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Human related root causes behind oil well drilling accidents

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ABSTRACT

Many accident investigation techniques and other methods used by the petroleum industry today list a set of underlying human related causes and subsequent improvement suggestions. Do these techniques address the root cause behind the problem so that the appropriate initiatives can be implemented? The focus of the present thesis was to determine the human related root cause of two major accidents in the North Sea. This in order to give recommendations to improve the safety levels in the organisation. In order to achieve the above-mentioned goals, the IPT Knowledge Model was adapted to the given accidents. The data input into the model was based on interpreted observations from former investigation reports. The analysis of the blowout on Snorre A and the well control incident on Gullfaks C resulted in 49 and 63 observations respectively. For both accidents, the Human Factor that was indicated to have the largest affect on the accidents was Training and Competence (29% for Snorre A and 19% for Gullfaks C). Lack of competence was indicated as the majority subclass. Collectively, management and supervision, or lack thereof, was also indicated as being a contributing factor to the accidents. These final results coincide with the findings in other investigation reports. However, these are more acute, indicating a specific area of improvement within the company. By increasing the competency levels within the company and ensuring that the leaders and management have the proper tools to follow-up their employees and their operations, the safety levels and safety culture will improve.

SAMMENDRAG

Mange ulykkesgranskningsteknikker og metoder som benyttes av petroleumsindustrien idag lister et sett med underliggende menneskelige årsaker og påfølgende forslag til forbedringer. Har disse teknikkene behandlet roten til årsaken til problemet slik at de riktige tiltakene kan iverksettes? Fokuset i denne avhandlingen var å finne den grunnleggende årsaken til to store ulykker i Nordsjøen for deretter å gi anbefalinger som kan forbedre sikkerhetsnivået i selskapet. For å oppnå de overnevnte målene, ble IPT Kunnskapsmodell utvidet for de gitte ulykkene. Tolkede observasjoner fra tilgjengelige granskningsrapporter ble benyttet som et grunnlag for analysen. Analysen av utblåsningen på Snorre A og brønnkontroll hendelsen på Gullfaks C resulterte i henholdsvis 49 og 63 observasjoner. Opplæring og kompetanse var den menneskelige faktoren som ble angitt å ha størst innvirkning på begge ulykker (29% for Snorre A og 19% for Gullfaks C). Manglende kompetanse var indikert som den underklassen med størst betydning. Sammenlagt var ledelse og styring, eller mangelen på, også indikert som en medvirkende faktor til ulykkene. Disse samsvarer med resultatene i andre granskningsrapporter. Resultatene her er dog mer tilspisset og gir da et konkret område som behøver forbedring.Ved å øke kompetansen blant de ansatte i selskapet og sikre at ledere og ledelsen har de riktige verktøyene for å følge opp sine ansatte og operasjoner, kan sikkerhetsnivået og sikkerhetskulturen forbedres.

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Trondheim, December 2012

Marthe Pernille Voltersvik Hernæs

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1. INTRODUCTION

"To err is human" (Arnstein 1997)

1.1. MOTIVATION

Many accident investigation reports (Austnes-Underhaug et. al. 2005; Schiefloe et. al. 2005; Gundersen et. al. 2010; Talberg et. al. 2010) list a set of both the triggering and underlying causes of the accidents. The triggering causes are often of a technical nature, whilst the underlying causes relate to aspects of human error. The companys own internal investigation reports (Kjeldstad et. al. 2005; Schiefloe et. al. 2005; Talberg et. al. 2010) list, based on the causal findings, a set of actions or initiatives to be implemented within both the given department and the company in its entirety. Are these causes detailed enough to allow efficient implementation of organisational change? Do the methods used today define the root cause of an accident in such a manner that sufficient changes can be made to counteract the challenge? Or are they too simple in their conclusions resulting in initiatives being implemented across the board?

"Human errors account for all errors and failures in offshore related operations if the chain of cause-effect is pursued deeply enough" (Skalle and Busch 2012).

Over time, the industry's attention has moved from the immediate causes (often human error) and over to the challenge relating to organisation and management (Hovden et. al. 2012). However, the industry lacks consensus of what organisational dimensions that are relevant to address (Thunem et. al. 2009).

Technical errors are somehow less complex to deal with than human errors, as they are easier to define. However, the release of technical errors is largely influenced by organisational culture and human errors. By understanding which human errors have the largest effect on mistakes, slips and lapses, management is able to concentrate their attention on the correct organisational change instead of implementing initiatives across the board.

After the ballast tank on Floatel Superior, 7 November 2012, in the Njord field in the North Sea, was damaged causing the installation to list, many professionals have released to the media their concern with how the Norwegian Petroleum Safety Authority (PSA) and the oil industry work with Quality, Health, Safety and Environment (Q-HSE). The listing of Floatel Superior happened only months after the same incident occurred on Scarabeo 8 in the Barents Sea. The industry is challenged by the ability to learn from previous mistakes.

The environmental organisation, Bellona, stated to Aftenposten on 7 November 2012 (Kvilesjø and Seglem 2012) that what happened in early morning on 7 November, should not have happen. It is likely that there have been violations of regulations. Either the owner or the operator has been inattentive or the Norwegian supervisory system grants dispensations too easily, which should never have been granted. Bellona has been working actively to ensure that PSA intensify its supervisory activities on the Norwegian Continental Shelf, they fear that an organisational culture of granting dispensations has evolved from the Norwegian government.

Bellona continues to state that the accident potential for offshore Norway is too large. With better investigation techniques the industry may be able to change the negative trend in a positive direction. Any written rules, regulations or plans can best be evaluated when an accident occurs; learning from previous mistakes can lead to updated and more reliable versions. The weaknesses are then detected, sufficient countermeasures issued and the new realisation can be entered into existing documents, which can then be revised and updated.

1.2. GOALS

The goal of present thesis is two-fold:

1. Determine which Human Factor has had the largest influence on the two accidents within the company. The root cause is defined as the highest concentration of weighted relationships between observations and potential errors / failures

2. Improve safety levels in the organisation during drilling operations, based on findings in goal one.

1.3. APPROACH

The present thesis is presented in cooperation with NTNU and Statoil ASA (later referred to as Statoil) regarding Human Factors effect on their accidents. Throughout the Specialisation Project titled *Human Aspects in Major Accidents* (Hernæs 2012), basic knowledge was gained as to the importance of managing human error. The present thesis builds on this knowledge resulting in a more comprehensive analysis. The analysis and results presented by Hernæs (2012) was a simplified version of the one completed here, making those results less reliable.

The accident investigation models applied by the petroleum industry in Norway today are assessed according to the goals of the present thesis and a model is chosen for application. One example of accident investigation modelling is the Knowledge Model developed at the Department of Petroleum Engineering and Applied Geophysics at NTNU.

This model is further developed and fine-tuned according to the findings made during the specialisation project. The goal of the model development is to create a more conclusive and comprehensive model, thus resulting in more reliable conclusions.

The analysis phase will evaluate two accidents, the blowout on Snorre A in 2004 and the well control incident on Gullfaks C in 2010. The scope of the present thesis limits the field data to accident investigation reports, both internally in Statoil and externally by PSA and the International Research Institute in Stavanger (IRIS). These findings will allow us to conclude with what Human Factor had the largest effect on the accidents, separately as well as combined. When completing this analysis, it will be possible to conclude with which Human Factor has the largest affect on how the company operates.

Based on the results, suggestions will be made in order to improve the safety levels within the organisation in order to prevent or minimize the effect of the next major accident.

2. EXISTING MODELS FOR ACCIDENT INVESTIGATION

This chapter presents examples of accident investigation models that are applied by the industry today. Table 3 in chapter 2.3 lists what company applies the different models in their accident investigations. This is presented to give the reader an introduction to state of the art accident investigation techniques and a broader perspective of the challenges.

2.1. INTRODUCTION TO ACCIDENT INVESTIGATION

NORSOK (2001) defines an accident as an acute unwanted and unplanned event or chain of events resulting in loss of lives or injury to health, environment or financial values. Another way of putting it is energy gone astray (Hovden et. al. 2012). What differentiates two accidents is primarily the type and amount of energy astray.

Hovden et. al. (2012) exemplifies this by comparing that of a little girl climbing a tree and falling down to the Chernobyl disaster in 1986. Inadequate education and training to master the task both for the operator in Chernobyl and the girl in the tree, failure of management- and control systems (the girls parents have been negligent, in the same way as the management of the nuclear power plant and the government in Moscow), barrier failure, experimentation, testing of boundaries for behaviour/operations and more.

The knowledge of accidents is important in order to operate with efficient risk management and preventative work. In order to increase the knowledge of accidents, they must be investigated. Accident investigation models aim to simplify complex events to something tangible and understandable. This maintains the most significant characteristics of an accident, what is unique and what it has in common with other accidents.

Sklet (2002) defines the purpose of accident investigation as:

1. Identify and describe the true chain of events
2. Identify the direct cause of the accident
3. Identify risk reducing measures to prevent similar accidents/incidents in the future
4. Identify need for prosecution
5. Evaluate the question of guilt and responsibility in relation to liability

The present thesis focuses on issues 1.–3. as they are the most relevant based on the goals presented in chapter 1.2. By completing 1. and 2. the root cause of the two accidents can be defined. 3. allows us to work towards our goal of improving safety levels in the organisation. The responsibility of identifying the need for prosecution and liability lies in the hands of government agencies or the company itself and will not be addressed here.

In order to achieve the purpose of accident investigation, a set of procedures need to be implemented. Figure 1 shows Cacciabue´s (2004) guideline to accident investigation. This process has been simplified according to the scope of the present thesis. Originally there were 7 steps, but two steps have been eliminated [select models of organisation and Human Machine Interaction (HMI) and evaluate organisation by ethnographic studies and Cognitive Task Analysis (CTA)]. This is because they are considered too complex compared to the goals of the present thesis. The goal of finding the root cause does not require multiple models or an ethnographic study into the specific culture.

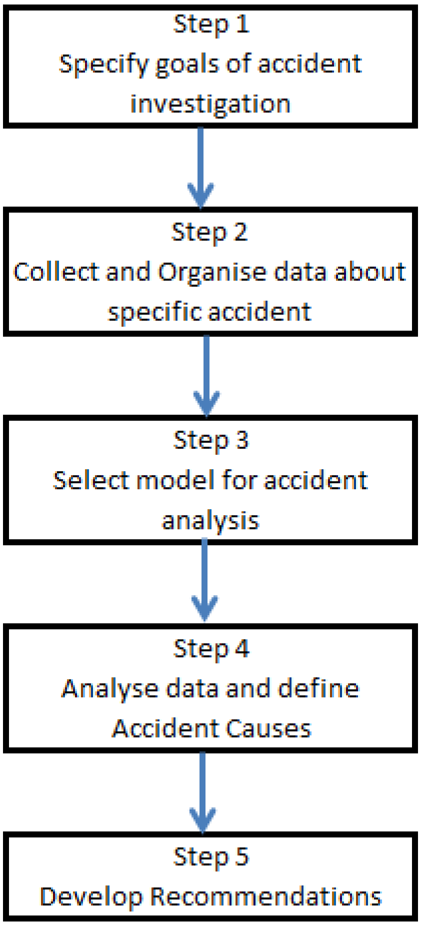

Figure 1 - Stepwise procedure for accident investigation (redrawn from Cacciabue 2004)

Cacciabue (2004) differentiates between accident investigation/analysis and root cause analysis (RCA). RCA does not solely investigate the accident in question but also previous events leading up to the accident. Consequently, it focuses more on the evaluation of cause and effect of the specific incident.

