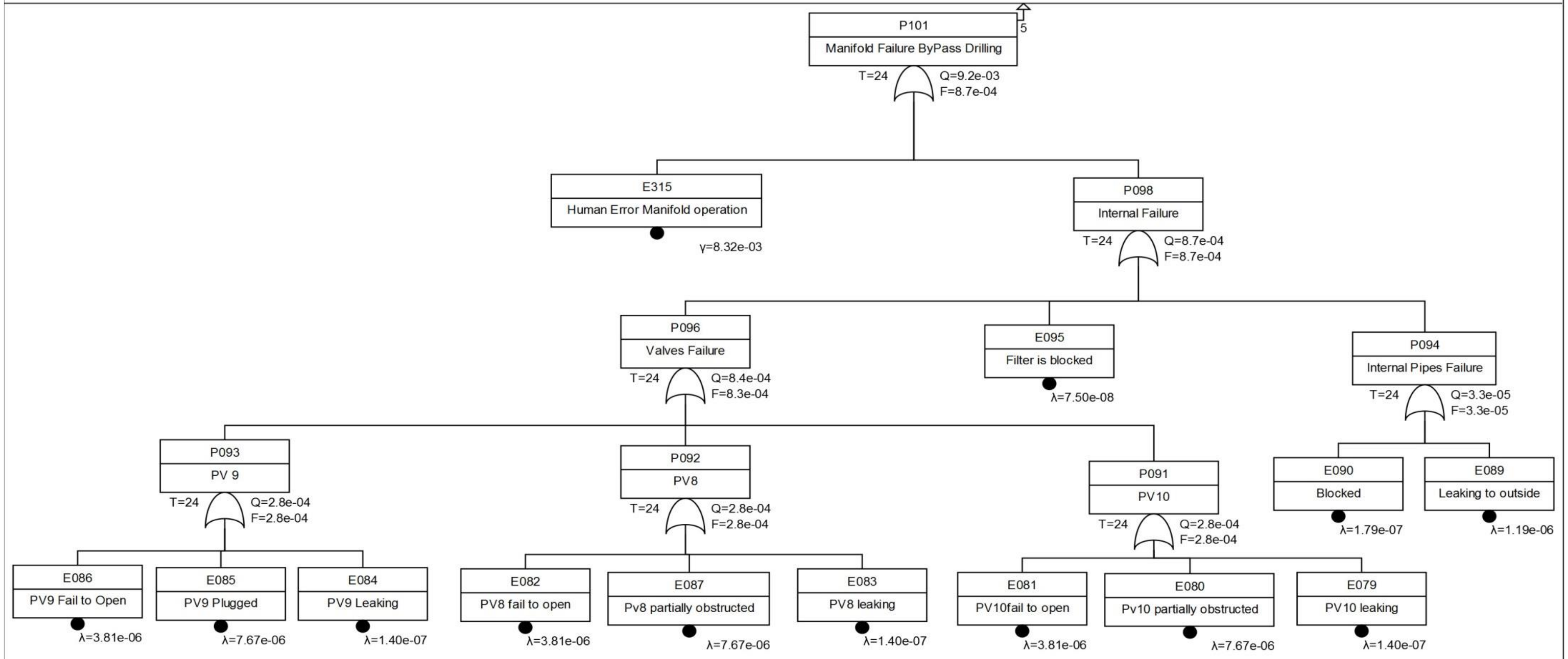
Fault Tree Analysis – ***HoD® - Bypass Drilling Phase***

Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: Failure HoD By Pass Drilling	Page 5/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06

Arbre Analyste - version 2.3.2 - 2014-19



Project: Failure HoD	Company:		Author: Magdalena Vera Chena
Name: Manifold bypass drilling Page 12/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06
Arbre Analyste - version 2.3.2 - 2014-19			



Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: SUB Drilling	Page 16/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06

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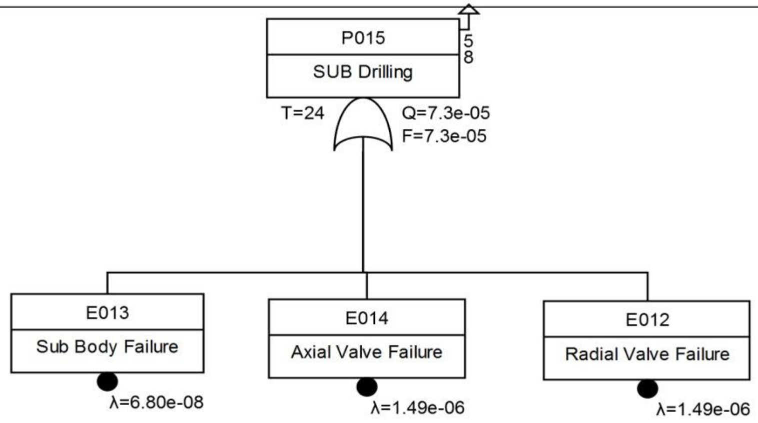
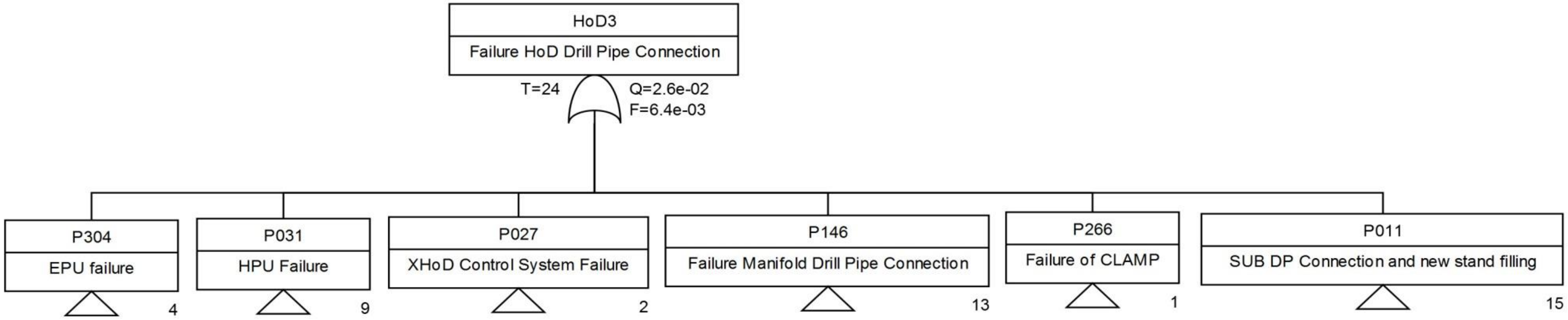
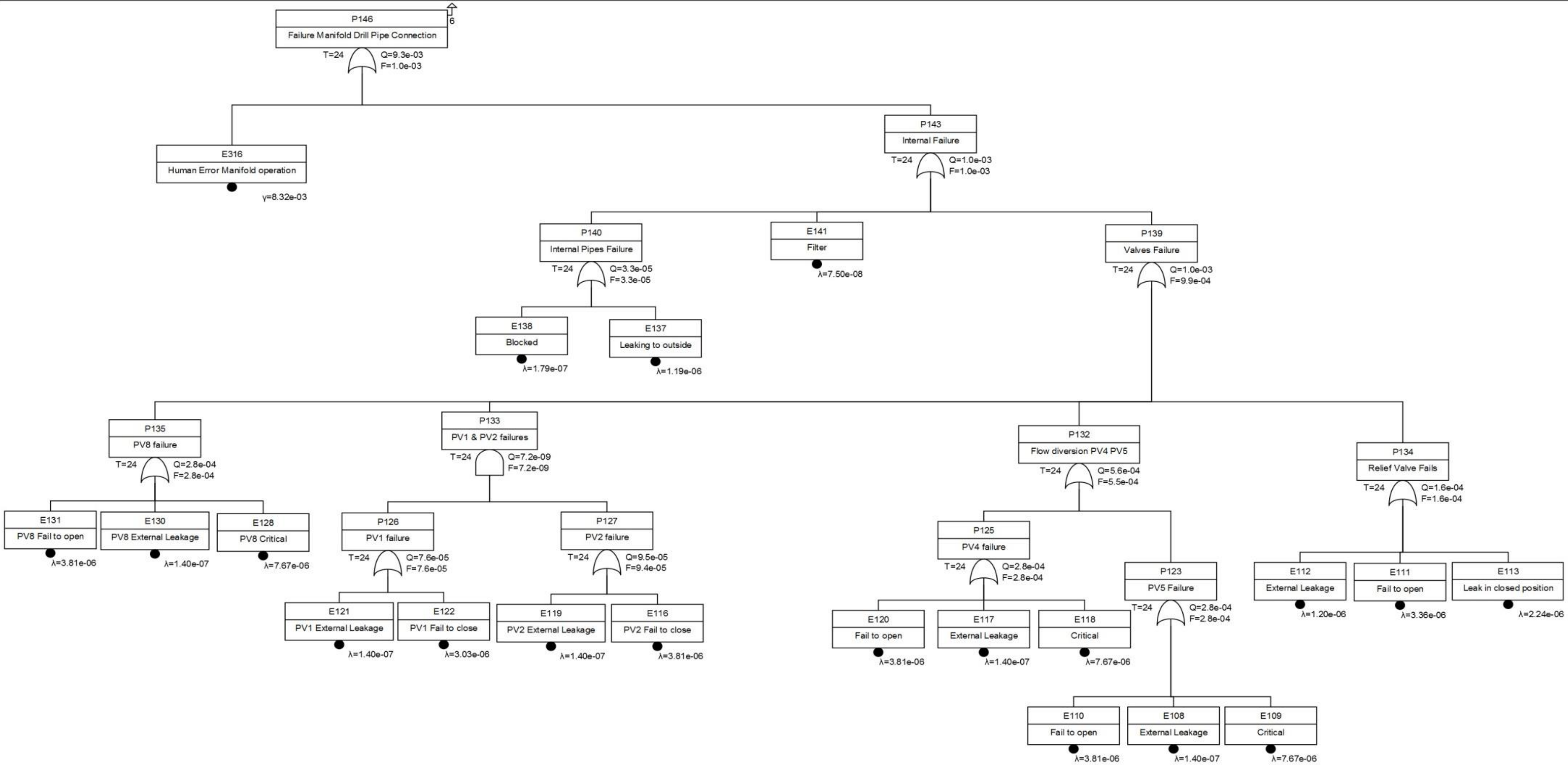


Fault Tree Analysis – ***HoD® - Drillpipe Connection Phase***

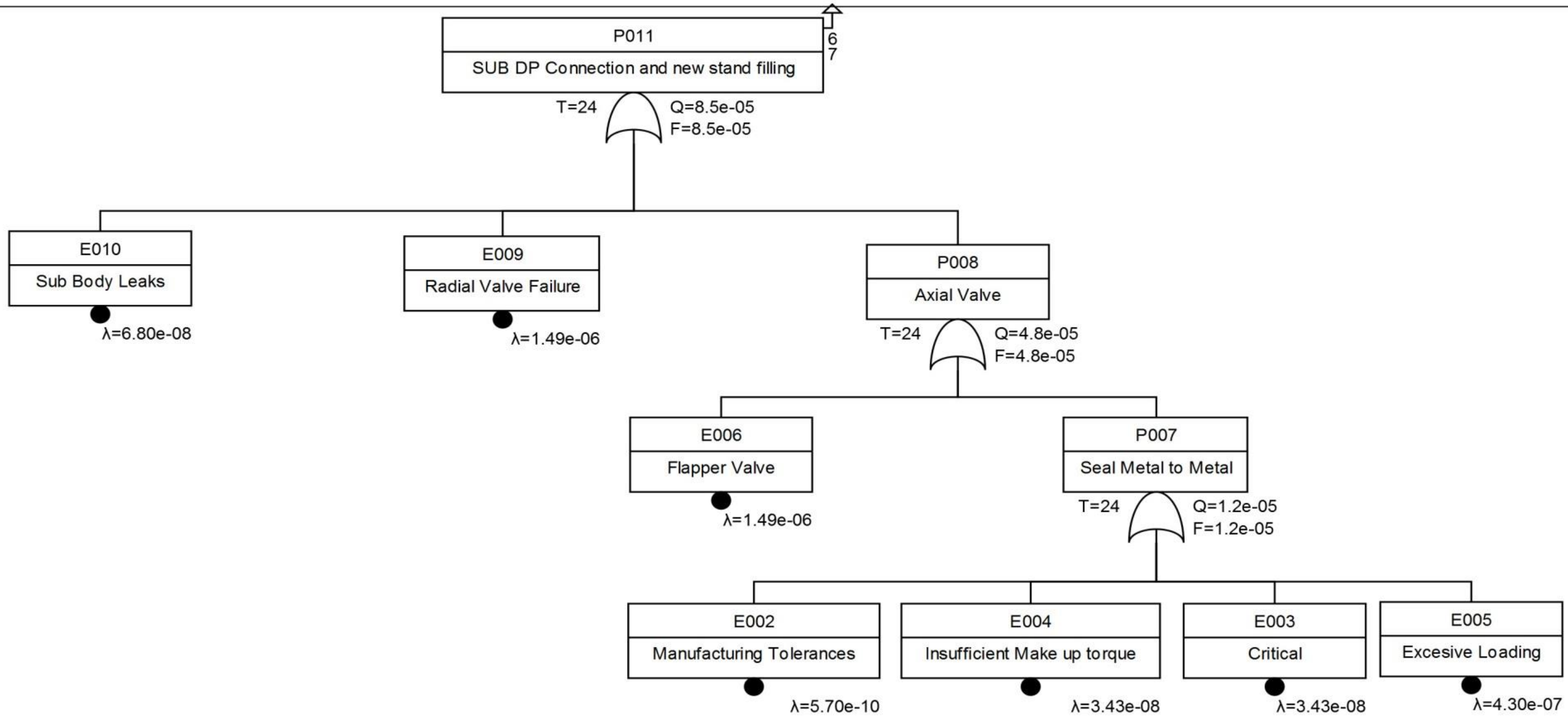


HoD3
Failure HoD Drill Pipe Connection
T=24
Q=2.6e-02
F=6.4e-03
P304
EPU failure
4
P031
HPU Failure
9
P027
XHoD Control System Failure
2
P146
Failure Manifold Drill Pipe Connection
13
P266
Failure of CLAMP
1
P011
SUB DP Connection and new stand filling
15

Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: Manifold drillpipe conection	Page 13/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06
Arbre Analyste - version 2.3.2 - 2014-19				

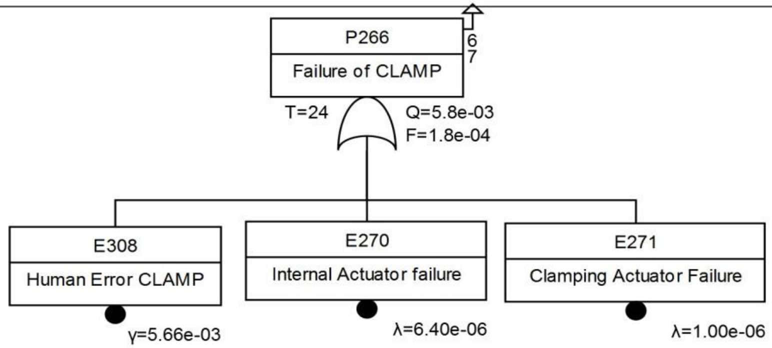


Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: SUB Connections	Page 15/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06
Arbre Analyste - version 2.3.2 - 2014-19				



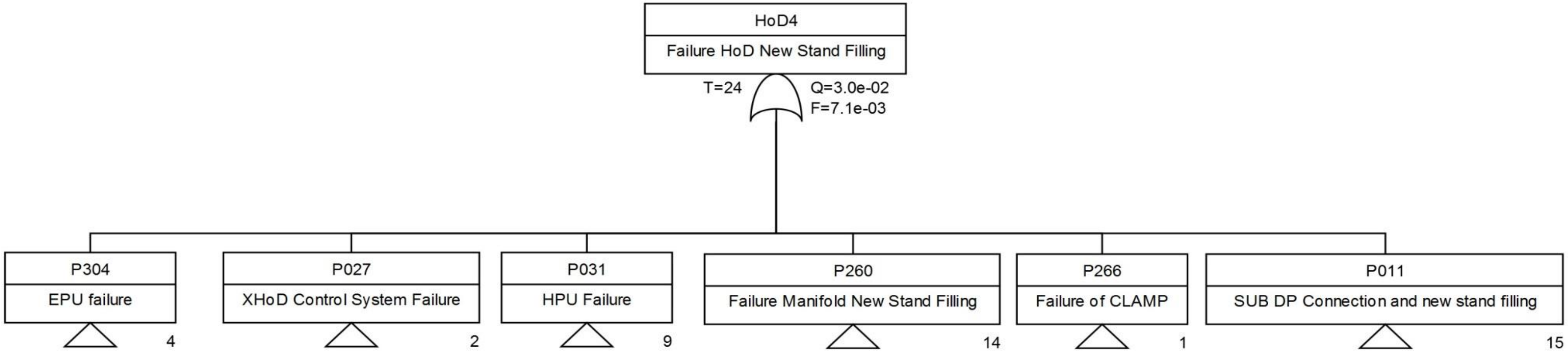
Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: CLAMP	Page 1/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06

Arbre Analyste - version 2.3.2 - 2014-19



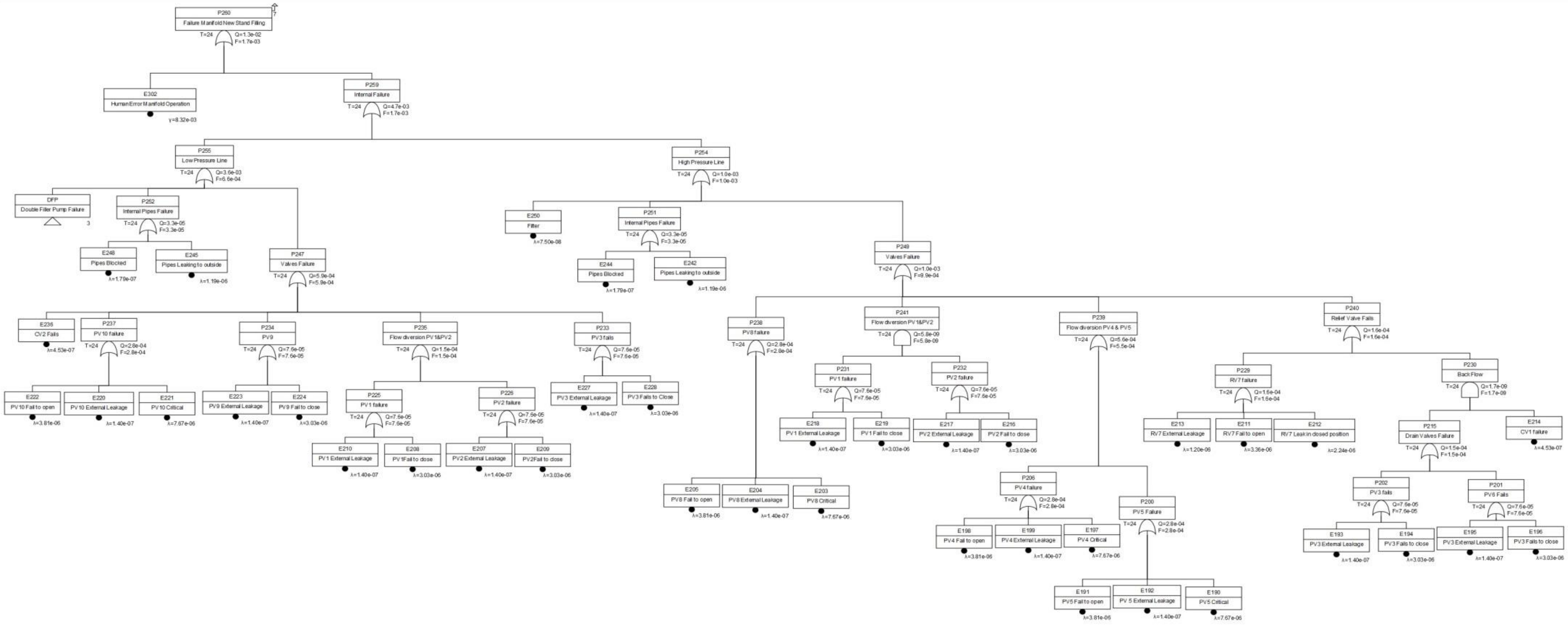
Fault Tree Analysis – *HoD® - New Stand Filling Phase*

Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: Failure HoD New Stand Filling	Page 7/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06
Arbre Analyste - version 2.3.2 - 2014-19				

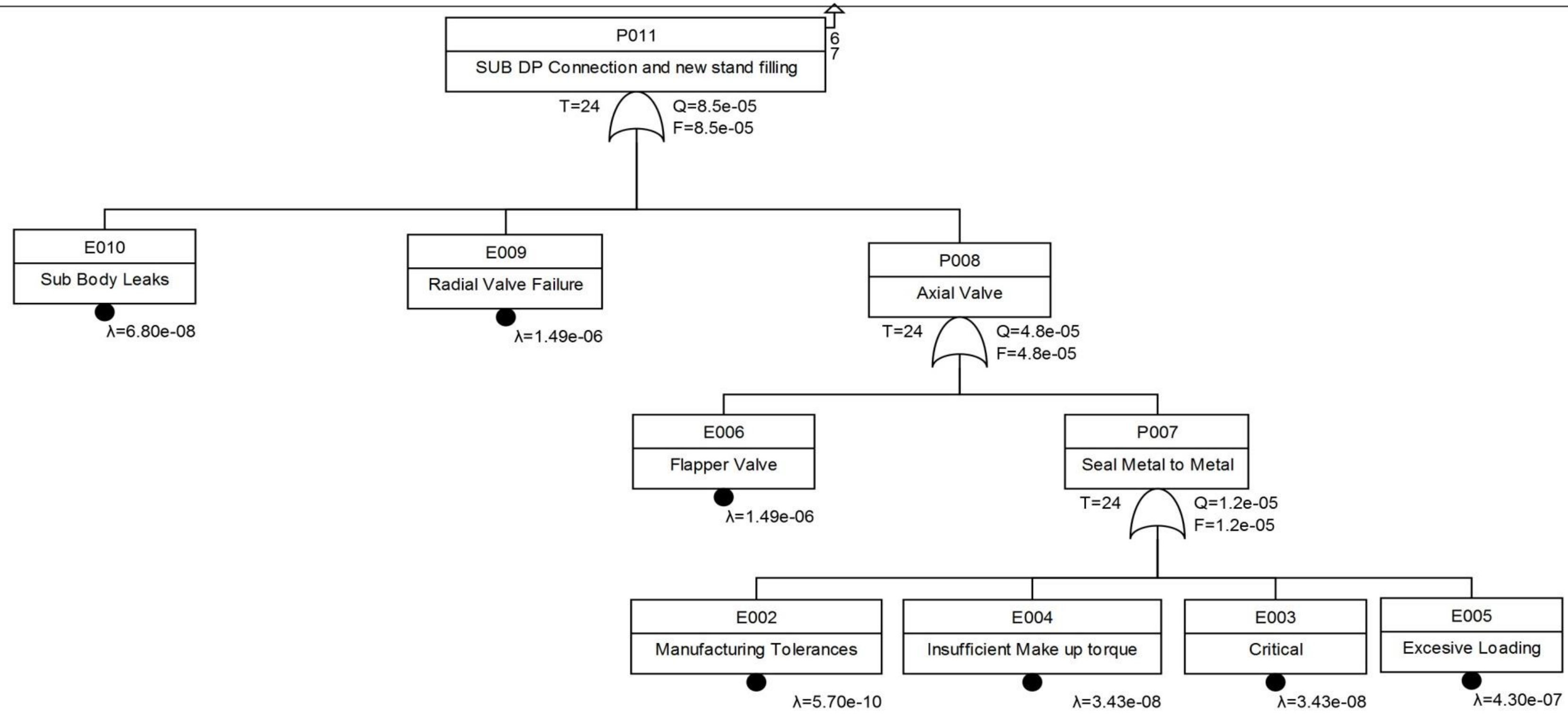


Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: Manifold new stand filling	Page 14/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06

Arbre Analyste - version 2.3.2 - 2014-19

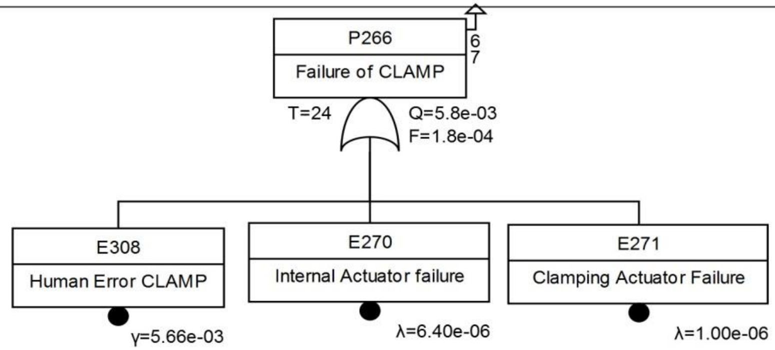


Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: SUB Connections	Page 15/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06
Arbre Analyste - version 2.3.2 - 2014-19				



Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: CLAMP	Page 1/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06

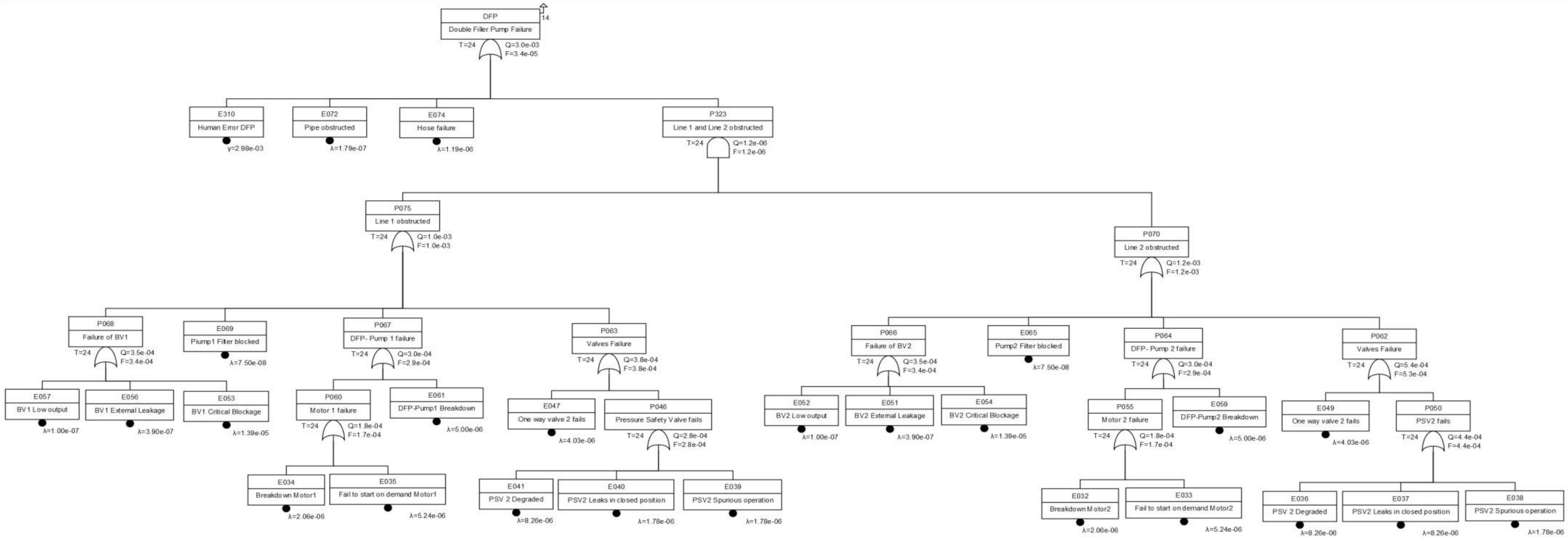
Arbre Analyste - version 2.3.2 - 2014-19