Related to Human Factors (HF) evaluation of the reasons and causes behind a single inappropriate performance or error constitutes the RCA of an event. Any irregularity regarding human behaviour is addressed when taking HFs into account through accident investigation.

One of the challenges for accident investigation models is the difficulty of including the complexity and dynamics of the organisation into the model (Thunem et. al. 2009). There are a number of available accident investigation models that include organisational factors in their analysis, a selection of them are presented in chapter 2.2.

2.2. MODELS

The challenge with finding good models is the balance between models that are too simple and merely conclude with the obvious result and models that are too complex for practicality (Thunem et. al. 2009). The accidents have been selected and data collected (presented in chapter 4), in order to complete step 3: Select model for accident analysis. Six models are presented below used in accident investigation in technical industries. Based on the information given below the model of best fit regarding the scope of the present thesis will be accepted. There are several criteria for accepting a model to apply in the present thesis, the main criteria are:

- That the results determine the root human error
- That the model has not previously been applied to the accidents in question
- That there is limited necessity for training and education
- That the model does not require software

A comparison of the models based on the list above can be found in Table 4 in chapter 2.4.

Tinnmannsvik et. al. (2004) has summarized these models, other references used are accredited in each sub-chapter.

2.2.1. Man-Technology-Organisation

The idea behind Man-Technology-Organisation (MTO) analysis is that the human, technological and organisational factors are given equal attention during accident investigation. MTO analysis is based on what is internationally known as Human Performance Evaluation System (HPES).

MTO-analysis is executed based on the following four methods (Holmefjord and Nielsen 2002):

1. Perform a structured analysis using an event- and cause-diagram.

2. Perform a change analysis by characterizing how the events of the given incident/accident deviated from standard/normal practice.
3. Perform a barrier analysis by identifying what technical, human or organisational barriers have been lacking or broken.
4. Identify the cause of the incident/accident, including any relevant MTO factors.

A barrier is defined as all the organisational, operational and administrative protections (Holmefjord and Nielsen 2002) available in the organisation and/or a specific workplace to prevent or limit consequences of mistakes and erroneous actions. Examples are regulations, safety systems and procedures (Tinmannsvik et.al. 2004).

The MTO-analysis worksheet is shown in Figure 2. Based on the four methods presented above an MTO-analysis is performed by completing the following four steps (Tinmannsvik et. al. 2004):

1. The event sequence is developed longitudinally and illustrated in a block diagram. Possible technical and human related causes of each event should be identified and drawn, connected vertically to its coinciding event.
2. A change analysis is made by distinguishing between normal situations and deviations, these are drawn in vertically above the causes in the worksheet.
3. An analysis of the failed or missing barriers is completed and illustrated below the chain of events.
4. Realistic and specific recommendations regarding technical, human and organisational factors are presented based on the findings throughout this analysis.

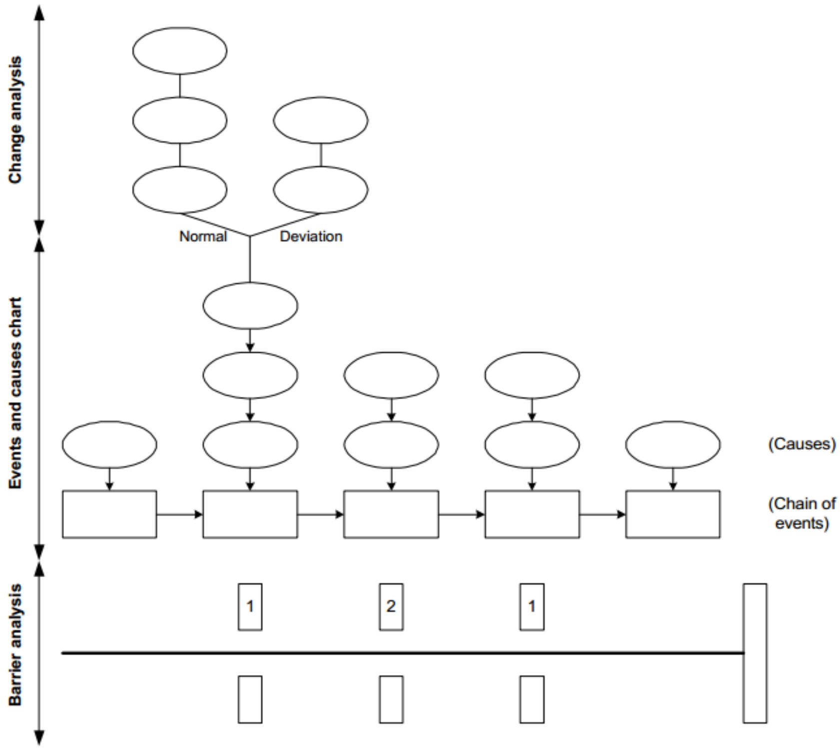

Figure 2 - MTO-analysis worksheet (Tinmannsvik et. al. 2004)

A checklist is used in order to identify underlying causes of failed or missing barriers, the key points are (Tinmannsvik et. al 2004):

- Work environment
- Work organisation
- Routines regarding change operations
- Company management/Platform organisation
- Ergonomics – inadequate technique
- Shift work
- Communication
- Written instruction
- Work management
- Common practice/individuals
- Training and competence

The main goal of MTO analysis is to keep the operators focused on preventing the next accident. Causes must be identified to such an extent that it is possible to implement effective preventative measures (Holmefjord and Nielsen 2002).

2.2.2. TRIPOD

The main principal behind the TRIPOD concept is that the primary cause of accidents is organisational failure. Organisational failure is a latent error and as a contributor to accidents it is followed by numerous technical and human errors.

The TRIPOD model is shown in Figure 3.

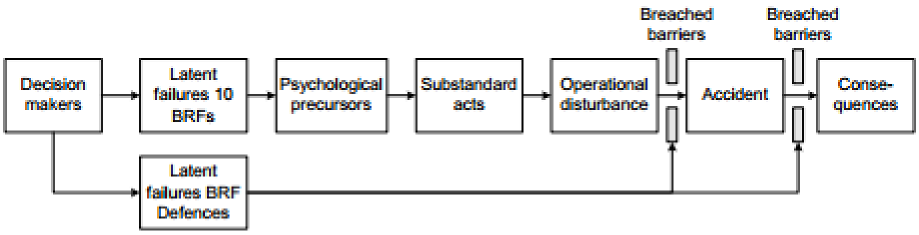

Figure 3 - TRIPOD model (Tinmannsvik et. al. 2004)

Acts and situations of a substandard nature are developed by mechanisms in an organisation, they do not just occur. The underlying mechanisms, often from decisions made higher up in the organisation, are referred to as Basic Risk Factors (BRF). BRFs may lead to substandard activities by generating differing psychological precursors. Psychological precursors may be exemplified in the form of slips, lapses and violations due to pressure regarding time, poorly motivated workers or depression. By eliminating or reducing the consequences of latent errors, psychological precursors will be prevented thus resulting in accident prevention.

Table 1 shows the 11 BRFs used in this model. These cover technical, human and organisational issues. BRF 1-5 are specific BRFs, whilst 6-10 are generic, all of these being preventive BRFs. BRF 11 is a mitigation BRF and refers to controlling the effect of an operational disturbance once it has occurred.

Table 1 - Definition of BRFs in TRIPOD (Tinmannsvik et. al. 2004)

No	Basic Risk Factor	Abbr.	Definition
1	Design	DE	Ergonomically poor design of tools or equipment (user-unfriendly)
2	Tools and equipment	TE	Poor quality, condition, suitability or availability of materials, tools, equipment and components
3	Maintenance management	MM	No or inadequate performance of maintenance tasks and repairs
4	Housekeeping	HK	No or insufficient attention given to keeping the work floor clean or tidied up
5	Error enforcing conditions	EC	Unsuitable physical performance of maintenance tasks and repairs
6	Procedures	PR	Insufficient quality or availability of procedures, guidelines, instructions and manuals (specifications, "paperwork", use in practice)
7	Training	TR	No or insufficient competence or experience among employees (not sufficiently suited/inadequately trained)
8	Communication	CO	No or ineffective communication between the various sites, departments or employees of a company or with the official bodies
9	Incompatible goals	IG	The situation in which employees must choose between optimal working methods according to the established rules on one hand, and the pursuit of production, financial, political, social or individual goals on the other
10	Organisation	OR	Shortcomings in the organisation's structure, organisation's philosophy, organisational processes or management strategies, resulting in inadequate or ineffective management of the company
11	Defences	DF	No or insufficient protection of people, material and environment against the consequences of the operational disturbances.

2.2.3. Safety through Organisational Learning

Safety through Organisational Learning (SOL) uses standardised steps in order to develop event analysis. It is a system used to learn from previous events in order to prevent future ones, adopted from the German and Swiss nuclear industry (Becker *unknown year*). Three guidelines are used to support the event analysis:

1. *Description of situation*

As soon as an event has occurred, it should be described by breaking it down into a chain of events. This means that the event is broken down into single actions with different actors (person or object involved). This stage is solely to create event building blocks as a basis for future analysis and no causes or contributing factors should be acknowledged here. This process is similar to the STEP model.

The goal of Sequentially Timed Event Plotting (STEP) was developed in order to give a realistic description of the chain of events, not focusing on the cause. The goal of the method is two-fold; graphic portrayal of the chain of events and identify and consider necessary actions. Chain of events is presented by a time axis (x-axis at top) and an actor axis (y-axis down) as shown in Figure 4. The actor is any person or object/machine involved in the accident. Safety issues are then identified, followed by reasoned recommendations of initiatives to be implemented.

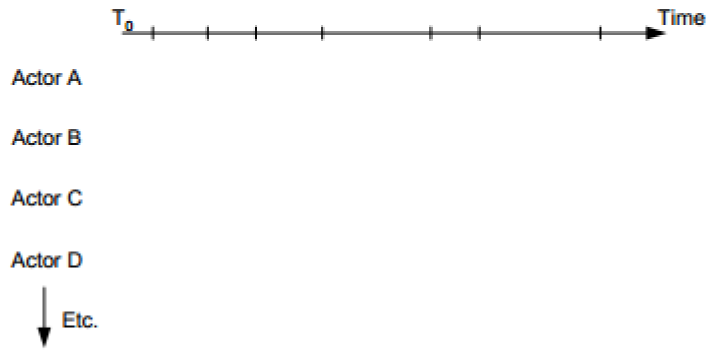

Figure 4 - STEP worksheet (Tinmannsvik et. al. 2004)

STEP is constructed of four concepts:

1. Several activities occur simultaneously. This means that neither the incident nor the following investigation consists of one chain of events, but many.
2. The Building Block format is used to display the accident description. One building block equals one event.
3. Events are displayed and flow logically in the worksheet. Arrows illustrate flow.
4. Processes regarding production and accidents are similar and can therefore be investigated similarly. Both involve actions with coinciding actors and may be repeated, once understanding is in place.

When applying the SOL model, a sequence of single actions by differing actors between start and finish determine the accidental event. The start of an accidental event is defined by an alarm or perception of a deviation/discrepancy from acceptable course of action. The finish point or end of an accidental event is when all systems are back on track in a safe system state.

2. *Identifying contributing factors (CF)*

This guideline features the next step in the analysis, when every action has a corresponding actor in the building block. In this step every action is analysed and questions regarding why it occurred are brought up. The building block is here completed by identifying and adding CFs that can be complemented by adding more CFs. The five subsystems related to CFs are shown in Figure 5. Now, a graphical representation of sequence of events and all contributing factors is presented in its entirety and complexity.

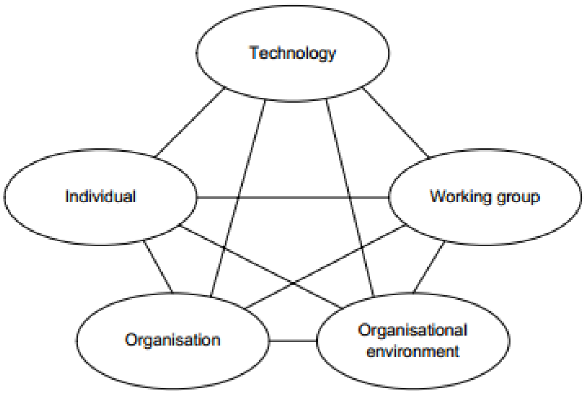

Figure 5 - Socio-technical system model of event genesis (Tinmannsvik et. al. 2004)

This model differentiates between direct and indirect CFs. Examples of direct CFs are *information*, *communication* and *working conditions* whilst indirect CFs may be exemplified as *operation scheduling*, *responsibility* and *control and supervision*.

The comprehensiveness of the analysis is ensured by general questions in the aid relating to possible CFs. I.e. contributing factor *working conditions* has the corresponding general question *"Could operator performance been influenced by the working conditions at the time of the event?"*

3. *Reporting*

This guideline is not described further in the present thesis as the system for reporting is not relevant for the process used in analysing the accident.

These three guidelines ensure a standardised process without preventing mobilization of expertise and creativity.

2.2.4. Management Oversight Risk Tree

Management Oversight Risk Tree (MORT) allows for a systematic approach to a comprehensive accident investigation. Investigators can, by using MORT, identify discrepancies and/or deficiencies of specific control or management system factors (Tinmannsvik et. al. 2004). Identifying and evaluating these deficiencies can identify the causal factors of the accident. MORT is an analytical process that determines causes and CFs of incidents/accidents (ICMA 2011).

The basis for MORT analysis is a graphical checklist designed to answer generic questions using the information available. It requires extensive training of the investigators in order for them to have the high level of competency required to execute such an analysis. The analysis starts with choosing which MORT form to use, depending on the safety program being analysed (Tinmannsvik et. al. 2004). The investigators work their way down the tree, level by level, and when a sufficient part of the tree has been analysed the cause and effect may easily be traced. The tree highlights which areas need auditing and actions to prevent a similar accident.

MORT defines accidents as unplanned events resulting in losses, i.e. producing harm (ICMA 2011). These losses arise in the interface between a person/asset and a harmful agent. MORT differentiates between causal types; failure of prevention or an acceptable, yet unfortunate, result of a risk well analysed and compensated for, namely an assumed risk. The failure of prevention is always analysed prior to deliberating the assumed risks.

Firstly, key episodes are identified, in order to do so a barrier analysis is performed in order to focus the analysis. International Crisis Management Association (ICMA) recommends that MORT analysis only be used when completing it will add value to investigation (ICMA 2011). In order to perform such analysis, the investigator must be familiar with the system and have performed accident investigation using this method at least once before. This recommendation is presented in order for the investigator to be able to be in such a position that he/she can make sound judgements.

MORT analysis is a time consuming and costly process and is mainly used for the highest risks or operation critical activities.

2.2.5. Root Cause Analysis

Information regarding RCA is obtained from Sklet (2002).

Root Cause Analysis (RCA) identifies the underlying faults in a companys safety management system. When these faults or deficiencies are corrected the same or a similar incident will be prevented.

RCA is executed by using the results found from the previous presented models and from this find the largest contributing factor to the accident. The other models provide an answer to the questions of what, when, who, where and how and RCA takes this and answers the question of why, finding one reason. This form of analysis requires judgement and comprehension.

2.2.6. IPT Knowledge Model

Information presented below is obtained from Skalle and Busch (2012), Skalle (2012) and Hernæs (2012).

As per October 2012 the IPT Knowledge Model (KM) includes 9 different themes for analysis. These include human error, technical error, drilling parameter and so on. As the scope of the present thesis focuses on finding the human related root cause, the rest of the model is presented here solely based on the theme human error.

To initiate the analysis, all information available related to the accident must be made available. Now steps 1-3 of the stepwise procedure for accident investigation is completed (Figure 1, Chapter 2.1) and step 4: Analyse data and define accident causes, can be initiated.

The first step is to list all *observations*. An *observation* can be defined as any discrepancy, deficiency, non-compliance or similar present during planning and execution of the operation.

Examples of *observations* may be:

1. *"Risk register did not reflect the risk analyses and discussions in the planning group."*[1]
2. *"Drilling contractor not involved in planning of operations"*[2]

These are both examples of unwanted behaviour from involved personnel. No observation is too small or insignificant; any aspect of the operation that is not ideal should be registered as an *observation*. Later the effect the different observations have on an accident will be seen.

When all *observations* are registered they must be translated into *symbolic concepts*. A *symbolic concept* is a short sentence, which simplifies the *observation* into its essence. The circumstances are eliminated and the actual error is left. This makes the assignment easier for the investigator. Each *observation* may have more than one symbolic concept.

Examples of *symbolic concepts* (continuing from example above):

1. *"Inadequate documentation."*
2. *"Inadequate use of essential resources in planning."*

The symbolic concepts are then set in relation to a predetermined list of subclasses of HF and thus set in relation to a given HF. As for observations having more than one symbolic concept, the symbolic concept can be set in relation to several subclasses.

Throughout the process from observation to HF the numerical relationships must be analysed. There is no relation between observation and symbolic concept as these are rewritten versions of the first and the relation would therefore be 1.0. Subclasses are defined to have relation strength 0.9. The other relationships are based on the values given in Table 2.

[1] Observation made from the well control incident on GFC
[2] Observation made from the blowout on SNA

Table 2 - Relations and numerical values (free after Skalle 2012)

Relation	Numerical value
Causes always	1.0
Causes (typically)	0.9
Leads to	0.8
Implies	0.7
Causes sometimes	0.6
Enables	0.5
Reduces effect of	0.5
Involves	0.5
Indicates	0.4
Causes occasionally	0.3

These relations result in a path strength. The path strength results in the value of the given observation using the equation (1).

$$path\ strength = \prod_{i=1}^{n} relation\ strength_i \tag{1}$$

After calculating the path strengths, the explanation strength can, by using equation (2), be found.

$$explanation\ strength = \sum_{j=1}^{m} path\ strength_j \tag{2}$$

Here, m equals the number of paths relating the given HF. The HF with the highest explanation strength is the one that has had the greatest effect on the incident.

This model is a dynamic model, which means that when an accident is exposed to evaluation, all new, involved concepts have to be merged into existing model. This process is referred to as Bottom-Up Modelling, as opposed to Top-Down Modelling. Top Down modelling is based on general knowledge typically found in textbooks. The new concepts and adaptations of the model as a result of the present thesis are presented in Chapter 3.2.

2.3. WHO USES WHICH MODEL?

After Tinmannsvik et. al. (2004) a list of Norwegian operator companys internal accident investigation methods is presented in Table 3, with reservations that this may have changed since 2004.

Table 3 - Operator internal investigation methods (free after Tinmannsvik et. al. (2004))

Operator	Investigative model
British Petroleum	Root cause
ConocoPhillips	TapRoot[3]
Esso	TapRoot
Shell	Tripod Beta[4]
Statoil	MTO, STEP
Talisman	Root Cause
Total	ILSI model/MTO methodology with barrier failure

2.4. COMPARISON

The previous subchapter gave an overview of six models available today regarding the assessment of human and organisational factors in accident investigation. The six models were chosen because they address the organisational factors and have the ability to conclude with the relationship between the accident and the organisation. Table 4 compares the models in relation to their characteristics; their positive and negative characteristics based on the scope of the present thesis. The second column lists the training necessary to apply the given model. Expert refers to the need for formal training prior to applying the model in its proper form; experience with the application of the model is beneficial (Sklet 2002). A novice is someone who is able to apply the model without hands-on training or experience. A specialist falls somewhere between these two categories.

[3] Software for Root Cause Analysis
[4] Software used for the TRIPOD model

Table 4 – Comparison of accident investigation models based on criteria. Training column derived from Sklet (2002). Advantages and limitations are from the present thesis based on the criteria for accident selection.

Model	Training	Advantages	Limitations
MTO	Expert	Comprehensive analysis, takes all aspects into account, defines the root cause. No software necessary.	Main model used by Statoil in their accident investigations. Expert training and experience necessary.
TRIPOD	Specialist	Defines the underlying organisational cause. Not previously applied to the accidents.	Software necessary to complete the analysis. Specialist training necessary.
SOL/STEP	Novice	Sequential analysis, graphical representation of results. Can be applied with limited training and experience. Not previously applied. No software necessary.	
MORT	Expert	Identifies discrepancies with management system factors. Not previously applied.	Expert training and experience necessary. Time consuming and costly process. (software necessary)
RCA	Specialist	Determines the underlying faults in the company's safety management system.	Specialist training necessary. Supplementary model, may not be used on its own.
IPT KM	Novice	Highlights root cause using logical groupings of observations. May be used on its own or in collaboration with other models. Limited training and experience necessary. No software needed.	Model is still under development, this may affect the results.

Chapter 3 addresses the comparison in Table 4 and the information given above in order to select a model for analysis which best fits the criteria listed in the introduction to chapter 2.2.

3. SELECTED METHODOLOGY

The investigatiion model to be used in the analysis of the chosen accidents is the IPT Knowledge Model (KM). The model has been adapted based on the work done in the present thesis. The adaptations are presented in this chapter.