Project: Failure HoD | Company: | Author: Magdalena Vera Chena

Name: DFP | Page 3/16 | Version: Finale | Created on: 19/10/30 at 16:29 | Last changed: 19/11/12 at 13:06

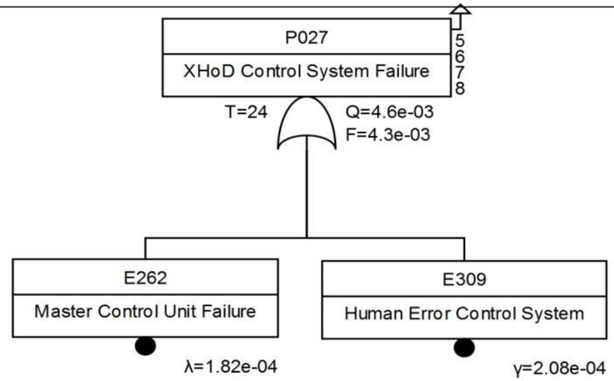
Arbre Analyste - version 2.3.2 - 2014-19



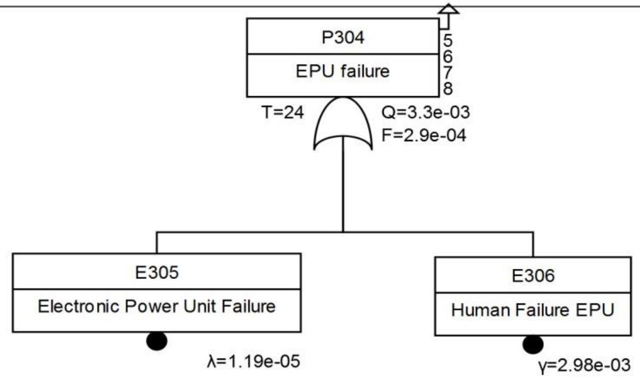
Fault Tree Analysis – ***HoD® - General Equipment related to all the phases***

Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: Control System	Page 2/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06

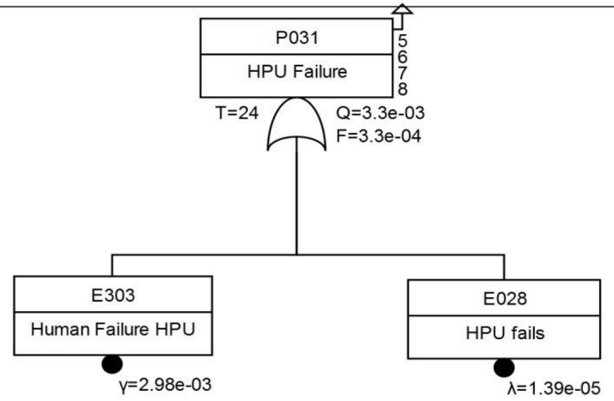
Arbre Analyste - version 2.3.2 - 2014-19



Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: EPU	Page 4/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06
Arbre Analyste - version 2.3.2 - 2014-19				



Project: Failure HoD		Company:		Author: Magdalena Vera Chena
Name: HPU	Page 9/16	Version: Finale	Created on: 19/10/30 at 16:29	Last changed: 19/11/12 at 13:06
Arbre Analyste - version 2.3.2 - 2014-19				



ANNEX VII *–Report of Fault Tree Analysis for the different failure sceneries (including Human Error)*

Report 1: HoD Drilling Phase

General information	
Project	Failure HoD
Version	Finale
Author	Magdalena Vera Chena
Society	
Calculation name	Temporaire
Top gate	HoD1
Mission time	24.0

Results	
Probability:	0.0202
System unreliability:	0.00594
Lambda system:	0.00025
Number of failures:	0.00585
System MTTR	83.53

Confidence level analysis

The table below contains the results of the sensitivity analysis to assess the level of confidence in the top gate probability.

Sensitivity analysis	
Average:	2.04e-02
Standard deviation:	1.00e-09
Confidence interval:	2.04e-02
	2.04e-02
Error factor:	1

Importance factors

The table below contains the magnitudes of each of the basic factors of events contributing to the dreaded event.

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E028	HPU fails	1	0.00033	1	0.017
E303	Human Failure HPU	1	0.003	1	0.15
E012	Radial Valve Failure	1	3.6e-05	1	0.0018
E013	Sub Body Failure	1	1.6e-06	1	8.2e-05
E014	Axial Valve Failure	1	3.6e-05	1	0.0018
E305	Electronic Power Unit Failure	1	0.00029	1	0.014
E306	Human Failure EPU	1	0.003	1	0.15
E317	Human Error Manifold Operation	1	0.0083	1	0.41
E179	Filter Blocked	1	1.8e-06	1	9e-05
E170	CV2 failure	1	1.1e-05	1	0.00054
E151	PV8 Fail to open	1	9.1e-05	1	0.0046
E149	PV8 External Leakage	1	3.4e-06	1	0.00017
E150	PV8 Critical	1	0.00018	1	0.0092
E159	PV9 External Leak	1	3.4e-06	1	0.00017
E161	PV9 Failure to close	1	7.3e-05	1	0.0036
E160	PV10 Critical	1	0.00018	1	0.0092
E158	PV10 External Leakage	1	3.4e-06	1	0.00017
E162	PV10 Fail to open	1	9.1e-05	1	0.0046
E156	PV1 Critical	3	0.00018	0.00028	0.00019
E157	PV1 Fail to open	3	9.1e-05	0.00028	9.3e-05
E154	PV1 External Leakage	3	3.4e-06	0.00028	3.4e-06
E155	PV 2 External Leakage	3	3.4e-06	0.00028	3.4e-06
E152	PV2 Fail to open	3	9.1e-05	0.00028	9.3e-05
E153	PV2 Critical	3	0.00018	0.00028	0.00019

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E148	PV4 External leakage	1	3.4e-06	1	0.00017
E147	PV4 Fail to close	1	7.3e-05	1	0.0036
E164	PV5 External Leakage	1	3.4e-06	1	0.00017
E163	PV5 Fail to close	1	7.3e-05	1	0.0036
E176	Internal Pipes Blocked	1	4.3e-06	1	0.00022
E178	Internal pipes Leaking to outside	1	2.9e-05	1	0.0014
E309	Human Error Control System	1	0.00021	1	0.01
E262	Master Control Unit Failure	1	0.0044	1	0.22

Qualitative Analysis

The following table contains the total number of min cuts per order.

Order	Quantity
1	26
2	9

Minimal cuts of order 1

The table below contains all the min cuts of order 1.

N°	Order	Probability	Percent	Event	Description
1	1	0.00832	40.8%	E317	Human Error Manifold Operation
2	1	0.00436	21.4%	E262	Master Control Unit Failure
3	1	0.00298	14.6%	E303	Human Failure HPU
4	1	0.00298	14.6%	E306	Human Failure EPU
5	1	0.000334	1.6%	E028	HPU fails
6	1	0.000286	1.4%	E305	Electronic Power Unit Failure
7	1	0.000208	1.0%	E309	Human Error Control System
8	1	0.000184	0.9%	E150	PV8 Critical
9	1	0.000184	0.9%	E160	PV10 Critical
10	1	9.14e-05	0.4%	E151	PV8 Fail to open
11	1	9.14e-05	0.4%	E162	PV10 Fail to open
12	1	7.27e-05	0.4%	E161	PV9 Failure to close
13	1	7.27e-05	0.4%	E147	PV4 Fail to close
14	1	7.27e-05	0.4%	E163	PV5 Fail to close
15	1	3.58e-05	0.2%	E012	Radial Valve Failure
16	1	3.58e-05	0.2%	E014	Axial Valve Failure
17	1	2.86e-05	0.1%	E178	Internal pipes Leaking to outside
18	1	1.09e-05	0.1%	E170	CV2 failure
19	1	4.3e-06	0.0%	E176	Internal Pipes Blocked
20	1	3.36e-06	0.0%	E149	PV8 External Leakage
21	1	3.36e-06	0.0%	E159	PV9 External Leak
22	1	3.36e-06	0.0%	E158	PV10 External Leakage
23	1	3.36e-06	0.0%	E148	PV4 External leakage
24	1	3.36e-06	0.0%	E164	PV5 External Leakage
25	1	1.8e-06	0.0%	E179	Filter Blocked
26	1	1.63e-06	0.0%	E013	Sub Body Failure

Minimal cuts set

The following table contains the 100 most contributors minimal cutsets.

N°	Order	Probability	Percent	Event	Description
1	1	0.00832	40.8%	E317	Human Error Manifold Operation
2	1	0.00436	21.4%	E262	Master Control Unit Failure
3	1	0.00298	14.6%	E303	Human Failure HPU
4	1	0.00298	14.6%	E306	Human Failure EPU
5	1	0.000334	1.6%	E028	HPU fails

N°	Order	Probability	Percent	Event	Description
6	1	0.000286	1.4%	E305	Electronic Power Unit Failure
7	1	0.000208	1.0%	E309	Human Error Control System
8	1	0.000184	0.9%	E150	PV8 Critical
9	1	0.000184	0.9%	E160	PV10 Critical
10	1	9.14e-05	0.4%	E151	PV8 Fail to open
11	1	9.14e-05	0.4%	E162	PV10 Fail to open
12	1	7.27e-05	0.4%	E161	PV9 Failure to close
13	1	7.27e-05	0.4%	E147	PV4 Fail to close
14	1	7.27e-05	0.4%	E163	PV5 Fail to close
15	1	3.58e-05	0.2%	E012	Radial Valve Failure
16	1	3.58e-05	0.2%	E014	Axial Valve Failure
17	1	2.86e-05	0.1%	E178	Internal pipes Leaking to outside
18	1	1.09e-05	0.1%	E170	CV2 failure
19	1	4.3e-06	0.0%	E176	Internal Pipes Blocked
20	1	3.36e-06	0.0%	E149	PV8 External Leakage
21	1	3.36e-06	0.0%	E159	PV9 External Leak
22	1	3.36e-06	0.0%	E158	PV10 External Leakage
23	1	3.36e-06	0.0%	E148	PV4 External leakage
24	1	3.36e-06	0.0%	E164	PV5 External Leakage
25	1	1.8e-06	0.0%	E179	Filter Blocked
26	1	1.63e-06	0.0%	E013	Sub Body Failure
27	2	3.39e-08	0.0%	E153	PV2 Critical
				E156	PV1 Critical
28	2	1.68e-08	0.0%	E152	PV2 Fail to open
				E156	PV1 Critical
29	2	1.68e-08	0.0%	E153	PV2 Critical
				E157	PV1 Fail to open
30	2	8.36e-09	0.0%	E152	PV2 Fail to open
				E157	PV1 Fail to open
31	2	6.18e-10	0.0%	E155	PV 2 External Leakage
				E156	PV1 Critical
32	2	6.18e-10	0.0%	E153	PV2 Critical
				E154	PV1 External Leakage
33	2	3.07e-10	0.0%	E155	PV 2 External Leakage
				E157	PV1 Fail to open
34	2	3.07e-10	0.0%	E152	PV2 Fail to open
				E154	PV1 External Leakage
35	2	1.13e-11	0.0%	E154	PV1 External Leakage
				E155	PV 2 External Leakage

Report 2: HoD By-Pass Drilling Phase

General information	
Project	Failure HoD
Version	Finale
Author	Magdalena Vera Chena
Society	
Calculation name	Temporaire
Top gate	HoD2
Mission time	24.0
Limit	

Results	
Probability:	0.0203
System unreliability:	0.00598
Lambda system:	0.000251
Number of failures:	0.00589
System MTTR	83.13

Confidence level analysis

The table below contains the results of the sensitivity analysis to assess the level of confidence in the top gate probability.

Sensitivity analysis	
Average:	2.04e-02
Standard deviation:	4.05e-09
Confidence interval:	2.04e-02
	2.04e-02
Error factor:	1

Importance factors

The table below contains the magnitudes of each of the basic factors of events contributing to the dreaded event.

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E309	Human Error Control System	1	0.00021	1	0.01
E262	Master Control Unit Failure	1	0.0044	1	0.22
E305	Electronic Power Unit Failure	1	0.00029	1	0.014
E306	Human Failure EPU	1	0.003	1	0.15
E028	HPU fails	1	0.00033	1	0.017
E303	Human Failure HPU	1	0.003	1	0.15
E012	Radial Valve Failure	1	3.6e-05	1	0.0018
E013	Sub Body Failure	1	1.6e-06	1	8.2e-05
E014	Axial Valve Failure	1	3.6e-05	1	0.0018
E315	Human Error Manifold operation	1	0.0083	1	0.41
E095	Filter is blocked	1	1.8e-06	1	9e-05
E079	PV10 leaking	1	3.4e-06	1	0.00017
E081	PV10fail to open	1	9.1e-05	1	0.0046
E080	Pv10 partially obstructed	1	0.00018	1	0.0092
E086	PV9 Fail to Open	1	9.1e-05	1	0.0046
E085	PV9 Plugged	1	0.00018	1	0.0092
E084	PV9 Leaking	1	3.4e-06	1	0.00017
E082	PV8 fail to open	1	9.1e-05	1	0.0046
E083	PV8 leaking	1	3.4e-06	1	0.00017
E087	Pv8 partially obstructed	1	0.00018	1	0.0092
E089	Internal Pipes Leaking to outside	1	2.9e-05	1	0.0014
E090	Internal pipes obstructed	1	4.3e-06	1	0.00021

Qualitative Analysis

The following table contains the total number of min cuts per order.

Order	Quantity
1	22

Minimal cuts of order 1

The table below contains all the min cuts of order 1.