3.1. JUSTIFICATION OF CHOICE

The comparison between the different accident investigation models completed in Table 4, shows that SOL/STEP and the IPT KM satisfy the criteria from Chapter 2.2. The other models need either expert or specialist experience, the investigator here has neither. MTO has already been applied and thus this model is eliminated. If the decision was only based on the four criteria, the obvious choice would be SOL/STEP, but based on Thunem et. al.'s (2009) statements portrayed throughout the previous chapters relating to the challenges of accident investigation models not taking into account the complexity and dynamics of an organisation and also the characteristics of models being either too simple or too complex, the IPT KM is a clear choice. This is because the IPT KM is a bottom-up form of modelling which is dynamic in nature and constantly under development, when the model adapts according to the situation. Whether the model is too simple or too complex is at the moment challenging to determine because it has only been applied to a limited number of accidents, but by applying the model here and fine-tuning it, it may result in a model that is just the right amount of simplicity and complexity.

3.2. ADAPTATION OF MODEL

In Skalle and Busch (2012) work they refer to organisational indicators. The candidate believes that the term Human Factor is more preferential as this is a well-established term used in organisational psychology and accident investigation. HF is defined as (HSE 2012):

"…environmental, organisational and job factors, and human and individual characteristics, which influence behaviour at work in a way which can affect health and safety"

Human error consists of three types of behaviour: Intentional behaviour, non-intentional behaviour and unintentional behaviour. The focus here will be on unintentional behaviour excluding violations and spontaneous actions.

Humans show three types of behaviour when executing tasks, skill based, rule based and knowledge based (Human factors briefing note no. 12 2012). The three types of behaviour refer to the level of consciousness we contribute to the task at hand. Skill based error refers to slips and lapses while executing routine and simple tasks errors (Reason 1990). Rule based error refers to mistakes made in execution as a result of forgetting a step in an operation or applying the wrong rule to the given situation. Knowledge based errors are mistakes made as a result of inaccurate conclusions or incomplete analysis based on the information available. Each HF can be related to one or more of these error behaviour types as shown in Figure 6.

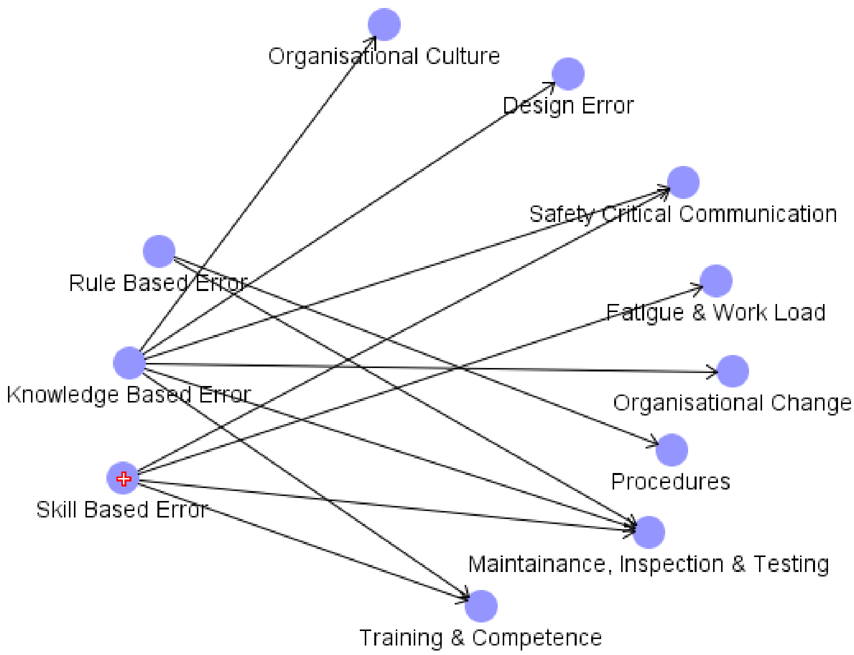

Figure 6 – Relation between behavioural error and HF (free after Skalle 2012)

The eight HFs shown in Figure 6 are from Skalle (2012), but as this model is bottom-up modelling and open to adaptation, one new HF has been introduced to the model, management and supervision. Safety critical communication, fatigue and workload and maintenance, inspection and training have been re-defined. The explanations can be seen below. Now there are nine HFs, they are briefly described below and their corresponding subclasses are presented in Table 5, this can give the reader a better understanding of what is meant by each HF. These are:

1. Procedures

Procedures relate to governing documents and systems set in play in the organisation that relate to how a certain activity should be executed in order to ensure reliability and quality of product. Compliance with governing documents is not included here. Procedures merely include the procedure or steering document itself, is it good enough, simply explained, easy to find etcetera.

2. Maintenance Error

Maintenance is a human task, both evaluating the need for maintenance as well as executing the job itself. Poor or incorrect maintenance is therefore dependent on the ability and performance of maintenance personnel and may have consequences related to human and operational safety. This HF does not include the actual maintenance procedures, they are implemented in HF 1 above, but it refers to task analysis, and the ability to see the maintenance challenge and define the correct course of action to fix it.

3. Organisational Culture

Personal and team related values, attitudes and behaviour all result in a certain organisational culture. This is a human factor, which is not easily assessed or altered. The culture has to come from management and slowly but surely be implemented in how the company does their job.

The hearts and minds culture ladder in Figure 7 shows how the safety culture of an organisation changes from pathological to generative; it is at generative that an organisation should strive to be.

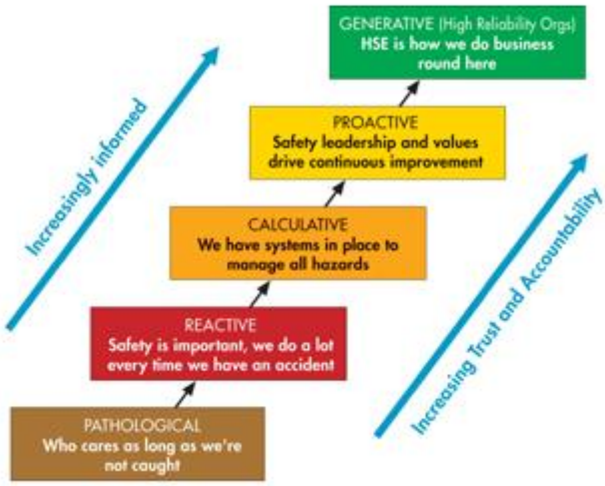

Figure 7 - Hearts and Minds culture ladder (Energy Institute UK microsites 2012)

A company needs to have good governing systems set in play that the employees support and trust. Including the employees in this process will increase their affiliation and compliance with the system.

4. Organisational Change

Organisational change is any alteration to the way employees perform their work, including down-sizing, restructuring teams or changing administrative arrangements. Organisational change may shed light on other challenges within the company that management was not previously aware of. Changing an organisation can cause a variety of challenges that had not been foreseen due to inadequate change processes and lack of assessment regarding the consequences of change.

5. Design Error

Design error is error related to the setup of, for example, a control room or alarm handling. The design of a system should take into consideration the fact that people will be operating them in order to maintain the safety, efficiency and operability of the system. Design error also includes the design of the operation; detailed operations plans.

6. Management and Supervision

This HF is not presented as its own organisational indicator in the KM presented by Skalle and Busch (2012), but merely as a subclass of fatigue (management related fatigue factors). Management is related to handling, direction or control and is an important part of the safety work within an organisation. Without sufficient and competent management, the company will not be able to reach the goals that have been set or implement organisational changes. Supervision is necessary for a company to identify where improvements need to be made, which training is necessary and to make sure that their employees have the necessary information to comply with regulations and governing documents. With this justification management and supervision has been applied here as its own factor.

7. Training and Competence

In order to assure that one's employees have the necessary knowledge and information to perform their job in a safe and reliable manner, training and elevation of competence is key. Training refers to a tool used by management to ensure that their employees have the necessary knowledge and attitudes to perform their job. Competence does not only include an employees ability to perform their day-to-day tasks, but also the ability to identify risks and potential hazards, which could result in incidents or worst case, major accidents. The identification of risks and hazards allows the employee to stop operation if it is deemed unsafe, thus reducing the potential effects.

8. Communication

Any form of interaction between a human and an interface, for example human to human or human to machine, is communication. Communication creates the foundation for anything that a human does. The lack of efficient communication methods is an accident risk as a result of inaccurate or lacking information. In order for a worker to execute a task they must be aware of what is expected of them and have the necessary competence to complete the task. The model presented by Skalle and Busch (2012) uses Safety Critical Communication as an organisational indicator, however, any form of communication, whether for safety critical purposes or others is important and therefore this HF encompasses all forms of communication within an operation.

9. Fatigue

Fatigue is defined as impaired human reliability, both physical and mental. A fatigued worker is more likely to make skill-based errors.

The KM includes a list of symbolic concepts related to the different HF, these are presented in Table 5. The subclasses of HF highlighted in green are the ones implemented as a result of the analysis completed in the present thesis, these were not included in the original model by Skalle and Busch (2012).

Table 5- Human Factors and respective subclasses. HF and subclasses highlighted in green are implemented as a result of the analysis completed in the present thesis.

HUMAN FACTOR	SUBCLASSES OF HF
Procedures	Inadequate planning procedure Inadequate engineering procedure Inadequate safety procedure Inadequate reporting procedure
Maintenance Error	Inadequate maintenance Inspection error Inadequate maintenance risk analysis Unrealistic maintenance task
Organisational Culture	Safety culture Guiding safety principle Inflexible organisation
Organisational Change	Inadequate change process Integrating HF (Safety Management System) Inadequate evaluation of change
Design Error	Planning error Equipment design error Labelling error
Management and Leadership	Lack of management prioritization Inadequate auditing Inadequate follow-up of operations Inadequate resource management
Training and Competence	Lack of competence Lack of procedural training Inadequate task analysis
Communication	Poor quality of information Poor quality of communication Inadequate application of information
Fatigue	External fatigue factors Personal fatigue factors

The KM is applied to two selected major accidents in the North Sea. Chapter 4 addresses them.

4. SELECTED ACCIDENTS

The criterion for selecting the accidents was that they occurred within the past 10 years. The time frame is due to the data and information available. Also, to best evaluate how to improve safety levels, evaluation must to be completed based on the situation today and not 20-30 years ago. When investigating accidents in the past 10 years, two accidents distinguished themselves as major accidents in the North Sea, the blowout on SNA in 2004 and the well control incident on GFC in 2010.

The data collection prior to the analysis is limited to investigation reports from Statoil, PSA and IRIS. Chapter 4.1 and 4.2 explain which reports have been used for each accident.

In the following subchapters, the accidents are summarized, including a list of causes determined in the reports. The entire sequence of events for each accident is available in the appendices along with the observations. The observations are interpreted for the purpose of the analysis based on the information given in the reports. The candidates own interpretations of this information, i.e. the observations, give the field data that is used to analyse the accidents and the result. The analysis is further presented in Chapter 5. Statoil implemented a number of initiatives after each accident; these are presented at the end of each subchapter. These initiatives are included in order to compare them to the results presented in Chapter 6.