N°	Order	Probability	Percent	Event	Description
1	1	0.00832	40.8%	E315	Human Error Manifold operation
2	1	0.00436	21.4%	E262	Master Control Unit Failure
3	1	0.00298	14.6%	E306	Human Failure EPU
4	1	0.00298	14.6%	E303	Human Failure HPU
5	1	0.000334	1.6%	E028	HPU fails
6	1	0.000286	1.4%	E305	Electronic Power Unit Failure
7	1	0.000208	1.0%	E309	Human Error Control System
8	1	0.000184	0.9%	E080	Pv10 partially obstructed
9	1	0.000184	0.9%	E085	PV9 Plugged
10	1	0.000184	0.9%	E087	Pv8 partially obstructed
11	1	9.14e-05	0.4%	E081	PV10fail to open
12	1	9.14e-05	0.4%	E086	PV9 Fail to Open
13	1	9.14e-05	0.4%	E082	PV8 fail to open
14	1	3.58e-05	0.2%	E012	Radial Valve Failure
15	1	3.58e-05	0.2%	E014	Axial Valve Failure
16	1	2.86e-05	0.1%	E089	Internal Pipes Leaking to outside
17	1	4.3e-06	0.0%	E090	Internal pipes obstructed
18	1	3.36e-06	0.0%	E079	PV10 leaking
19	1	3.36e-06	0.0%	E084	PV9 Leaking
20	1	3.36e-06	0.0%	E083	PV8 leaking
21	1	1.8e-06	0.0%	E095	Filter is blocked
22	1	1.63e-06	0.0%	E013	Sub Body Failure

Minimal cuts set

The following table contains the 100 most contributors minimal cutsets.

N°	Order	Probability	Percent	Event	Description
1	1	0.00832	40.8%	E315	Human Error Manifold operation
2	1	0.00436	21.4%	E262	Master Control Unit Failure
3	1	0.00298	14.6%	E306	Human Failure EPU
4	1	0.00298	14.6%	E303	Human Failure HPU
5	1	0.000334	1.6%	E028	HPU fails
6	1	0.000286	1.4%	E305	Electronic Power Unit Failure
7	1	0.000208	1.0%	E309	Human Error Control System
8	1	0.000184	0.9%	E080	Pv10 partially obstructed
9	1	0.000184	0.9%	E085	PV9 Plugged
10	1	0.000184	0.9%	E087	Pv8 partially obstructed
11	1	9.14e-05	0.4%	E081	PV10fail to open
12	1	9.14e-05	0.4%	E086	PV9 Fail to Open
13	1	9.14e-05	0.4%	E082	PV8 fail to open
14	1	3.58e-05	0.2%	E012	Radial Valve Failure
15	1	3.58e-05	0.2%	E014	Axial Valve Failure
16	1	2.86e-05	0.1%	E089	Internal Pipes Leaking to outside
17	1	4.3e-06	0.0%	E090	Internal pipes obstructed
18	1	3.36e-06	0.0%	E079	PV10 leaking
19	1	3.36e-06	0.0%	E084	PV9 Leaking
20	1	3.36e-06	0.0%	E083	PV8 leaking
21	1	1.8e-06	0.0%	E095	Filter is blocked
22	1	1.63e-06	0.0%	E013	Sub Body Failure

Report 3: HoD Drillpipe Connection Phase

General information	
Project	Failure HoD
Version	Finale
Author	Magdalena Vera Chena
Society	
Calculation name	Temporaire
Top gate	HoD3
Mission time	24.0
Limit	

Results	
Probability:	0.0261
System unreliability:	0.00637
Lambda system:	0.000268
Number of failures:	0.00624
System MTTR	101.6

Confidence level analysis

The table below contains the results of the sensitivity analysis to assess the level of confidence in the top gate probability.

Sensitivity analysis	
Average:	2.64e-02
Standard deviation:	2.08e-09
Confidence interval:	2.64e-02
	2.64e-02
Error factor:	1

Importance factors

The table below contains the magnitudes of each of the basic factors of events contributing to the dreaded event.

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E009	Radial Valve Failure	1	3.6e-05	0.0014	0.0014
E010	Sub Body Leaks	1	1.6e-06	6.2e-05	6.3e-05
E006	Flapper Valve	1	3.6e-05	0.0014	0.0014
E005	Excesive Loading	1	1e-05	0.00039	0.0004
E004	Insufficient Make up torque	1	8.2e-07	3.1e-05	3.2e-05
E002	Manufacturing Tolerances	1	1.4e-08	5.2e-07	5.3e-07
E003	Critical	1	8.2e-07	3.1e-05	3.2e-05
E028	HPU fails	1	0.00033	0.013	0.013
E303	Human Failure HPU	1	0.003	0.11	0.12
E308	Human Error CLAMP	1	0.0057	0.21	0.22
E271	Clamping Actuator Failure	1	2.4e-05	0.00091	0.00093
E270	Internal Actuator failure	1	0.00015	0.0058	0.006
E316	Human Error Manifold operation	1	0.0083	0.31	0.32
E141	Filter obstructed	1	1.8e-06	6.8e-05	7e-05
E138	Internal pipes Blocked	1	4.3e-06	0.00016	0.00017
E137	Internal Pipes Leaking to outside	1	2.9e-05	0.0011	0.0011
E119	PV2 External Leakage	2	3.4e-06	9.7e-09	3.4e-06
E116	PV2 Fail to close	2	9.1e-05	2.6e-07	9.2e-05
E121	PV1 External Leakage	2	3.4e-06	1.2e-08	3.4e-06
E122	PV1 Fail to close	2	7.3e-05	2.6e-07	7.3e-05
E110	PV5 Fail to open	1	9.1e-05	0.0035	0.0036
E108	PV5 External Leakage	1	3.4e-06	0.00013	0.00013
E109	PV5 Critical	1	0.00018	0.007	0.0071
E117	PV4 External Leakage	1	3.4e-06	0.00013	0.00013

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E118	PV4 Critical	1	0.00018	0.007	0.0071
E120	PV4 Fail to open	1	9.1e-05	0.0035	0.0036
E131	PV8 Fail to open	1	9.1e-05	0.0035	0.0036
E130	PV8 External Leakage	1	3.4e-06	0.00013	0.00013
E128	PV8 Critical	1	0.00018	0.007	0.0071
E112	RV External Leakage	1	2.9e-05	0.0011	0.0011
E113	RV Leak in closed position	1	5.4e-05	0.002	0.0021
E111	RV Fail to open	1	8.1e-05	0.0031	0.0031
E309	Human Error Control System	1	0.00021	0.0079	0.0081
E262	Master Control Unit Failure	1	0.0044	0.16	0.17
E305	Electronic Power Unit Failure	1	0.00029	0.011	0.011
E306	Human Failure EPU	1	0.003	0.11	0.12

Qualitative Analysis

The following table contains the total number of min cuts per order.

Order	Quantity
1	32
2	4

Minimal cuts of order 1

The table below contains all the min cuts of order 1.

N°	Order	Probability	Percent	Event	Description
1	1	0.00832	31.5%	E316	Human Error Manifold operation
2	1	0.00566	21.4%	E308	Human Error CLAMP
3	1	0.00436	16.5%	E262	Master Control Unit Failure
4	1	0.00298	11.3%	E303	Human Failure HPU
5	1	0.00298	11.3%	E306	Human Failure EPU
6	1	0.000334	1.3%	E028	HPU fails
7	1	0.000286	1.1%	E305	Electronic Power Unit Failure
8	1	0.000208	0.8%	E309	Human Error Control System
9	1	0.000184	0.7%	E109	PV5 Critical
10	1	0.000184	0.7%	E118	PV4 Critical
11	1	0.000184	0.7%	E128	PV8 Critical
12	1	0.000154	0.6%	E270	Internal Actuator failure
13	1	9.14e-05	0.3%	E110	PV5 Fail to open
14	1	9.14e-05	0.3%	E120	PV4 Fail to open
15	1	9.14e-05	0.3%	E131	PV8 Fail to open
16	1	8.06e-05	0.3%	E111	RV Fail to open
17	1	5.38e-05	0.2%	E113	RV Leak in closed position
18	1	3.58e-05	0.1%	E009	Radial Valve Failure
19	1	3.58e-05	0.1%	E006	Flapper Valve
20	1	2.88e-05	0.1%	E112	RV External Leakage
21	1	2.86e-05	0.1%	E137	Internal Pipes Leaking to outside
22	1	2.4e-05	0.1%	E271	Clamping Actuator Failure
23	1	1.03e-05	0.0%	E005	Excesive Loading
24	1	4.3e-06	0.0%	E138	Internal pipes Blocked
25	1	3.36e-06	0.0%	E108	PV5 External Leakage
26	1	3.36e-06	0.0%	E117	PV4 External Leakage
27	1	3.36e-06	0.0%	E130	PV8 External Leakage
28	1	1.8e-06	0.0%	E141	Filter obstructed
29	1	1.63e-06	0.0%	E010	Sub Body Leaks
30	1	8.23e-07	0.0%	E004	Insufficient Make up torque
31	1	8.23e-07	0.0%	E003	Critical
32	1	1.37e-08	0.0%	E002	Manufacturing Tolerances

Minimal cuts set

The following table contains the 100 most contributors minimal cutsets.

N°	Order	Probability	Percent	Event	Description
1	1	0.00832	31.5%	E316	Human Error Manifold operation
2	1	0.00566	21.4%	E308	Human Error CLAMP
3	1	0.00436	16.5%	E262	Master Control Unit Failure
4	1	0.00298	11.3%	E303	Human Failure HPU
5	1	0.00298	11.3%	E306	Human Failure EPU
6	1	0.000334	1.3%	E028	HPU fails
7	1	0.000286	1.1%	E305	Electronic Power Unit Failure
8	1	0.000208	0.8%	E309	Human Error Control System
9	1	0.000184	0.7%	E109	PV5 Critical
10	1	0.000184	0.7%	E118	PV4 Critical
11	1	0.000184	0.7%	E128	PV8 Critical
12	1	0.000154	0.6%	E270	Internal Actuator failure
13	1	9.14e-05	0.3%	E110	PV5 Fail to open
14	1	9.14e-05	0.3%	E120	PV4 Fail to open
15	1	9.14e-05	0.3%	E131	PV8 Fail to open
16	1	8.06e-05	0.3%	E111	RV Fail to open
17	1	5.38e-05	0.2%	E113	RV Leak in closed position
18	1	3.58e-05	0.1%	E009	Radial Valve Failure
19	1	3.58e-05	0.1%	E006	Flapper Valve
20	1	2.88e-05	0.1%	E112	RV External Leakage
21	1	2.86e-05	0.1%	E137	Internal Pipes Leaking to outside
22	1	2.4e-05	0.1%	E271	Clamping Actuator Failure
23	1	1.03e-05	0.0%	E005	Excesive Loading
24	1	4.3e-06	0.0%	E138	Internal pipes Blocked
25	1	3.36e-06	0.0%	E108	PV5 External Leakage
26	1	3.36e-06	0.0%	E117	PV4 External Leakage
27	1	3.36e-06	0.0%	E130	PV8 External Leakage
28	1	1.8e-06	0.0%	E141	Filter obstructed
29	1	1.63e-06	0.0%	E010	Sub Body Leaks
30	1	8.23e-07	0.0%	E004	Insufficient Make up torque
31	1	8.23e-07	0.0%	E003	Critical
32	1	1.37e-08	0.0%	E002	Manufacturing Tolerances
33	2	6.65e-09	0.0%	E116	PV2 Fail to close
				E122	PV1 Fail to close
34	2	3.07e-10	0.0%	E116	PV2 Fail to close
				E121	PV1 External Leakage
35	2	2.44e-10	0.0%	E119	PV2 External Leakage
				E122	PV1 Fail to close
36	2	1.13e-11	0.0%	E119	PV2 External Leakage
				E121	PV1 External Leakage

Report 3: HoD New Standpipe Filling Phase

General information	
Project	Failure HoD
Version	Finale
Author	Magdalena Vera Chena
Society	
Calculation name	Temporaire
Top gate	HoD4
Mission time	24.0
Limit	

Results	
Probability:	0.0297
System unreliability:	0.00707
Lambda system:	0.000298
Number of failures:	0.0069
System MTTR	104.6

Confidence level analysis

The table below contains the results of the sensitivity analysis to assess the level of confidence in the top gate probability.

Sensitivity analysis	
Average:	3.01e-02
Standard deviation:	8.39e-09
Confidence interval:	3.01e-02
	3.01e-02
Error factor:	1

Importance factors

The table below contains the magnitudes of each of the basic factors of events contributing to the dreaded event.

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E302	Human Error Manifold Operation	1	0.0083	1	0.28
E250	Filter	1	1.8e-06	1	6.2e-05
E217	PV2 External Leakage	2	3.4e-06	7.6e-05	3.4e-06
E216	PV2 Fail to close	2	7.3e-05	7.6e-05	7.3e-05
E219	PV1 Fail to close	2	7.3e-05	7.6e-05	7.3e-05
E218	PV1 External Leakage	2	3.4e-06	7.6e-05	3.4e-06
E204	PV8 External Leakage	1	3.4e-06	1	0.00012
E203	PV8 Critical	1	0.00018	1	0.0063
E205	PV8 Fail to open	1	9.1e-05	1	0.0031
E211	RV7 Fail to open	1	8.1e-05	1	0.0028
E212	RV7 Leak in closed position	1	5.4e-05	1	0.0018
E213	RV7 External Leakage	1	2.9e-05	1	0.00099
E214	CV1 failure	4	1.1e-05	0.00015	1.1e-05
E196	PV3 Fails to close	1	7.3e-05	1.1e-05	7.3e-05
E195	PV3 External Leakage	1	3.4e-06	1.1e-05	3.4e-06
E193	PV3 External Leakage	1	3.4e-06	1.1e-05	3.4e-06
E194	PV3 Fails to close	1	7.3e-05	1.1e-05	7.3e-05
E199	PV4 External Leakage	1	3.4e-06	1	0.00012
E198	PV4 Fail to open	1	9.1e-05	1	0.0031
E197	PV4 Critical	1	0.00018	1	0.0063
E190	PV5 Critical	1	0.00018	1	0.0063
E192	PV 5 External Leakage	1	3.4e-06	1	0.00012
E191	PV5 Fail to open	1	9.1e-05	1	0.0031

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E244	Pipes Blocked	1	4.3e-06	1	0.00015
E242	Pipes Leaking to outside	1	2.9e-05	1	0.00098
E236	CV2 Fails	1	1.1e-05	1	0.00037
E223	PV9 External Leakage	1	3.4e-06	1	0.00012
E224	PV9 Fail to close	1	7.3e-05	1	0.0025
E220	PV10 External Leakage	1	3.4e-06	1	0.00012
E222	PV10 Fail to open	1	9.1e-05	1	0.0031
E221	PV10 Critical	1	0.00018	1	0.0063
E227	PV3 External Leakage	1	3.4e-06	1	0.00012
E228	PV3 Fails to Close	1	7.3e-05	1	0.0025
E209	PV2Fail to close	1	7.3e-05	1	0.0025
E207	PV2 External Leakage	1	3.4e-06	1	0.00012
E208	PV1Fail to close	1	7.3e-05	1	0.0025
E210	PV1 External Leakage	1	3.4e-06	1	0.00012
E248	Pipes Blocked	1	4.3e-06	1	0.00015
E245	Pipes Leaking to outside	1	2.9e-05	1	0.00098
E310	Human Error DFP	1	0.003	1	0.1
E072	Pipe obstructed	1	4.3e-06	1	0.00015
E074	Hose failure	1	2.9e-05	1	0.00098
E065	Pump2 Filter blocked	11	1.8e-06	0.001	1.9e-06
E049	One way valve 2 fails	11	9.7e-05	0.001	0.0001
E036	PSV 2 Degraded	11	0.0002	0.001	0.0002
E038	PSV2 Spurious operation	11	4.3e-05	0.001	4.4e-05
E037	PSV2 Leaks in closed position	11	0.0002	0.001	0.0002
E052	BV2 Low output	11	2.4e-06	0.001	2.5e-06
E054	BV2 Critical Blockage	11	0.00033	0.001	0.00034
E051	BV2 External Leakage	11	9.4e-06	0.001	9.7e-06
E059	DFP-Pump2 Breakdown	11	0.00012	0.001	0.00012
E032	Breakdown Motor2	11	4.9e-05	0.001	5.1e-05
E033	Fail to start on demand Motor2	11	0.00013	0.001	0.00013
E069	Piump1 Filter blocked	11	1.8e-06	0.0012	1.9e-06
E047	One way valve 2 fails	11	9.7e-05	0.0012	0.0001
E041	PSV 2 Degraded	11	0.0002	0.0012	0.00021
E039	PSV2 Spurious operation	11	4.3e-05	0.0012	4.4e-05
E040	PSV2 Leaks in closed position	11	4.3e-05	0.0012	4.4e-05
E057	BV1 Low output	11	2.4e-06	0.0012	2.5e-06
E056	BV1 External Leakage	11	9.4e-06	0.0012	9.7e-06
E053	BV1 Critical Blockage	11	0.00033	0.0012	0.00035
E061	DFP-Pump1 Breakdown	11	0.00012	0.0012	0.00012
E034	Breakdown Motor1	11	4.9e-05	0.0012	5.1e-05
E035	Fail to start on demand Motor1	11	0.00013	0.0012	0.00013
E308	Human Error CLAMP	1	0.0057	1	0.19
E271	Clamping Actuator Failure	1	2.4e-05	1	0.00082
E270	Internal Actuator failure	1	0.00015	1	0.0053
E305	Electronic Power Unit Failure	1	0.00029	1	0.0098
E306	Human Failure EPU	1	0.003	1	0.1
E028	HPU fails	1	0.00033	1	0.011
E303	Human Failure HPU	1	0.003	1	0.1
E009	Radial Valve Failure	1	3.6e-05	1	0.0012
E010	Sub Body Leaks	1	1.6e-06	1	5.6e-05
E006	Flapper Valve	1	3.6e-05	1	0.0012
E005	Excesive Loading	1	1e-05	1	0.00035
E004	Insufficient Make up torque	1	8.2e-07	1	2.8e-05
E002	Manufacturing Tolerances	1	1.4e-08	1	4.7e-07
E003	Critical	1	8.2e-07	1	2.8e-05
E309	Human Error Control System	1	0.00021	1	0.0071
E262	Master Control Unit Failure	1	0.0044	1	0.15

Qualitative Analysis

The following table contains the total number of min cuts per order.

Order	Quantity
1	49
2	129

Minimal cuts of order 1

The table below contains all the min cuts of order 1.

N°	Order	Probability	Percent	Event	Description
1	1	0.00832	27.7%	E302	Human Error Manifold Operation
2	1	0.00566	18.8%	E308	Human Error CLAMP
3	1	0.00436	14.5%	E262	Master Control Unit Failure
4	1	0.00298	9.9%	E310	Human Error DFP
5	1	0.00298	9.9%	E306	Human Failure EPU
6	1	0.00298	9.9%	E303	Human Failure HPU
7	1	0.000334	1.1%	E028	HPU fails
8	1	0.000286	1.0%	E305	Electronic Power Unit Failure
9	1	0.000208	0.7%	E309	Human Error Control System
10	1	0.000184	0.6%	E203	PV8 Critical
11	1	0.000184	0.6%	E197	PV4 Critical
12	1	0.000184	0.6%	E190	PV5 Critical
13	1	0.000184	0.6%	E221	PV10 Critical
14	1	0.000154	0.5%	E270	Internal Actuator failure
15	1	9.14e-05	0.3%	E205	PV8 Fail to open
16	1	9.14e-05	0.3%	E198	PV4 Fail to open
17	1	9.14e-05	0.3%	E191	PV5 Fail to open
18	1	9.14e-05	0.3%	E222	PV10 Fail to open
19	1	8.06e-05	0.3%	E211	RV7 Fail to open
20	1	7.27e-05	0.2%	E224	PV9 Fail to close
21	1	7.27e-05	0.2%	E228	PV3 Fails to Close
22	1	7.27e-05	0.2%	E209	PV2Fail to close
23	1	7.27e-05	0.2%	E208	PV1Fail to close
24	1	5.38e-05	0.2%	E212	RV7 Leak in closed position
25	1	3.58e-05	0.1%	E009	Radial Valve Failure
26	1	3.58e-05	0.1%	E006	Flapper Valve
27	1	2.88e-05	0.1%	E213	RV7 External Leakage
28	1	2.86e-05	0.1%	E242	Pipes Leaking to outside
29	1	2.86e-05	0.1%	E245	Pipes Leaking to outside
30	1	2.86e-05	0.1%	E074	Hose failure
31	1	2.4e-05	0.1%	E271	Clamping Actuator Failure
32	1	1.09e-05	0.0%	E236	CV2 Fails
33	1	1.03e-05	0.0%	E005	Excesive Loading
34	1	4.3e-06	0.0%	E244	Pipes Blocked
35	1	4.3e-06	0.0%	E248	Pipes Blocked
36	1	4.3e-06	0.0%	E072	Pipe obstructed
37	1	3.36e-06	0.0%	E204	PV8 External Leakage
38	1	3.36e-06	0.0%	E199	PV4 External Leakage
39	1	3.36e-06	0.0%	E192	PV 5 External Leakage
40	1	3.36e-06	0.0%	E223	PV9 External Leakage
41	1	3.36e-06	0.0%	E220	PV10 External Leakage
42	1	3.36e-06	0.0%	E227	PV3 External Leakage
43	1	3.36e-06	0.0%	E207	PV2 External Leakage
44	1	3.36e-06	0.0%	E210	PV1 External Leakage
45	1	1.8e-06	0.0%	E250	Filter
46	1	1.63e-06	0.0%	E010	Sub Body Leaks
47	1	8.23e-07	0.0%	E004	Insufficient Make up torque
48	1	8.23e-07	0.0%	E003	Critical
49	1	1.37e-08	0.0%	E002	Manufacturing Tolerances

Minimal cuts set

The following table contains the 100 most contributors minimal cutsets.

N°	Order	Probability	Percent	Event	Description
1	1	0.00832	27.7%	E302	Human Error Manifold Operation
2	1	0.00566	18.8%	E308	Human Error CLAMP
3	1	0.00436	14.5%	E262	Master Control Unit Failure
4	1	0.00298	9.9%	E310	Human Error DFP
5	1	0.00298	9.9%	E306	Human Failure EPU
6	1	0.00298	9.9%	E303	Human Failure HPU
7	1	0.000334	1.1%	E028	HPU fails
8	1	0.000286	1.0%	E305	Electronic Power Unit Failure
9	1	0.000208	0.7%	E309	Human Error Control System
10	1	0.000184	0.6%	E203	PV8 Critical
11	1	0.000184	0.6%	E197	PV4 Critical
12	1	0.000184	0.6%	E190	PV5 Critical
13	1	0.000184	0.6%	E221	PV10 Critical
14	1	0.000154	0.5%	E270	Internal Actuator failure
15	1	9.14e-05	0.3%	E205	PV8 Fail to open
16	1	9.14e-05	0.3%	E198	PV4 Fail to open
17	1	9.14e-05	0.3%	E191	PV5 Fail to open
18	1	9.14e-05	0.3%	E222	PV10 Fail to open
19	1	8.06e-05	0.3%	E211	RV7 Fail to open
20	1	7.27e-05	0.2%	E224	PV9 Fail to close
21	1	7.27e-05	0.2%	E228	PV3 Fails to Close
22	1	7.27e-05	0.2%	E209	PV2Fail to close
23	1	7.27e-05	0.2%	E208	PV1Fail to close
24	1	5.38e-05	0.2%	E212	RV7 Leak in closed position
25	1	3.58e-05	0.1%	E009	Radial Valve Failure
26	1	3.58e-05	0.1%	E006	Flapper Valve
27	1	2.88e-05	0.1%	E213	RV7 External Leakage
28	1	2.86e-05	0.1%	E242	Pipes Leaking to outside
29	1	2.86e-05	0.1%	E245	Pipes Leaking to outside
30	1	2.86e-05	0.1%	E074	Hose failure
31	1	2.4e-05	0.1%	E271	Clamping Actuator Failure
32	1	1.09e-05	0.0%	E236	CV2 Fails
33	1	1.03e-05	0.0%	E005	Excesive Loading
34	1	4.3e-06	0.0%	E244	Pipes Blocked
35	1	4.3e-06	0.0%	E248	Pipes Blocked
36	1	4.3e-06	0.0%	E072	Pipe obstructed
37	1	3.36e-06	0.0%	E204	PV8 External Leakage
38	1	3.36e-06	0.0%	E199	PV4 External Leakage
39	1	3.36e-06	0.0%	E192	PV 5 External Leakage
40	1	3.36e-06	0.0%	E223	PV9 External Leakage
41	1	3.36e-06	0.0%	E220	PV10 External Leakage
42	1	3.36e-06	0.0%	E227	PV3 External Leakage
43	1	3.36e-06	0.0%	E207	PV2 External Leakage
44	1	3.36e-06	0.0%	E210	PV1 External Leakage
45	1	1.8e-06	0.0%	E250	Filter
46	1	1.63e-06	0.0%	E010	Sub Body Leaks
47	1	8.23e-07	0.0%	E004	Insufficient Make up torque
48	1	8.23e-07	0.0%	E003	Critical
49	2	1.11e-07	0.0%	E053	BV1 Critical Blockage
				E054	BV2 Critical Blockage
50	2	6.61e-08	0.0%	E036	PSV 2 Degraded
				E053	BV1 Critical Blockage
51	2	6.61e-08	0.0%	E037	PSV2 Leaks in closed position
				E053	BV1 Critical Blockage
52	2	6.61e-08	0.0%	E041	PSV 2 Degraded
				E054	BV2 Critical Blockage
53	2	4.19e-08	0.0%	E035	Fail to start on demand Motor1
				E054	BV2 Critical Blockage

N°	Order	Probability	Percent	Event	Description
54	2	4.19e-08	0.0%	E033	Fail to start on demand Motor2
				E053	BV1 Critical Blockage
55	2	4e-08	0.0%	E054	BV2 Critical Blockage
				E061	DFP-Pump1 Breakdown
56	2	4e-08	0.0%	E053	BV1 Critical Blockage
				E059	DFP-Pump2 Breakdown
57	2	3.93e-08	0.0%	E036	PSV 2 Degraded
				E041	PSV 2 Degraded
58	2	3.93e-08	0.0%	E037	PSV2 Leaks in closed position
				E041	PSV 2 Degraded
59	2	3.23e-08	0.0%	E049	One way valve 2 fails
				E053	BV1 Critical Blockage
60	2	3.23e-08	0.0%	E047	One way valve 2 fails
				E054	BV2 Critical Blockage
61	2	2.49e-08	0.0%	E035	Fail to start on demand Motor1
				E036	PSV 2 Degraded
62	2	2.49e-08	0.0%	E035	Fail to start on demand Motor1
				E037	PSV2 Leaks in closed position
63	2	2.49e-08	0.0%	E033	Fail to start on demand Motor2
				E041	PSV 2 Degraded
64	2	2.38e-08	0.0%	E036	PSV 2 Degraded
				E061	DFP-Pump1 Breakdown
65	2	2.38e-08	0.0%	E037	PSV2 Leaks in closed position
				E061	DFP-Pump1 Breakdown
66	2	2.38e-08	0.0%	E041	PSV 2 Degraded
				E059	DFP-Pump2 Breakdown
67	2	1.92e-08	0.0%	E041	PSV 2 Degraded
				E049	One way valve 2 fails
68	2	1.92e-08	0.0%	E036	PSV 2 Degraded
				E047	One way valve 2 fails
69	2	1.92e-08	0.0%	E037	PSV2 Leaks in closed position
				E047	One way valve 2 fails
70	2	1.65e-08	0.0%	E034	Breakdown Motor1
				E054	BV2 Critical Blockage
71	2	1.65e-08	0.0%	E032	Breakdown Motor2
				E053	BV1 Critical Blockage
72	2	1.58e-08	0.0%	E033	Fail to start on demand Motor2
				E035	Fail to start on demand Motor1
73	2	1.51e-08	0.0%	E035	Fail to start on demand Motor1
				E059	DFP-Pump2 Breakdown
74	2	1.51e-08	0.0%	E033	Fail to start on demand Motor2
				E061	DFP-Pump1 Breakdown
75	2	1.44e-08	0.0%	E059	DFP-Pump2 Breakdown
				E061	DFP-Pump1 Breakdown
76	2	1.42e-08	0.0%	E038	PSV2 Spurious operation
				E053	BV1 Critical Blockage
77	2	1.42e-08	0.0%	E039	PSV2 Spurious operation
				E054	BV2 Critical Blockage
78	2	1.42e-08	0.0%	E040	PSV2 Leaks in closed position
				E054	BV2 Critical Blockage
79	1	1.37e-08	0.0%	E002	Manufacturing Tolerances
80	2	1.22e-08	0.0%	E035	Fail to start on demand Motor1
				E049	One way valve 2 fails
81	2	1.22e-08	0.0%	E033	Fail to start on demand Motor2
				E047	One way valve 2 fails
82	2	1.16e-08	0.0%	E049	One way valve 2 fails
				E061	DFP-Pump1 Breakdown
83	2	1.16e-08	0.0%	E047	One way valve 2 fails
				E059	DFP-Pump2 Breakdown
84	2	9.8e-09	0.0%	E034	Breakdown Motor1
				E036	PSV 2 Degraded