4.1. BLOWOUT ON SNA

18 November 2004, whilst preparing to sidetrack well P-31 A on the Snorre A (SNA) platform, an uncontrolled well situation arose. The work being executed when situation occurred was pulling of pipe. During the course of the day the situation developed to an uncontrollable blowout of gas to seabed with consequent gas under the offshore installation. Due to the presence of gas below the installation (the sea was observed to be boiling) the work to secure the well barriers and gain control of the situation was very difficult; supply vessels were prevented from approaching the installation in order to, for example, load extra mud. Mud was pumped into the well after mixing the chemicals available on board on the 19 November 2004 and the well stabilized. Now, that the well was stabilized and the flow of gas

ceased, the work to secure the well and establish necessary barriers could commence (Austnes-Underhaug et. al. 2005).

The blowout resulted in 100 – 200 m^3 of OBM released to sea, more than 10 kg/s of gas leakages, material damage and other economic losses of over 50 MNOK and subsequent production loss of more than 50 MNOK/day (Kjeldstad et. al. 2005).

The incident is explained in its entirety in Appendix A.

Kjeldstad et. al. (2005) identifies four triggering causes of the blowout:

1. Well opened to communication with reservoir when perforating tail pipe in lower completion.
2. Hydrocarbons, gas, were sucked into the well while pulling 7 5/8” casing.
3. The well had holes in the 9 5/8” casing and external 13 3/8” casing which may have suffered reduced strength as a result of drilling of two side tracks or erosion at the same time as the 9 5/8” casing eroded.
4. The technical state of the well made the operation of maintaining control of the well volume and analysis of changes very difficult.

They also present in their report three underlying causes of the blowout:

1. Consequences of alterations in plans were not sufficiently analysed with regards to risks or understood.
2. The complexity of the well and risks involved were underestimated.
3. The organisation has shown inadequate understanding for the necessity of risk analysis and management.

49 observations are presented in Table 8 in Appendix A, these are interpreted based on the information given in Austnes-Underhaug et. al. (2005), Nygaard and Skoland (2011) and Schiefloe et. al. (2005).

After this accident in 2004, Statoil implemented fourteen initiatives as a result of investigations. Six of them were directly linked to technical relations at SNA and will not be presented here, the remaining eight were implemented in the entire Statoil Norway organisation and can therefore prove valuable when comparing to the results from GFC. The initiatives implemented were (Nygaard and Skoland 2011):

1. Planning, risk reviews and management involvement regarding Drilling and Well (D&W) operations in Statoil – ensure quality in the planning process, new requirements.
2. Competency on well control issues and barrier understanding in Statoil – Certification course and seminars focusing on previous events.
3. Well integrity for Statoils wells on the Norwegian Continental Shelf (NCS) – review of all of Statoils wells
4. Subsurface Support Centre in Technology and Projects D&W – competency and contact centre for D&W operations.
5. Governing documents in Statoil – Simplification and training, clear definition between requirement and method.
6. Management training for operational leaders – ensure that experiences from causal analysis is implemented in leader training.
7. "The administrative workday" for operational leaders in Exploration and Production Norway (UPN) – redistribution of responsibility and reduce bureaucracy.
8. HSE tools, systems and analysis in UPN – simplify reporting and enhance analysis in Synergi[5].

[5] Synergi: Statoils incident reporting tool

4.2. WELL CONTROL INCIDENT ON GFC

Well C-06 AT5 was drilled using Managed Pressure Drilling (MPD)[6] mode to total depth (TD) of 4800 mMD (measured depth). May 19th 2010, the final circulation and clean out of reservoir section resulted in a hole in the 13 3/8" casing with subsequent mud loss to formation. The 13 3/8" casing was a common barrier element; the hole in the casing therefore caused both the barriers to be lost. Due to the loss of backpressure, the exposed reservoir was allowed to flow into the well until the well was sealed at the 9 5/8" shoe due to packing off of debris or cuttings. This seal limited the flow of hydrocarbons into the well. During the first 24 hours after incident occurrence, both the offshore and onshore organisation failed to understand and manage the complex situation. Almost two months were spent attempting to stabilize the well and re-establish well barriers (Talberg et.al. 2010).

The well control incident resulted in 0,15 kg/s of gas leakage, loss of common barrier element, reputation challenges relating to coverage in national and international media, overall production loss of 1084 MNOK and 677 MNOK in material and other economic losses (Talberg et. al. 2010).

The incident in its entirety is explained in Appendix B.

Talberg et. al. (2010) identifies five triggering causes of the well control incident:

1. Use of casing with inadequate technical integrity
2. Monitoring control of pressure in C-annulus
3. Margin between pore and fracture pressure
4. Contingency procedures do not cover loss of common barrier element in a well control situation
5. Drilling supervisor and tool pusher perform shift change at the same time

[6] Managed Pressure Drilling is a drilling method used when conventional methods are undesirable, for example when drilling through depleted reservoirs and fracture formations. The BHP is managed dynamically using backpressure and the mud weight is usually lower than the pore pressure, however overbalance with the reservoir is maintained by managing the backpressure in a closed return line using a choke valve. A closed system with good volume control allows for quick feedback from the well regarding losses or influx. During MPD operations, several barrier elements are common for both primary and secondary well barrier.

They also present in their report four underlying causes of the incident:

1. Risk assessment related to casing as a common barrier element
2. Risk assessment prior to start-up of MPD operations
3. Risk assessment during MPD operations
4. Inclusion of experiences from C-01

63 observations are presented in Table 9 in Appendix B, these are interpreted based on the information given in Gundersen et. al. (2010), Nygaard and Skoland (2011) and Talberg et. al. (2010).

As a result of the well control incident on GFC and criticism directed at Statoil for not learning from their mistakes (Nygaard and Skoland 2011), seven initiatives have been implemented in the Statoil Norway organisation (Statoil press release 2011):

1. Strengthened safety culture through simplified steering system and reduced bureaucracy.
2. Continue to develop Statoil as a robust organisation for safe and efficient operations by developing authority and leadership in the line.
3. Enhance the practice of Statoils values[7] through a more open and caring business culture.
4. Continue to develop investigation as a central tool to secure learning from incidents in the company.
5. Reduce the risk of major accidents in the company.
6. Enhance and develop organisational learning within the company.
7. Secure better learning and management of Statoils service and contractor companies.

[7] Statoil's values: Courageous, Open, Hands-On and Caring (www.statoil.com)

5. ANALYSIS

Table 6 shows the analysis from observation to HF for the blowout on SNA. The observation numbers correlate with the observations listed at the end of Appendix A. Chapter 6 shows the relationship between the explanation strengths of the HFs. Some of the observations have been translated into the same symbolic concept; these are listed as multiples in column one. The relationship between subclass of HF and HF is constant at 0.9 and is therefore not shown in Table 6 or Table 7 (analysis of well control incident on GFC).

Table 6 - Analysis of the interpreted observations from the blowout on SNA, from observation to HF including relations.

Obs. No.	SYMBOLIC CONCEPT		SUBCLASS OF HF	HUMAN FACTOR
1	Inadequate understanding of consequences of change	0,9	Inadequate evaluation of change	Organisational change
2	Inadequate implementation of change	0,7	Inadequate change process	Organisational change
3	Inadequate knowledge of change	0,8	Poor quality of information	Communication
4	Inadequate follow-up of audit results	0,7	Inadequate auditing	Management and supervision
5	Inadequate auditing methods	0,9	Inadequate auditing	Management and supervision
6	Lack of milestones in planning	0,6	Inadequate planning procedure	Procedures
7 10	Planned with insufficient barriers	0,8	Planning error	Design error
8	Consequences of plan alterations not analysed	0,4	Inadequate task analysis	Training and competence
9	Inadequate use of previous experiences	0,7	Inadequate application of information	Communication
11	Inadequate risk analysis	0,5	Lack of competence	Training and competence
12 30 36	Inadequate compensating measures	0,5	Inadequate safety procedure	Procedures
13	Inadequate management prioritization of peer assist	0,9	Lack of management prioritization	Management and supervision
14	Inadequate documentation	0,6	Poor quality of information	Communication
15	Inadequate approval	0,3	Inadequate follow-up of operations	Management and supervision

Obs. No.	SYMBOLIC CONCEPT		SUBCLASS OF HF	HUMAN FACTOR
16	Insufficient prioritization of risk assessment	0,5	Safety culture	Organisational culture
17	Lack of use of previous experiences	0,7	Inadequate application of information	Communication
18	Inadequate understanding of deviation processes	0,4	Inadequate reporting procedure	Procedures
19	Inadequate understanding of terms	0,4	Lack of procedural training	Training and competence
20	Inadequate approval of executed HAZOPs	0,3	Inadequate follow-up of operations	Management and supervision
21	Inadequate safety communication	0,9	Poor quality of communication	Communication
22	Inadequate use of previous experiences	0,7	Inadequate application of information	Communication
23	Insufficient competency requirements	0,8	Lack of competency	Training and competence
		0,7	Inadequate resource management	Management and supervision
24	Inadequate use of essential resources in planning	0,8	Lack of competence	Training and competence
25	Lack of installation specific competency	0,9	Inadequate resource management	Management and supervision
		0,8	Lack of competency	Training and competence
26	Unwillingness to use external expertise	0,5	Safety culture	Organisational culture
		0,6	Lack of competency	Training and competence
27	Program engineer hired consultant	0,8	Inadequate resource management	Management and supervision
28	Poor prioritization of resources from management	0,8	Inadequate resource management	Management and supervision
29	Planning not prioritized	0,8	Safety culture	Organisational culture
31	Inadequate understanding of severity	0,5	Inadequate follow-up of operations	Management and supervision
32	Inadequate of involvement of competent personnel	0,8	Lack of competence	Training and competence
33	Inadequate understanding of planning procedures	0,5	Lack of procedural training	Training and competence
34	Pressure testing not performed	0,4	Lack of competence	Training and competence

Obs. No.	SYMBOLIC CONCEPT		SUBCLASS OF HF	HUMAN FACTOR
35 37	Inadequate preparation for well control incident	0,5	Planning error	Design error
38	Accident severity downgraded	0,6	Lack of competency	Training and competence
39	Wrong contact information in procedures	0,5	Inadequate safety procedure	Procedures
40 42	Lack of knowledge of communication lines	0,7	Lack of procedural training	Training and competence
41	Inadequate alarm system	0,5	Equipment design error	Design error
42	Lack of knowledge of communication lines	0,7	Lack of procedural training	Training and competence
43	Emergency personnel exposed to unnecessary danger	0,8	External fatigue factors	Fatigue
44	Earlier start-up	0,7	Inadequate planning procedure	Procedures
45	High activity on installation	0,6	External fatigue factors	Fatigue
46	Rig unprepared for operations	0,9	Planning error	Design error
47	Inadequate emergency response	0,5	Lack of procedural training	Training and competence
48	PA messages inaudible	0,9	Equipment design error	Design error
49	Lack of understanding of risks	0,4	Lack of competence	Training and competence

Based on the analysis completed in Table 6, Table 10 in Appendix C shows the explanation strengths per HF. These are further graphically presented in Chapter 6.

Table 7 shows the same type of analysis as above, this time for the well control incident on GFC. This analysis is based on the 63 interpreted observations presented in Table 9 in Appendix B.

Table 7 - Analysis of interpreted observations from the well control incident on GFC, from interpreted observation to HF including relations.