N°	Order	Probability	Percent	Event	Description
85	2	9.8e-09	0.0%	E034	Breakdown Motor1
				E037	PSV2 Leaks in closed position
86	2	9.8e-09	0.0%	E032	Breakdown Motor2
				E041	PSV 2 Degraded
87	2	9.35e-09	0.0%	E047	One way valve 2 fails
				E049	One way valve 2 fails
88	2	8.47e-09	0.0%	E036	PSV 2 Degraded
				E039	PSV2 Spurious operation
89	2	8.47e-09	0.0%	E036	PSV 2 Degraded
				E040	PSV2 Leaks in closed position
90	2	8.47e-09	0.0%	E038	PSV2 Spurious operation
				E041	PSV 2 Degraded
91	2	8.47e-09	0.0%	E037	PSV2 Leaks in closed position
				E039	PSV2 Spurious operation
92	2	8.47e-09	0.0%	E037	PSV2 Leaks in closed position
				E040	PSV2 Leaks in closed position
93	2	6.22e-09	0.0%	E032	Breakdown Motor2
				E035	Fail to start on demand Motor1
94	2	6.22e-09	0.0%	E033	Fail to start on demand Motor2
				E034	Breakdown Motor1
95	2	5.93e-09	0.0%	E034	Breakdown Motor1
				E059	DFP-Pump2 Breakdown
96	2	5.93e-09	0.0%	E032	Breakdown Motor2
				E061	DFP-Pump1 Breakdown
97	2	5.37e-09	0.0%	E035	Fail to start on demand Motor1
				E038	PSV2 Spurious operation
98	2	5.37e-09	0.0%	E033	Fail to start on demand Motor2
				E039	PSV2 Spurious operation
99	2	5.37e-09	0.0%	E033	Fail to start on demand Motor2
				E040	PSV2 Leaks in closed position

ANNEX VIII *–Report of Fault Tree Analysis for the different failure sceneries (not considering Human Error)*

Report 1A: HoD Drilling Phase (no Human Error considered)

General information	
Project	Failure HoD without human Error
Version	Finale
Author	Magdalena Vera Chena
Society	
Calculation name	Temporaire
Top gate	HoD1
Mission time	24.0

Results	
Probability:	0.00588
System unreliability:	0.00585
Lambda system:	0.000246
Number of failures:	0.00585
System MTTR	24.12

Confidence level analysis

The table below contains the results of the sensitivity analysis to assess the level of confidence in the top gate probability.

Sensitivity analysis	
Average:	5.88e-03
Standard deviation:	5.71e-10
Confidence interval:	5.88e-03
	5.88e-03
Error factor:	1

Importance factors

The table below contains the magnitudes of each of the basic factors of events contributing to the dreaded event.

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E028	HPU fails	1	0.00033	1	0.057
E014	Axial Valve Failure	1	3.6e-05	1	0.0061
E013	Sub Body Failure	1	1.6e-06	1	0.00028
E012	Radial Valve Failure	1	3.6e-05	1	0.0061
E305	Electronic Power Unit Failure	1	0.00029	1	0.049
E262	Master Control Unit Failure	1	0.0044	1	0.74
E179	Filter Blocked	1	1.8e-06	1	0.00031
E178	Internal pipes Leaking to outside	1	2.9e-05	1	0.0049
E176	Internal Pipes Blocked	1	4.3e-06	1	0.00073
E170	CV2 failure	1	1.1e-05	1	0.0019
E160	PV10 Critical	1	0.00018	1	0.031
E162	PV10 Fail to open	1	9.1e-05	1	0.016
E158	PV10 External Leakage	1	3.4e-06	1	0.00057
E151	PV8 Fail to open	1	9.1e-05	1	0.016
E150	PV8 Critical	1	0.00018	1	0.031
E149	PV8 External Leakage	1	3.4e-06	1	0.00057
E161	PV9 Failure to close	1	7.3e-05	1	0.012
E159	PV9 External Leak	1	3.4e-06	1	0.00057
E155	PV 2 External Leakage	3	3.4e-06	0.00028	3.5e-06
E152	PV2 Fail to open	3	9.1e-05	0.00028	9.6e-05
E153	PV2 Critical	3	0.00018	0.00028	0.00019
E157	PV1 Fail to open	3	9.1e-05	0.00028	9.6e-05
E156	PV1 Critical	3	0.00018	0.00028	0.00019
E154	PV1 External Leakage	3	3.4e-06	0.00028	3.5e-06

E148	PV4 External leakage	1	3.4e-06	1	0.00057
E147	PV4 Fail to close	1	7.3e-05	1	0.012
E163	PV5 Fail to close	1	7.3e-05	1	0.012
E164	PV5 External Leakage	1	3.4e-06	1	0.00057

Qualitative Analysis

The following table contains the total number of min cuts per order.

Order	Quantity
1	22
2	9

Minimal cuts of order 1

The table below contains all the min cuts of order 1.

°	Order	Probability	Percent	Event	Description
1	1	0.00436	74.1%	E262	Master Control Unit Failure
2	1	0.000334	5.7%	E028	HPU fails
3	1	0.000286	4.9%	E305	Electronic Power Unit Failure
4	1	0.000184	3.1%	E160	PV10 Critical
5	1	0.000184	3.1%	E150	PV8 Critical
6	1	9.14e-05	1.6%	E162	PV10 Fail to open
7	1	9.14e-05	1.6%	E151	PV8 Fail to open
8	1	7.27e-05	1.2%	E161	PV9 Failure to close
9	1	7.27e-05	1.2%	E147	PV4 Fail to close
10	1	7.27e-05	1.2%	E163	PV5 Fail to close
11	1	3.58e-05	0.6%	E014	Axial Valve Failure
12	1	3.58e-05	0.6%	E012	Radial Valve Failure
13	1	2.86e-05	0.5%	E178	Internal pipes Leaking to outside
14	1	1.09e-05	0.2%	E170	CV2 failure
15	1	4.3e-06	0.1%	E176	Internal Pipes Blocked
16	1	3.36e-06	0.1%	E158	PV10 External Leakage
17	1	3.36e-06	0.1%	E149	PV8 External Leakage
18	1	3.36e-06	0.1%	E159	PV9 External Leak
19	1	3.36e-06	0.1%	E148	PV4 External leakage
20	1	3.36e-06	0.1%	E164	PV5 External Leakage
21	1	1.8e-06	0.0%	E179	Filter Blocked
22	1	1.63e-06	0.0%	E013	Sub Body Failure

Minimal cuts set

The following table contains the 100 most contributors minimal cutsets.

N°	Order	Probability	Percent	Event	Description
1	1	0.00436	74.1%	E262	Master Control Unit Failure
2	1	0.000334	5.7%	E028	HPU fails
3	1	0.000286	4.9%	E305	Electronic Power Unit Failure
4	1	0.000184	3.1%	E160	PV10 Critical
5	1	0.000184	3.1%	E150	PV8 Critical
6	1	9.14e-05	1.6%	E162	PV10 Fail to open
7	1	9.14e-05	1.6%	E151	PV8 Fail to open
8	1	7.27e-05	1.2%	E161	PV9 Failure to close
9	1	7.27e-05	1.2%	E147	PV4 Fail to close
10	1	7.27e-05	1.2%	E163	PV5 Fail to close
11	1	3.58e-05	0.6%	E014	Axial Valve Failure
12	1	3.58e-05	0.6%	E012	Radial Valve Failure
13	1	2.86e-05	0.5%	E178	Internal pipes Leaking to outside

N°	Order	Probability	Percent	Event	Description
14	1	1.09e-05	0.2%	E170	CV2 failure
15	1	4.3e-06	0.1%	E176	Internal Pipes Blocked
16	1	3.36e-06	0.1%	E158	PV10 External Leakage
17	1	3.36e-06	0.1%	E149	PV8 External Leakage
18	1	3.36e-06	0.1%	E159	PV9 External Leak
19	1	3.36e-06	0.1%	E148	PV4 External leakage
20	1	3.36e-06	0.1%	E164	PV5 External Leakage
21	1	1.8e-06	0.0%	E179	Filter Blocked
22	1	1.63e-06	0.0%	E013	Sub Body Failure
23	2	3.39e-08	0.0%	E153	PV2 Critical
				E156	PV1 Critical
24	2	1.68e-08	0.0%	E152	PV2 Fail to open
				E156	PV1 Critical
25	2	1.68e-08	0.0%	E153	PV2 Critical
				E157	PV1 Fail to open
26	2	8.36e-09	0.0%	E152	PV2 Fail to open
				E157	PV1 Fail to open
27	2	6.18e-10	0.0%	E155	PV 2 External Leakage
				E156	PV1 Critical
28	2	6.18e-10	0.0%	E153	PV2 Critical
				E154	PV1 External Leakage
29	2	3.07e-10	0.0%	E155	PV 2 External Leakage
				E157	PV1 Fail to open
30	2	3.07e-10	0.0%	E152	PV2 Fail to open
				E154	PV1 External Leakage
31	2	1.13e-11	0.0%	E154	PV1 External Leakage
				E155	PV 2 External Leakage

Report 2A: HoD By-Pass Drilling Phase (no Human Error considered)

General information	
Project	Failure HoD without human Error
Version	Finale
Author	Magdalena Vera Chena
Society	
Calculation name	Temporaire
Top gate	HoD2
Mission time	24.0
Limit	

Results	
Probability:	0.00591
System unreliability:	0.00589
Lambda system:	0.000248
Number of failures:	0.00589
System MTTR	24.12

Confidence level analysis

The table below contains the results of the sensitivity analysis to assess the level of confidence in the top gate probability.

Sensitivity analysis	
Average:	5.92e-03
Standard deviation:	1.27e-09
Confidence interval:	5.92e-03
	5.92e-03
Error factor:	1

Importance factors

The table below contains the magnitudes of each of the basic factors of events contributing to the dreaded event.

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E262	Master Control Unit Failure	1	0.0044	1	0.74
E028	HPU fails	1	0.00033	1	0.057
E305	Electronic Power Unit Failure	1	0.00029	1	0.049
E095	Filter is blocked	1	1.8e-06	1	0.00031
E083	PV8 leaking	1	3.4e-06	1	0.00057
E082	PV8 fail to open	1	9.1e-05	1	0.016
E087	Pv8 partially obstructed	1	0.00018	1	0.031
E085	PV9 Plugged	1	0.00018	1	0.031
E084	PV9 Leaking	1	3.4e-06	1	0.00057
E086	PV9 Fail to Open	1	9.1e-05	1	0.016
E081	PV10fail to open	1	9.1e-05	1	0.016
E080	Pv10 partially obstructed	1	0.00018	1	0.031
E079	PV10 leaking	1	3.4e-06	1	0.00057
E090	Internal pipes obstructed	1	4.3e-06	1	0.00073
E089	Internal Pipes Leaking to outside	1	2.9e-05	1	0.0049
E014	Axial Valve Failure	1	3.6e-05	1	0.0061
E013	Sub Body Failure	1	1.6e-06	1	0.00028
E012	Radial Valve Failure	1	3.6e-05	1	0.0061

Qualitative Analysis

The following table contains the total number of min cuts per order.

Order	Quantity

1	18

Minimal cuts of order 1

The table below contains all the min cuts of order 1.

N°	Order	Probability	Percent	Event	Description
1	1	0.00436	73.6%	E262	Master Control Unit Failure
2	1	0.000334	5.6%	E028	HPU fails
3	1	0.000286	4.8%	E305	Electronic Power Unit Failure
4	1	0.000184	3.1%	E087	Pv8 partially obstructed
5	1	0.000184	3.1%	E085	PV9 Plugged
6	1	0.000184	3.1%	E080	Pv10 partially obstructed
7	1	9.14e-05	1.5%	E082	PV8 fail to open
8	1	9.14e-05	1.5%	E086	PV9 Fail to Open
9	1	9.14e-05	1.5%	E081	PV10fail to open
10	1	3.58e-05	0.6%	E014	Axial Valve Failure
11	1	3.58e-05	0.6%	E012	Radial Valve Failure
12	1	2.86e-05	0.5%	E089	Internal Pipes Leaking to outside
13	1	4.3e-06	0.1%	E090	Internal pipes obstructed
14	1	3.36e-06	0.1%	E083	PV8 leaking
15	1	3.36e-06	0.1%	E084	PV9 Leaking
16	1	3.36e-06	0.1%	E079	PV10 leaking
17	1	1.8e-06	0.0%	E095	Filter is blocked
18	1	1.63e-06	0.0%	E013	Sub Body Failure

Minimal cuts set

The following table contains the 100 most contributors minimal cutsets.

N°	Order	Probability	Percent	Event	Description
1	1	0.00436	73.6%	E262	Master Control Unit Failure
2	1	0.000334	5.6%	E028	HPU fails
3	1	0.000286	4.8%	E305	Electronic Power Unit Failure
4	1	0.000184	3.1%	E087	Pv8 partially obstructed
5	1	0.000184	3.1%	E085	PV9 Plugged
6	1	0.000184	3.1%	E080	Pv10 partially obstructed
7	1	9.14e-05	1.5%	E082	PV8 fail to open
8	1	9.14e-05	1.5%	E086	PV9 Fail to Open
9	1	9.14e-05	1.5%	E081	PV10fail to open
10	1	3.58e-05	0.6%	E014	Axial Valve Failure
11	1	3.58e-05	0.6%	E012	Radial Valve Failure
12	1	2.86e-05	0.5%	E089	Internal Pipes Leaking to outside
13	1	4.3e-06	0.1%	E090	Internal pipes obstructed
14	1	3.36e-06	0.1%	E083	PV8 leaking
15	1	3.36e-06	0.1%	E084	PV9 Leaking
16	1	3.36e-06	0.1%	E079	PV10 leaking
17	1	1.8e-06	0.0%	E095	Filter is blocked
18	1	1.63e-06	0.0%	E013	Sub Body Failure

Report 3A: HoD Drillpipe Connection Phase (no Human Error considered)

General information	
Project	Failure HoD without human Error
Version	Finale
Author	Magdalena Vera Chena
Society	
Calculation name	Temporaire
Top gate	HoD3
Mission time	24.0
Limit	

Results	
Probability:	0.00627
System unreliability:	0.00624
Lambda system:	0.000263
Number of failures:	0.00624
System MTTR	24.12

Confidence level analysis

The table below contains the results of the sensitivity analysis to assess the level of confidence in the top gate probability.

Sensitivity analysis	
Average:	6.28e-03
Standard deviation:	1.14e-09
Confidence interval:	6.28e-03
	6.28e-03
Error factor:	1

Importance factors

The table below contains the magnitudes of each of the basic factors of events contributing to the dreaded event.

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E028	HPU fails	1	0.00033	1	0.053
E141	Filter obstructed	1	1.8e-06	1	0.00029
E137	Internal Pipes Leaking to outside	1	2.9e-05	1	0.0046
E138	Internal pipes Blocked	1	4.3e-06	1	0.00069
E116	PV2 Fail to close	2	9.1e-05	7.6e-05	9.3e-05
E119	PV2 External Leakage	2	3.4e-06	7.6e-05	3.4e-06
E122	PV1 Fail to close	2	7.3e-05	9.5e-05	7.4e-05
E121	PV1 External Leakage	2	3.4e-06	9.5e-05	3.4e-06
E128	PV8 Critical	1	0.00018	1	0.03
E131	PV8 Fail to open	1	9.1e-05	1	0.015
E130	PV8 External Leakage	1	3.4e-06	1	0.00054
E108	PV5 External Leakage	1	3.4e-06	1	0.00054
E110	PV5 Fail to open	1	9.1e-05	1	0.015
E109	PV5 Critical	1	0.00018	1	0.03
E117	PV4 External Leakage	1	3.4e-06	1	0.00054
E120	PV4 Fail to open	1	9.1e-05	1	0.015
E118	PV4 Critical	1	0.00018	1	0.03
E111	RV Fail to open	1	8.1e-05	1	0.013
E112	RV External Leakage	1	2.9e-05	1	0.0046
E113	RV Leak in closed position	1	5.4e-05	1	0.0086
E262	Master Control Unit Failure	1	0.0044	1	0.7

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E270	Internal Actuator failure	1	0.00015	1	0.025
E271	Clamping Actuator Failure	1	2.4e-05	1	0.0038
E010	Sub Body Leaks	1	1.6e-06	1	0.00026
E009	Radial Valve Failure	1	3.6e-05	1	0.0057
E006	Flapper Valve	1	3.6e-05	1	0.0057
E003	Critical	1	8.2e-07	1	0.00013
E005	Excesive Loading	1	1e-05	1	0.0017
E002	Manufacturing Tolerances	1	1.4e-08	1	2.2e-06
E004	Insufficient Make up torque	1	8.2e-07	1	0.00013
E305	Electronic Power Unit Failure	1	0.00029	1	0.046

Qualitative Analysis

The following table contains the total number of min cuts per order.

Order	Quantity
1	27
2	4

Minimal cuts of order 1

The table below contains all the min cuts of order 1.

N°	Order	Probability	Percent	Event	Description
1	1	0.00436	69.5%	E262	Master Control Unit Failure
2	1	0.000334	5.3%	E028	HPU fails
3	1	0.000286	4.6%	E305	Electronic Power Unit Failure
4	1	0.000184	2.9%	E128	PV8 Critical
5	1	0.000184	2.9%	E109	PV5 Critical
6	1	0.000184	2.9%	E118	PV4 Critical
7	1	0.000154	2.4%	E270	Internal Actuator failure
8	1	9.14e-05	1.5%	E131	PV8 Fail to open
9	1	9.14e-05	1.5%	E110	PV5 Fail to open
10	1	9.14e-05	1.5%	E120	PV4 Fail to open
11	1	8.06e-05	1.3%	E111	RV Fail to open
12	1	5.38e-05	0.9%	E113	RV Leak in closed position
13	1	3.58e-05	0.6%	E009	Radial Valve Failure
14	1	3.58e-05	0.6%	E006	Flapper Valve
15	1	2.88e-05	0.5%	E112	RV External Leakage
16	1	2.86e-05	0.5%	E137	Internal Pipes Leaking to outside
17	1	2.4e-05	0.4%	E271	Clamping Actuator Failure
18	1	1.03e-05	0.2%	E005	Excesive Loading
19	1	4.3e-06	0.1%	E138	Internal pipes Blocked
20	1	3.36e-06	0.1%	E130	PV8 External Leakage
21	1	3.36e-06	0.1%	E108	PV5 External Leakage
22	1	3.36e-06	0.1%	E117	PV4 External Leakage
23	1	1.8e-06	0.0%	E141	Filter obstructed
24	1	1.63e-06	0.0%	E010	Sub Body Leaks
25	1	8.23e-07	0.0%	E003	Critical
26	1	8.23e-07	0.0%	E004	Insufficient Make up torque
27	1	1.37e-08	0.0%	E002	Manufacturing Tolerances

Minimal cuts set

The following table contains the 100 most contributors minimal cutsets.

N°	Order	Probability	Percent	Event	Description
1	1	0.00436	69.5%	E262	Master Control Unit Failure
2	1	0.000334	5.3%	E028	HPU fails
3	1	0.000286	4.6%	E305	Electronic Power Unit Failure

4	1	0.000184	2.9%	E128	PV8 Critical
5	1	0.000184	2.9%	E109	PV5 Critical
6	1	0.000184	2.9%	E118	PV4 Critical
7	1	0.000154	2.4%	E270	Internal Actuator failure
8	1	9.14e-05	1.5%	E131	PV8 Fail to open
9	1	9.14e-05	1.5%	E110	PV5 Fail to open
10	1	9.14e-05	1.5%	E120	PV4 Fail to open
11	1	8.06e-05	1.3%	E111	RV Fail to open
12	1	5.38e-05	0.9%	E113	RV Leak in closed position
13	1	3.58e-05	0.6%	E009	Radial Valve Failure
14	1	3.58e-05	0.6%	E006	Flapper Valve
15	1	2.88e-05	0.5%	E112	RV External Leakage
16	1	2.86e-05	0.5%	E137	Internal Pipes Leaking to outside
17	1	2.4e-05	0.4%	E271	Clamping Actuator Failure
18	1	1.03e-05	0.2%	E005	Excesive Loading
19	1	4.3e-06	0.1%	E138	Internal pipes Blocked
20	1	3.36e-06	0.1%	E130	PV8 External Leakage
21	1	3.36e-06	0.1%	E108	PV5 External Leakage
22	1	3.36e-06	0.1%	E117	PV4 External Leakage
23	1	1.8e-06	0.0%	E141	Filter obstructed
24	1	1.63e-06	0.0%	E010	Sub Body Leaks
25	1	8.23e-07	0.0%	E003	Critical
26	1	8.23e-07	0.0%	E004	Insufficient Make up torque
27	1	1.37e-08	0.0%	E002	Manufacturing Tolerances
28	2	6.65e-09	0.0%	E116	PV2 Fail to close
				E122	PV1 Fail to close
29	2	3.07e-10	0.0%	E116	PV2 Fail to close
				E121	PV1 External Leakage
30	2	2.44e-10	0.0%	E119	PV2 External Leakage
				E122	PV1 Fail to close
31	2	1.13e-11	0.0%	E119	PV2 External Leakage
				E121	PV1 External Leakage

Report 4A: HoD New Standpipe Filling Phase (no Human Error considered)

General information	
Project	Failure HoD without human Error
Version	Finale
Author	Magdalena Vera Chena
Society	
Calculation name	Temporaire
Top gate	HoD4
Mission time	24.0
Limit	

Results	
Probability:	0.00692
System unreliability:	0.0069
Lambda system:	0.000291
Number of failures:	0.0069
System MTTR	24.12

Confidence level analysis

The table below contains the results of the sensitivity analysis to assess the level of confidence in the top gate probability.

Sensitivity analysis	
Average:	6.94e-03
Standard deviation:	1.41e-09
Confidence interval:	6.94e-03
	6.94e-03
Error factor:	1

Importance factors

The table below contains the magnitudes of each of the basic factors of events contributing to the dreaded event.

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E305	Electronic Power Unit Failure	1	0.00029	1	0.042
E010	Sub Body Leaks	1	1.6e-06	1	0.00024
E009	Radial Valve Failure	1	3.6e-05	1	0.0052
E006	Flapper Valve	1	3.6e-05	1	0.0052
E003	Critical	1	8.2e-07	1	0.00012
E005	Excesive Loading	1	1e-05	1	0.0015
E002	Manufacturing Tolerances	1	1.4e-08	1	2e-06
E004	Insufficient Make up torque	1	8.2e-07	1	0.00012
E262	Master Control Unit Failure	1	0.0044	1	0.63
E270	Internal Actuator failure	1	0.00015	1	0.022
E271	Clamping Actuator Failure	1	2.4e-05	1	0.0035
E028	HPU fails	1	0.00033	1	0.048
E236	CV2 Fails	1	1.1e-05	1	0.0016
E220	PV10 External Leakage	1	3.4e-06	1	0.00049
E221	PV10 Critical	1	0.00018	1	0.027
E222	PV10 Fail to open	1	9.1e-05	1	0.013
E223	PV9 External Leakage	1	3.4e-06	1	0.00049
E224	PV9 Fail to close	1	7.3e-05	1	0.011
E209	PV2Fail to close	1	7.3e-05	1	0.011
E207	PV2 External Leakage	1	3.4e-06	1	0.00049
E208	PV1Fail to close	1	7.3e-05	1	0.011
E210	PV1 External Leakage	1	3.4e-06	1	0.00049
E227	PV3 External Leakage	1	3.4e-06	1	0.00049
E228	PV3 Fails to Close	1	7.3e-05	1	0.011

Event	Description	Occurrences	Pr	Birnbaum Index	Fussel Vesely Index
E248	Pipes Blocked	1	4.3e-06	1	0.00062
E245	Pipes Leaking to outside	1	2.9e-05	1	0.0041
E074	Hose failure	1	2.9e-05	1	0.0041
E072	Pipe obstructed	1	4.3e-06	1	0.00062
E065	Pump2 Filter blocked	11	1.8e-06	0.001	2.1e-06
E059	DFP-Pump2 Breakdown	11	0.00012	0.001	0.00014
E032	Breakdown Motor2	11	4.9e-05	0.001	5.7e-05
E033	Fail to start on demand Motor2	11	0.00013	0.001	0.00014
E049	One way valve 2 fails	11	9.7e-05	0.001	0.00011
E036	PSV 2 Degraded	11	0.0002	0.001	0.00023
E038	PSV2 Spurious operation	11	4.3e-05	0.001	4.9e-05
E037	PSV2 Leaks in closed position	11	0.0002	0.001	0.00023
E052	BV2 Low output	11	2.4e-06	0.001	2.8e-06
E054	BV2 Critical Blockage	11	0.00033	0.001	0.00038
E051	BV2 External Leakage	11	9.4e-06	0.001	1.1e-05
E069	Piump1 Filter blocked	11	1.8e-06	0.0012	2.1e-06
E047	One way valve 2 fails	11	9.7e-05	0.0012	0.00011
E039	PSV2 Spurious operation	11	4.3e-05	0.0012	5e-05
E041	PSV 2 Degraded	11	0.0002	0.0012	0.00023
E040	PSV2 Leaks in closed position	11	4.3e-05	0.0012	5e-05
E053	BV1 Critical Blockage	11	0.00033	0.0012	0.00039
E056	BV1 External Leakage	11	9.4e-06	0.0012	1.1e-05
E057	BV1 Low output	11	2.4e-06	0.0012	2.8e-06
E061	DFP-Pump1 Breakdown	11	0.00012	0.0012	0.00014
E035	Fail to start on demand Motor1	11	0.00013	0.0012	0.00015
E034	Breakdown Motor1	11	4.9e-05	0.0012	5.8e-05
E250	Filter	1	1.8e-06	1	0.00026
E190	PV5 Critical	1	0.00018	1	0.027
E191	PV5 Fail to open	1	9.1e-05	1	0.013
E192	PV 5 External Leakage	1	3.4e-06	1	0.00049
E197	PV4 Critical	1	0.00018	1	0.027
E198	PV4 Fail to open	1	9.1e-05	1	0.013
E199	PV4 External Leakage	1	3.4e-06	1	0.00049
E205	PV8 Fail to open	1	9.1e-05	1	0.013
E203	PV8 Critical	1	0.00018	1	0.027
E204	PV8 External Leakage	1	3.4e-06	1	0.00049
E218	PV1 External Leakage	2	3.4e-06	7.6e-05	3.4e-06
E219	PV1 Fail to close	2	7.3e-05	7.6e-05	7.4e-05
E217	PV2 External Leakage	2	3.4e-06	7.6e-05	3.4e-06
E216	PV2 Fail to close	2	7.3e-05	7.6e-05	7.4e-05
E211	RV7 Fail to open	1	8.1e-05	1	0.012
E213	RV7 External Leakage	1	2.9e-05	1	0.0042
E212	RV7 Leak in closed position	1	5.4e-05	1	0.0078
E214	CV1 failure	4	1.1e-05	0.00015	1.1e-05
E194	PV3 Fails to close	1	7.3e-05	1.1e-05	7.3e-05
E193	PV3 External Leakage	1	3.4e-06	1.1e-05	3.4e-06
E196	PV3 Fails to close	1	7.3e-05	1.1e-05	7.3e-05
E195	PV3 External Leakage	1	3.4e-06	1.1e-05	3.4e-06
E244	Pipes Blocked	1	4.3e-06	1	0.00062
E242	Pipes Leaking to outside	1	2.9e-05	1	0.0041

Qualitative Analysis

The following table contains the total number of min cuts per order.