Obs. No.	SYMBOLIC CONCEPT		SUBCLASS OF HF	HUMAN FACTOR
1	StatoilHydro merger (2007) resulted in personnel challenges	0,9	Inadequate change process	Organisational change
2	Inadequate concequence analysis	0,9	Inadequate change process	Organisational change
3	Inadequate technical understanding	0,7	Lack of competence	Training and competence
4	GF organisation seen as rigid and difficult to manage	0,9	Inflexible organisation	Organisational culture
5	Inadequate integration of governing systems	0,8	Integrating HF (Safety Management Systems)	Organisational change
6 14 50	Inadequate compensating measures	0,7	Inadequate safety procedure	Procedures
7	Planned with insufficient pressure margin	0,6	Guiding safety principle	Organisational culture
8 9 16 43	Inadequate risk analysis	0,5	Lack of competence	Training and competence
		0,5	Inadequate safety procedure	Procedures
10	Inadequate distribution of staff	0,4	Inadequate resource management	Management and supervision
11	Risk assessment group not composed of necessary expertise	0,7	Inadequate competency	Training and competence
12	Inadequate assessment of analysis needs	0,5	Lack of competence	Training and competence
13	Lack of understanding of complexity	0,5	Lack of competence	Training and competence
15	Inattention to risk	0,5	Inadequate safety procedure	Procedures
17	ALARP principle not used	0,9	Inadequate safety procedure	Procedures
18 22 23 47 57	Inadequate documentation	0,6	Poor quality of information	Communication
19	Lack of coherence between results and implementation	0,4	Inadequate application of information	Communication

Obs. No.	SYMBOLIC CONCEPT		SUBCLASS OF HF	HUMAN FACTOR
20 23 30 31	Lack of use of previous experience	0,7	Inadequate application of information	Communication
21	Inadequate approval	0,9	Inadequate follow-up of operations	Management and supervision
24	Lack of coherence in risk assessments	0,7	Inadequate safety procedure	Procedures
		0,5	Poor quality of communication	Communication
25 26	Lack of understanding of governing documents	0,7	Lack of procedural training	Training and competence
27	Insufficient resource capacity	0,7	Inadequate resource management	Management and supervision
	Simultaneous operations	0,5	External fatigue factors	Fatigue
28	Individual quality of work	0,7	Inadequate reporting procedure	Procedures
32	Lack of operational experience	0,9	Lack of competence	Training and competence
33	Inadequate field specific experience	0,7	Lack of competence	Training and competence
34	Lack of inclusion of field specific experience	0,4	Inadequate resource management	Management and supervision
35	Inadequate use of Peer Review	0,7	Safety culture	Organisational culture
36	Inadequate learning processes	0,8	Safety culture	Organisational culture
37	Unwillingness to receive external assistance	0,6	Inflexible organisation	Organisational culture
38	Inadequate inclusion of principle personnel	0,7	Guiding safety principle	Organisational culture
39	Inadequate monitoring of formation	0,6	Poor quality of information	Communication
40	Uninformed decision makers	0,5	Inadequate resource management	Management and supervision
41	Inadequate planning of alternative solutions	0,8	Planning error	Design error
42	Insufficient operational planning	0,7	Inadequate planning procedure	Procedures
44	Lack of operation related training	0,7	Lack of procedural training	Training and competence

Obs. No.	SYMBOLIC CONCEPT		SUBCLASS OF HF	HUMAN FACTOR
45	Interdepartmental communication challenges	0,7	Safety culture	Organisational culture
46	Inadequate understanding of key concepts	0,5	Lack of procedural training	Training and competence
48	Inadequate supervision from management	0,8	Inadequate follow-up of operations	Management and supervision
49	Actions implemented after SNA still not successful	0,9	Inadequate change process	Organisational change
51	Inadequate kick margin	0,4	Inadequate safety procedure	Procedure
52	Inadequate pressure monitoring	0,4	Inadequate safety procedure	Procedures
53	Inadequate shift change procedures	0,9	Poor quality of communication	Communication
54 55	Continued operations despite complications	0,7	Insufficient follow-up of operations	Management and supervision
56	MPD drillstring insufficient	0,8	Equipment design error	Design error
58	Inadequate risk communication	0,7	Poor quality of communication	Communication
59	Lack of open culture addressing concerns	0,8	Safety culture	Organisational culture
60	Inadequate pressure test	0,9	Planning error	Design error
61	Sheer ram not certified	0,7	Equipment design error	Design error
62	Inadequate emergency communication	0,8	Poor quality of communication	Communication
63	Severity of situation underestimated	0,4	Lack of competence	Training and competence

All the path strengths are summed up into explanation strengths, as per equation (2) and listed in Table 10 in Appendix C. Equation (3) shows how to transform the explanation strength from a number to a percentage, in order to compare them with each other.

$$Explanation\ strength\ [\%] = \frac{Explanation\ strength\ for\ given\ HF}{Total\ explanation\ strength\ for\ incident}\ x\ 100\% \tag{3}$$

The graphical representation of the results based on the information in Table 10 are shown in Figure 8, presenting the explanation strengths for SNA and GFC separately as well as the collectively per HF. Maintenance error has been omitted from the figures because its explanation strength equalled zero.

6. RESULTS

The results in Figure 8 show that training and competence is the HF with the highest explanation strength, but it is not significantly higher compared to the other seven. In order to see whether it is possible to make a conclusion as to the human related root cause of these accidents (reference goal no. 1), breaking down the HF into their subclasses and looking at the explanation strengths of the subclasses separately may allow for more conclusive results.

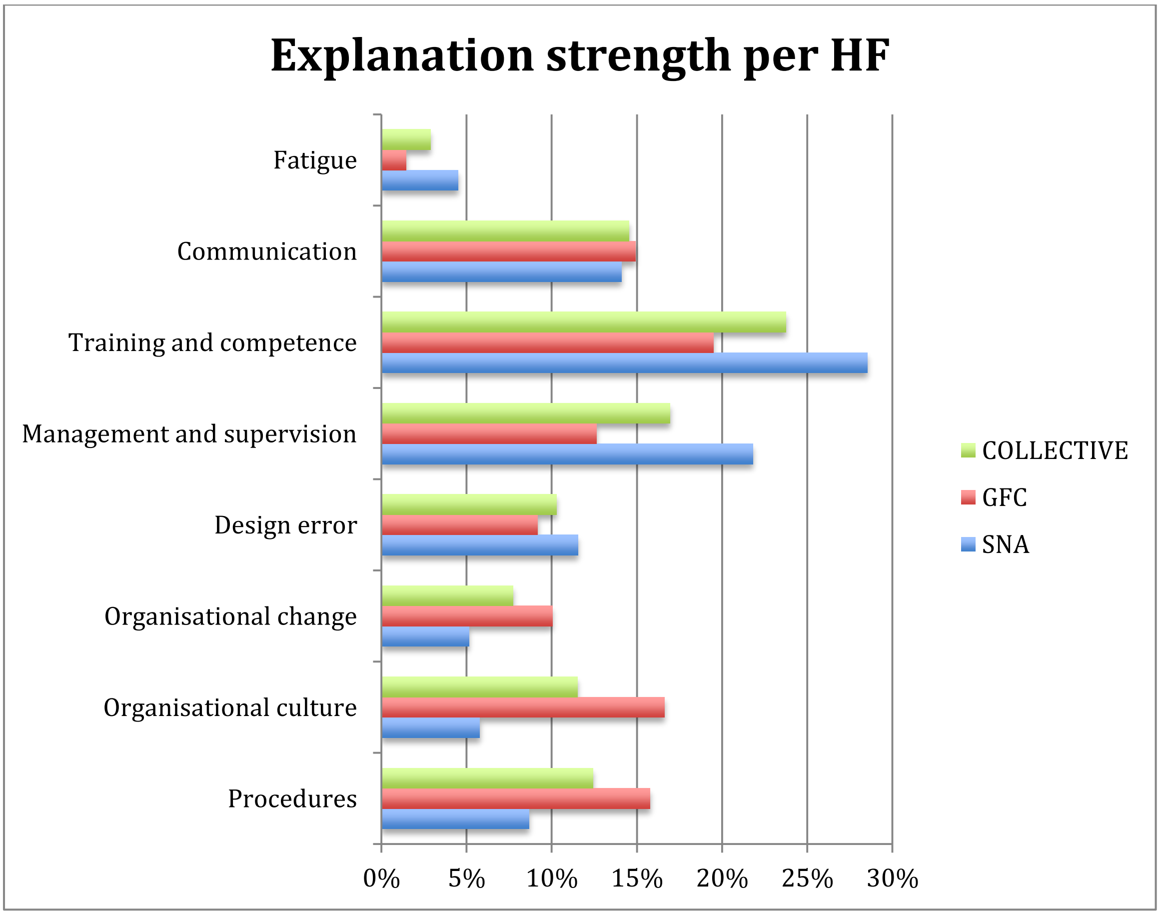

Figure 8 - Explanation strength per HF

Figure 9, Figure 10 and Figure 11 on the following pages show the explanation strengths of each subclass. By breaking down the HF into their subclasses, lack of competence represents a majority of the observations made, with the highest explanation strength.