Order	Quantity
1	43
2	129

Minimal cuts of order 1

The table below contains all the min cuts of order 1.

N°	Order	Probability	Percent	Event	Description
1	1	0.00436	62.8%	E262	Master Control Unit Failure
2	1	0.000334	4.8%	E028	HPU fails
3	1	0.000286	4.1%	E305	Electronic Power Unit Failure
4	1	0.000184	2.7%	E221	PV10 Critical
5	1	0.000184	2.7%	E190	PV5 Critical
6	1	0.000184	2.7%	E197	PV4 Critical
7	1	0.000184	2.7%	E203	PV8 Critical
8	1	0.000154	2.2%	E270	Internal Actuator failure
9	1	9.14e-05	1.3%	E222	PV10 Fail to open
10	1	9.14e-05	1.3%	E191	PV5 Fail to open
11	1	9.14e-05	1.3%	E198	PV4 Fail to open
12	1	9.14e-05	1.3%	E205	PV8 Fail to open
13	1	8.06e-05	1.2%	E211	RV7 Fail to open
14	1	7.27e-05	1.0%	E224	PV9 Fail to close
15	1	7.27e-05	1.0%	E209	PV2Fail to close
16	1	7.27e-05	1.0%	E208	PV1Fail to close
17	1	7.27e-05	1.0%	E228	PV3 Fails to Close
18	1	5.38e-05	0.8%	E212	RV7 Leak in closed position
19	1	3.58e-05	0.5%	E009	Radial Valve Failure
20	1	3.58e-05	0.5%	E006	Flapper Valve
21	1	2.88e-05	0.4%	E213	RV7 External Leakage
22	1	2.86e-05	0.4%	E245	Pipes Leaking to outside
23	1	2.86e-05	0.4%	E074	Hose failure
24	1	2.86e-05	0.4%	E242	Pipes Leaking to outside
25	1	2.4e-05	0.3%	E271	Clamping Actuator Failure
26	1	1.09e-05	0.2%	E236	CV2 Fails
27	1	1.03e-05	0.1%	E005	Excesive Loading
28	1	4.3e-06	0.1%	E248	Pipes Blocked
29	1	4.3e-06	0.1%	E072	Pipe obstructed
30	1	4.3e-06	0.1%	E244	Pipes Blocked
31	1	3.36e-06	0.0%	E220	PV10 External Leakage
32	1	3.36e-06	0.0%	E223	PV9 External Leakage
33	1	3.36e-06	0.0%	E207	PV2 External Leakage
34	1	3.36e-06	0.0%	E210	PV1 External Leakage
35	1	3.36e-06	0.0%	E227	PV3 External Leakage
36	1	3.36e-06	0.0%	E192	PV 5 External Leakage
37	1	3.36e-06	0.0%	E199	PV4 External Leakage
38	1	3.36e-06	0.0%	E204	PV8 External Leakage
39	1	1.8e-06	0.0%	E250	Filter
40	1	1.63e-06	0.0%	E010	Sub Body Leaks
41	1	8.23e-07	0.0%	E003	Critical
42	1	8.23e-07	0.0%	E004	Insufficient Make up torque
43	1	1.37e-08	0.0%	E002	Manufacturing Tolerances

Minimal cuts set

The following table contains the 100 most contributors minimal cutsets.

N°	Order	Probability	Percent	Event	Description
1	1	0.00436	62.8%	E262	Master Control Unit Failure
2	1	0.000334	4.8%	E028	HPU fails
3	1	0.000286	4.1%	E305	Electronic Power Unit Failure
4	1	0.000184	2.7%	E221	PV10 Critical
5	1	0.000184	2.7%	E190	PV5 Critical
6	1	0.000184	2.7%	E197	PV4 Critical
7	1	0.000184	2.7%	E203	PV8 Critical
8	1	0.000154	2.2%	E270	Internal Actuator failure

N°	Order	Probability	Percent	Event	Description
9	1	9.14e-05	1.3%	E222	PV10 Fail to open
10	1	9.14e-05	1.3%	E191	PV5 Fail to open
11	1	9.14e-05	1.3%	E198	PV4 Fail to open
12	1	9.14e-05	1.3%	E205	PV8 Fail to open
13	1	8.06e-05	1.2%	E211	RV7 Fail to open
14	1	7.27e-05	1.0%	E224	PV9 Fail to close
15	1	7.27e-05	1.0%	E209	PV2Fail to close
16	1	7.27e-05	1.0%	E208	PV1Fail to close
17	1	7.27e-05	1.0%	E228	PV3 Fails to Close
18	1	5.38e-05	0.8%	E212	RV7 Leak in closed position
19	1	3.58e-05	0.5%	E009	Radial Valve Failure
20	1	3.58e-05	0.5%	E006	Flapper Valve
21	1	2.88e-05	0.4%	E213	RV7 External Leakage
22	1	2.86e-05	0.4%	E245	Pipes Leaking to outside
23	1	2.86e-05	0.4%	E074	Hose failure
24	1	2.86e-05	0.4%	E242	Pipes Leaking to outside
25	1	2.4e-05	0.3%	E271	Clamping Actuator Failure
26	1	1.09e-05	0.2%	E236	CV2 Fails
27	1	1.03e-05	0.1%	E005	Excesive Loading
28	1	4.3e-06	0.1%	E248	Pipes Blocked
29	1	4.3e-06	0.1%	E072	Pipe obstructed
30	1	4.3e-06	0.1%	E244	Pipes Blocked
31	1	3.36e-06	0.0%	E220	PV10 External Leakage
32	1	3.36e-06	0.0%	E223	PV9 External Leakage
33	1	3.36e-06	0.0%	E207	PV2 External Leakage
34	1	3.36e-06	0.0%	E210	PV1 External Leakage
35	1	3.36e-06	0.0%	E227	PV3 External Leakage
36	1	3.36e-06	0.0%	E192	PV 5 External Leakage
37	1	3.36e-06	0.0%	E199	PV4 External Leakage
38	1	3.36e-06	0.0%	E204	PV8 External Leakage
39	1	1.8e-06	0.0%	E250	Filter
40	1	1.63e-06	0.0%	E010	Sub Body Leaks
41	1	8.23e-07	0.0%	E003	Critical
42	1	8.23e-07	0.0%	E004	Insufficient Make up torque
43	2	1.11e-07	0.0%	E053	BV1 Critical Blockage
				E054	BV2 Critical Blockage
44	2	6.61e-08	0.0%	E036	PSV 2 Degraded
				E053	BV1 Critical Blockage
45	2	6.61e-08	0.0%	E037	PSV2 Leaks in closed position
				E053	BV1 Critical Blockage
46	2	6.61e-08	0.0%	E041	PSV 2 Degraded
				E054	BV2 Critical Blockage
47	2	4.19e-08	0.0%	E033	Fail to start on demand Motor2
				E053	BV1 Critical Blockage
48	2	4.19e-08	0.0%	E035	Fail to start on demand Motor1
				E054	BV2 Critical Blockage
49	2	4e-08	0.0%	E053	BV1 Critical Blockage
				E059	DFP-Pump2 Breakdown
50	2	4e-08	0.0%	E054	BV2 Critical Blockage
				E061	DFP-Pump1 Breakdown
51	2	3.93e-08	0.0%	E036	PSV 2 Degraded
				E041	PSV 2 Degraded
52	2	3.93e-08	0.0%	E037	PSV2 Leaks in closed position
				E041	PSV 2 Degraded
53	2	3.23e-08	0.0%	E049	One way valve 2 fails
				E053	BV1 Critical Blockage
54	2	3.23e-08	0.0%	E047	One way valve 2 fails
				E054	BV2 Critical Blockage
55	2	2.49e-08	0.0%	E033	Fail to start on demand Motor2
				E041	PSV 2 Degraded
56	2	2.49e-08	0.0%	E035	Fail to start on demand Motor1

N°	Order	Probability	Percent	Event	Description
				E036	PSV 2 Degraded
57	2	2.49e-08	0.0%	E035	Fail to start on demand Motor1
				E037	PSV2 Leaks in closed position
58	2	2.38e-08	0.0%	E041	PSV 2 Degraded
				E059	DFP-Pump2 Breakdown
59	2	2.38e-08	0.0%	E036	PSV 2 Degraded
				E061	DFP-Pump1 Breakdown
60	2	2.38e-08	0.0%	E037	PSV2 Leaks in closed position
				E061	DFP-Pump1 Breakdown
61	2	1.92e-08	0.0%	E041	PSV 2 Degraded
				E049	One way valve 2 fails
62	2	1.92e-08	0.0%	E036	PSV 2 Degraded
				E047	One way valve 2 fails
63	2	1.92e-08	0.0%	E037	PSV2 Leaks in closed position
				E047	One way valve 2 fails
64	2	1.65e-08	0.0%	E032	Breakdown Motor2
				E053	BV1 Critical Blockage
65	2	1.65e-08	0.0%	E034	Breakdown Motor1
				E054	BV2 Critical Blockage
66	2	1.58e-08	0.0%	E033	Fail to start on demand Motor2
				E035	Fail to start on demand Motor1
67	2	1.51e-08	0.0%	E035	Fail to start on demand Motor1
				E059	DFP-Pump2 Breakdown
68	2	1.51e-08	0.0%	E033	Fail to start on demand Motor2
				E061	DFP-Pump1 Breakdown
69	2	1.44e-08	0.0%	E059	DFP-Pump2 Breakdown
				E061	DFP-Pump1 Breakdown
70	2	1.42e-08	0.0%	E038	PSV2 Spurious operation
				E053	BV1 Critical Blockage
71	2	1.42e-08	0.0%	E039	PSV2 Spurious operation
				E054	BV2 Critical Blockage
72	2	1.42e-08	0.0%	E040	PSV2 Leaks in closed position
				E054	BV2 Critical Blockage
73	1	1.37e-08	0.0%	E002	Manufacturing Tolerances
74	2	1.22e-08	0.0%	E033	Fail to start on demand Motor2
				E047	One way valve 2 fails
75	2	1.22e-08	0.0%	E035	Fail to start on demand Motor1
				E049	One way valve 2 fails
76	2	1.16e-08	0.0%	E047	One way valve 2 fails
				E059	DFP-Pump2 Breakdown
77	2	1.16e-08	0.0%	E049	One way valve 2 fails
				E061	DFP-Pump1 Breakdown
78	2	9.8e-09	0.0%	E032	Breakdown Motor2
				E041	PSV 2 Degraded
79	2	9.8e-09	0.0%	E034	Breakdown Motor1
				E036	PSV 2 Degraded
80	2	9.8e-09	0.0%	E034	Breakdown Motor1
				E037	PSV2 Leaks in closed position
81	2	9.35e-09	0.0%	E047	One way valve 2 fails
				E049	One way valve 2 fails
82	2	8.47e-09	0.0%	E036	PSV 2 Degraded
				E039	PSV2 Spurious operation
83	2	8.47e-09	0.0%	E036	PSV 2 Degraded
				E040	PSV2 Leaks in closed position
84	2	8.47e-09	0.0%	E038	PSV2 Spurious operation
				E041	PSV 2 Degraded
85	2	8.47e-09	0.0%	E037	PSV2 Leaks in closed position
				E039	PSV2 Spurious operation
86	2	8.47e-09	0.0%	E037	PSV2 Leaks in closed position
				E040	PSV2 Leaks in closed position
87	2	6.22e-09	0.0%	E032	Breakdown Motor2

N°	Order	Probability	Percent	Event	Description
				E035	Fail to start on demand Motor1
88	2	6.22e-09	0.0%	E033	Fail to start on demand Motor2
				E034	Breakdown Motor1
89	2	5.93e-09	0.0%	E034	Breakdown Motor1
				E059	DFP-Pump2 Breakdown
90	2	5.93e-09	0.0%	E032	Breakdown Motor2
				E061	DFP-Pump1 Breakdown
91	2	5.37e-09	0.0%	E033	Fail to start on demand Motor2
				E039	PSV2 Spurious operation
92	2	5.37e-09	0.0%	E033	Fail to start on demand Motor2
				E040	PSV2 Leaks in closed position
93	2	5.37e-09	0.0%	E035	Fail to start on demand Motor1
				E038	PSV2 Spurious operation
94	2	5.29e-09	0.0%	E216	PV2 Fail to close
				E219	PV1 Fail to close
95	2	5.13e-09	0.0%	E039	PSV2 Spurious operation
				E059	DFP-Pump2 Breakdown
96	2	5.13e-09	0.0%	E040	PSV2 Leaks in closed position
				E059	DFP-Pump2 Breakdown
97	2	5.13e-09	0.0%	E038	PSV2 Spurious operation
				E061	DFP-Pump1 Breakdown
98	2	4.78e-09	0.0%	E032	Breakdown Motor2
				E047	One way valve 2 fails
99	2	4.78e-09	0.0%	E034	Breakdown Motor1
				E049	One way valve 2 fails