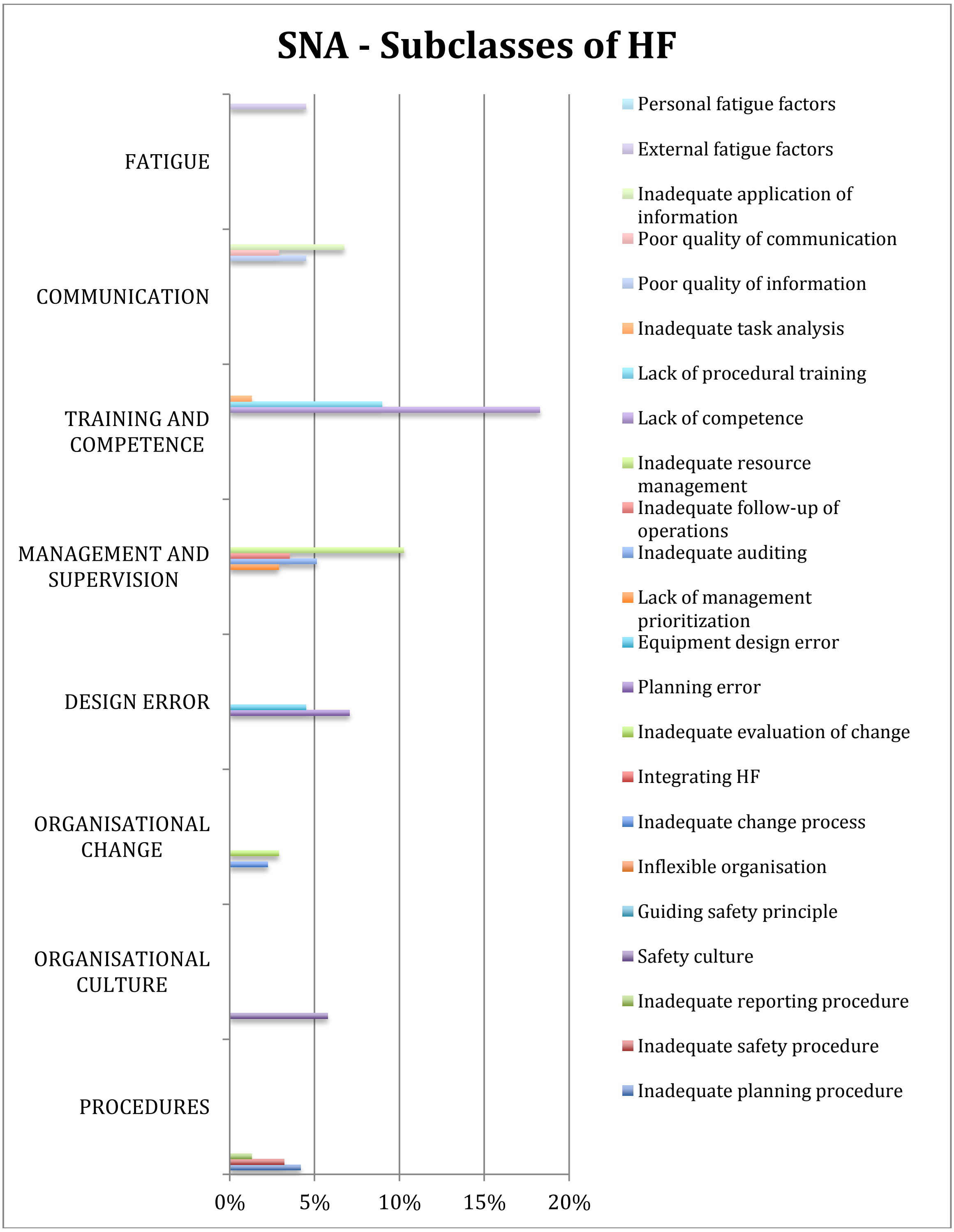

Figure 9 - Explanation Strength subclasses of HF – SNA

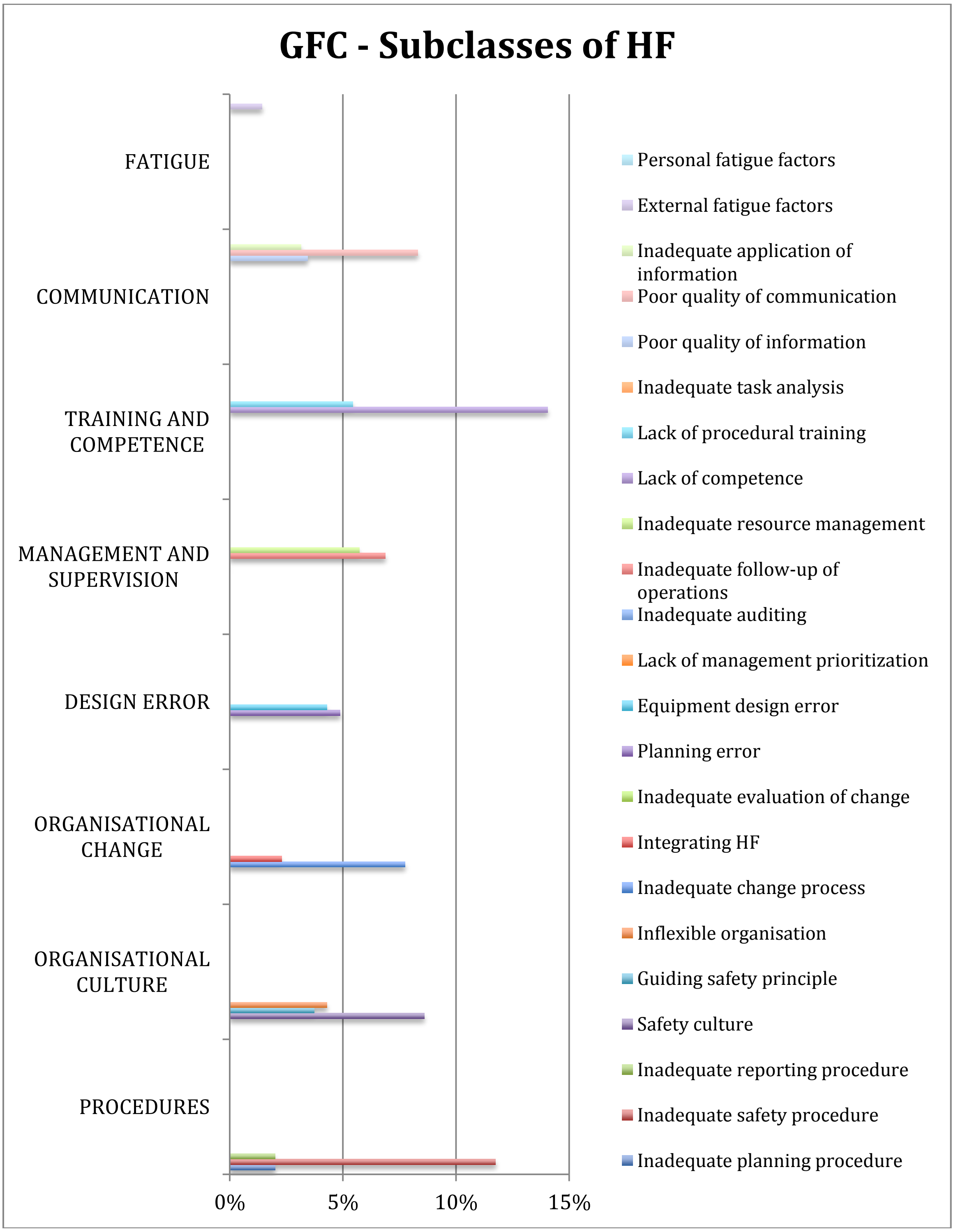

Figure 10 - Explanation Strength subclasses of HF – GFC

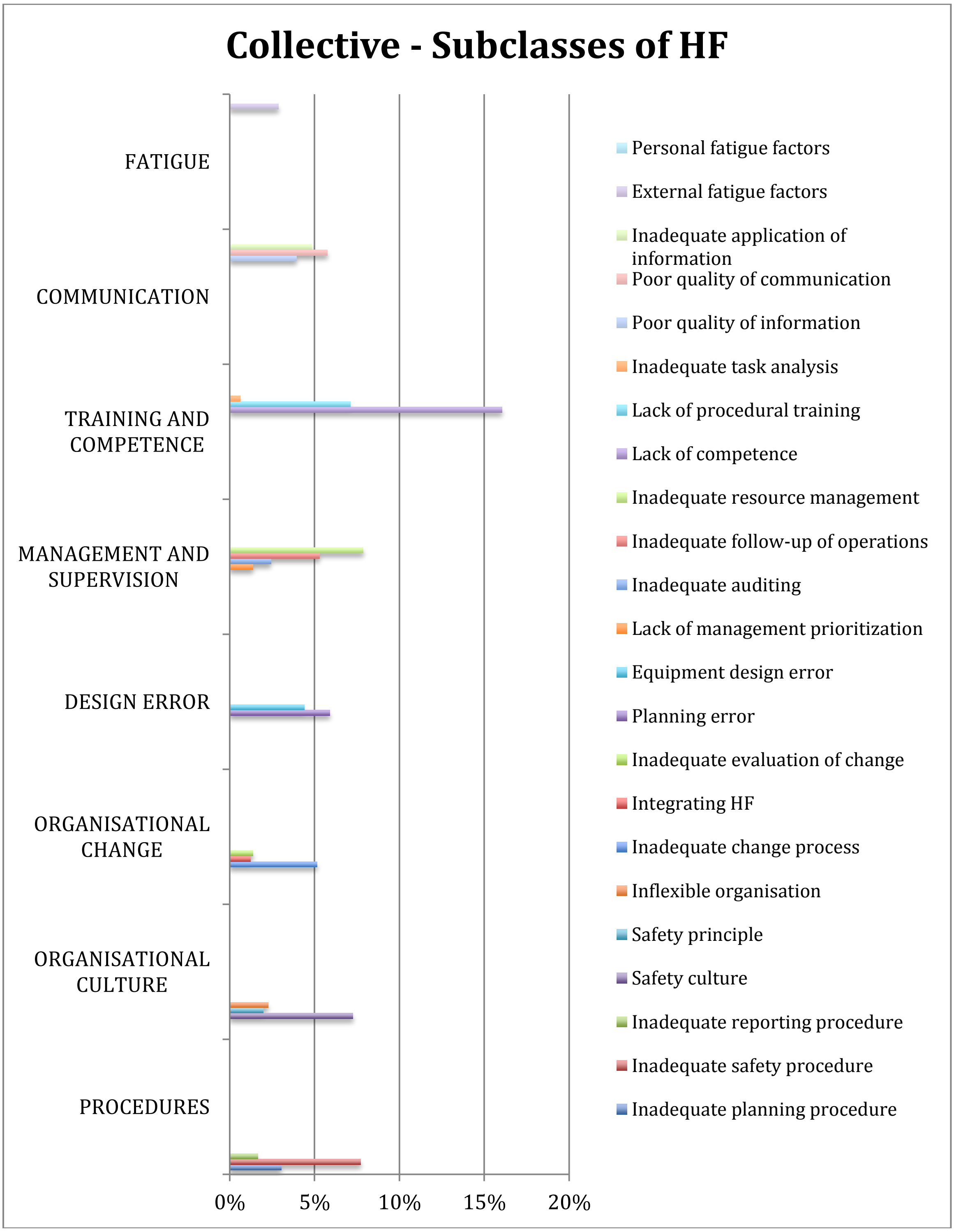

Figure 11 - Explanation Strength subclasses of HF - Collective

7. DISCUSSION

The results are discussed by topic, both in relation to themselves as well as to previous work and, in terms of suggestions to improve the safety level of the organisation. The KM and the data used have their advantages and limitations, these are discussed and improvements are suggested. The discussions presented in the following chapter are the candidates' own interpretations. These interpretations are based on the work done in the present thesis, chapters 1 through 6.

BLOWOUT ON SNA

The HF with the highest explanation strength after the analysis of the blowout on SNA is training and competence with 29%, followed by management and supervision with 22%. Added, these two HF represent 51% of the observations in the accident. The HF with the third highest explanation strength is communication with 14%.

When breaking down the HF, into their subclasses, and looking at the explanation strength here, lack of competence tops the list with 18%, followed by inadequate resource management and lack of procedural training at 10% and 9% respectively.

As presented in chapter 4.1, Kjeldstad et. al. (2005) found three underlying causes of the accident which were human related. These included a lack of understanding of the consequences relating to altering plans, underestimation of complexity and risks involved and lack of understanding of the necessity of risk analyses and management. All three underlying causes coincide with the two HF with the highest explanation strength, they all relate to a lack of competence and management involvement.

The initiatives implemented by Statoil as a result of this accident are also presented in chapter 4.1. They show that four out of eight, i.e. half the initiatives are related to training and competency and three out of eight are related to management. This means that both the results and the initiatives presented in earlier work coincide with the analysis done using the KM.

WELL CONTROL INCIDENT ON GFC

The analysis of the well control incident on GFC is less conclusive than for SNA. The explanation strengths are more evenly spread across the HF with training and competence in the lead with 19% followed by organisational culture and procedures at 17% and 16% respectively. The HF that differs from the others is fatigue with only 1%, otherwise the rest of the HF are within a 10% range. This makes concluding with a root cause more challenging.

The same form of even distribution of explanation strengths is seen when breaking the HF into their subclasses. Here lack of competence has 14%, followed by inadequate safety procedure at 12% and safety culture at 9%.

The results from GFC show that the GF organisation has challenges in all aspects of human error and that based on this; there is no distinctive root cause.

The triggering and underlying causes of Talberg et. al. (2010) refer to inadequate contingency procedures, inadequate risk assessment and lack of inclusion of previous experiences. In this KM these underlying causes can be related to procedures, training and competence and communication. This partly coincides with the HF that is presented above as having the highest explanation strength. However, organisational culture is not referred to in that document as an underlying cause and yet in this analysis 17% of the observations were related to it. The reason why organisational culture is not addressed as an underlying cause may be due to the fact that it is a factor that is challenging to capture; it involves human attitudes and behaviour.

The initiatives implemented by Statoil after SNA have, at the time of the GFC accident, six years later, still not resulted in the anticipated outcome. Lack of competence continues to pose as the largest challenge within the organisation. It may seem that Statoil is more concerned with presenting their plans, than learning from them and managing to permeate the entire organisation with these new changes. Their leaders and managers do not have the necessary knowledge to monitor and supervise changes and assure that they are implemented. They lack an open organisational culture.

Organisational culture may be the HF that is most difficult to change, however, in order to do so, the change has to start with management leading by example. If a well respected management initiates, the rest will follow, as long as they are included in the change process.

COLLECTIVE

When combining the results for SNA and GFC and looking at the collective analysis, training and competence has explanation strength of 24%, followed by management and supervision and communication summing up to 17% and 15% collectively. When breaking these results down into the subclasses of HF, lack of competence has explanation strength 16% whilst the rest of the subclasses are evenly distributed with explanation strengths ranging from 1% to 8%.

By taking the liberty of applying these results to the whole company, one can say that Statoil experiences challenges relating to the competency of their employees. The competence is available within the company, but using the correct knowledge and competence at the correct time seems to pose challenging.

Statoils management should focus on implementing and follow-up initiatives, which decrease the competency challenge. With increased competency comes increased understanding of complexities and the need for risk assessments. By completing the necessary and comprehensive risk assessments, resulting in the correct compensating measures, many incidents can be averted. By averting smaller incidents, the probability of these developing to major accidents is limited.

The work to increase competency levels within the organisation, should, based on observations start by addressing the following areas:

- Risk evaluation and risk assessments
- Management and organisational development
- Process and procedural development
- Safety culture
- Responsibility and management in crisis situations
- Crisis management

Accidents combined with IPT Knowledge Model, may be used as a tool in procedural training.

QUALITY ASSURANCE OF MODEL AND DATA

The IPT KM gives a numerical value to where the main challenge within the company lies. It gives management an indicator into how to prioritize organisational changes in the future. However, the results are prone to bias by the investigator. The investigators background and experience affects the results; it is their interpretation of the information available that results in observations. The only predetermined relation is the one between subclass of HF and HF (0.9). The investigator determines the relation between symbolic concept and subclass of HF as they see best fit. There are no statistics available that can give the relation as shown in Table 2 and therefore the results can have a large variation depending on who the investigator is. This is one of the strengths of the model, giving a probable relation where mathematical or statistical relations are lacking. Once the mathematical or statistical relations exist, the relations can be updated. This gives more reliable results.

As stated earlier, this model is continually under development, and at this point still in the early phase regarding major accidents. This gives the investigator leeway regarding how to apply the model to a given accident. This is both positive and negative as it allows the investigator to analyse according to the given accident and not a set of rules and regulations; at the same time this results in a wide range of results depending on the investigator.

Thunem et. al. (2009) stated that there is a lack of consensus in the industry as to what organisational dimensions that are relevant to address. Setting maintenance error aside (has not been addressed in the present thesis), this model has presented eight HF that, based on the analysis, show that every observation has its place. When looking at the results, it may be up to discussion whether the HF fatigue should be its own indicator or whether the subclasses here should be placed under one of the other HFs. For example, the subclass of fatigue, external fatigue factors that includes pressure to deliver within a time frame could also be a subclass of management and supervision or organisational culture.

Hernæs (2012) applied the same model to the blowout on SNA and the results there showed that almost 50% of the observations were related to procedures. When comparing the results from the specialisation project and the present thesis, there is significant variation in the results. In the present thesis, 9% of the observations were related to procedures. This shows that the same investigator can have variations in their conclusions. The KM used in the specialisation project was a simplified version of the one applied here, creating uncertain results. In the analysis shown above the investigator has a greater knowledge of the model and the steps in which to perform it.

It is challenging for the investigator to set an observation in relation to just one or two human factors. Many HF are related and observations can fit just as well into one as to another, depending on how the investigator chooses to translate it into a symbolic concept.

Engineers are familiar with numbers and statistics and tend to prefer precise and tangible data. This model gives a more technical approach to the accident resulting in numerical values. Based on the results it may be easier to present them to an organisation of engineers, giving them a better understanding of the challenges at hand and where the work needs to be done than by merely listing what went wrong. This is the main difference between this model and other models. Other models, as presented in chapter 2.2, do not conclude numerically.

Human behaviour is irrational and challenging to give numerical values to. The work started with the IPT KM is a step in the right direction in order to quantify human behaviour.

As this model is bottom-up modelling, the more it is applied to accidents the better it becomes and the conclusions will be strengthened. The model still needs development before it can be used as the main tool of accident investigation, equivalent to for example MTO-analysis. However, when the KM is commercially marketed, it will give more tangible results than its peers.

The field data applied in the present thesis is limited to the investigation reports by Statoil, PSA and IRIS. The analysis performed was therefore a complementary analysis based on the investigations of these three organisations. The investigator here is biased before the analysis started due to the conclusions presented in these reports. This may have affected the results.

The KM has never been applied to an accident where there have not been previous investigations and it would be interesting to the see how the model would function based on unbiased data collected directly from the source by the investigator.

Statoil has made changes to their internal reporting systems and also their team site functions after the blowout on SNA as well as the merger with Hydro in 2007. This means that, since GFC is the more recent of the two accidents, more information is available; this could have an effect on the number of observations for the two accidents.

This model should be applied to a number of accidents and calibrated for NCS. Unfortunately for the model, but fortunately for the industry, there have not been enough accidents of this calibre in the past 10 years in order to do so. This results in a limited applicable data set.

SUGGESTED IMPROVEMENTS

In order to diminish the effect of the investigators bias, it will be beneficial to have several investigators working separately with an analysis and then meeting to compare results and discuss the observations and path strengths/explanation strengths. This will give a more comprehensive analysis than when there is just one investigator. Putting together an investigative team that consists of both technical and HF experts will give the best results. A review of the organisational indicators and subclasses, where duplicity is eliminated, the model will give more precise results and will also decrease the interpretation from the investigator.

A dataset of statistics relating common symbolic concepts with subclasses will allow for a greater similarity between each analysis. However, when relating to human error, it is challenging to set everything into predetermined boxes, as humans are not necessarily as simple as this. The challenge here is to make it complex enough for a sound conclusion and also flexible enough to highlight new areas.

To ensure a proper understanding of how this model works and apply it to an accident it is important that the investigator has training in how to use it. Experience with the model and procedural training are both efficient ways of ensuring this. Chapter 2.4 suggests that the necessity for training regarding the use of this model is at novice level. This is still viable as the model itself can be used without much experience, but the more knowledge one has of it and the more one has applied it, the more reliable the results become. This is also applicable for anything in life, the more experience and training you have, the better you get.

In order to ensure the quality of the KM, the model must be applied to an accident that has not been investigated previously and the data is therefore raw data directly from the source. This may give better or different observations and therefore a more direct conclusion based solely on this accident. The next step for this model is for an investigative organisation, for example PSA, to implement this model into their work and in this way improve the model.

Since accidents of this calibre are a rarity, it will be necessary to apply the model to smaller incidents and discrepancies in order to create a more comprehensive model.

8. CONCLUSION

On basis of the work done in present thesis the following statements can be made;

Analysis and Results:

- Training and competency was indicated as the root cause of the two accidents, with subclass lack of competence as the major contributor.
- Management and supervision have also been indicated as having an effect on incidents and accidents within the company.
- By increasing the competency levels within the company and ensure that the leaders and management have the proper tools to follow-up their employees, one can improve the safety levels.
- Management lack the necessary knowledge to monitor and supervise changes, assuring that they are implemented. This results in inadequate change management and thus the inability to learn from previous accidents. An open organisational culture resulting in an improved safety culture will create the learning environment necessary to prevent the next major accident.

The Model:

- An adapted version of the IPT KM has been applied to the two accidents in question in order to find the root cause. Observations interpreted from investigation reports have been used as input parameters in the model. The final results show the explanation strengths per HF and the explanation strength per subclass of HF.
- The adapted model implemented a new HF, management and supervision. This proved to be a valuable HF, without proper resource management and follow-up of operations, the employees are allowed to continue as they see fit.

The Data:

- The data used was based on investigation reports using other accident investigation models, the data was therefore biased and this may have had an effect on the outcome.
- Engineers are familiar with numbers and statistics and tend to prefer precise and tangible data. This model results in numerical values that may be easier to present to

an organisation of engineers, giving them a better understanding of the challenges within the company.

Future improvements:

- The calculations to the explanation strength and thus the root cause of the given accidents are in large part prone to bias from the investigator. The results do coincide with previous published work, but by reducing the effect of investigator bias, the results can prove to be more conclusive.
- For future work, the data must be collected directly from the source without subjective thoughts from a third party.

ABBREVIATIONS

ALARP	As Low As Reasonably Possible
APOS	Arbeids- og Prosessorientert Styring
BHA	Bottom Hole Assembly
BHP	Bottom Hole Pressure
BOP	Blowout Preventer
BRF	Basic Risk Factors
BU	Bottoms Up
CF	Contributing Factors
CTA	Cognitive Task Analysis
D&W	Drilling and Well
DBR	Daily Drilling Report
DOP	Detailed Operations Plan
ECD	Equivalent circulating density
EPN	Exploration and Production Norway
FTA	Fault Tree Analysis
FWR	Final Well Report
GF	Gullfaks
GFC	Gullfaks C
Gp	Group (geological)
HAZID	Hazard Identification
HAZOP	Hazard and Operability Analysis
HF	Human Factor
HMI	Human-Machine Interaction
HPES	Human Performance Evaluation System
HRS	Hovedredningssentralen
HSE	Health, Safety and Environment
ICMA	International Crisis Management Association
IRIS	International Research Institute of Stavanger
KM	Knowledge Model
LOT	Leak off test
MD	Measured Depth
MORT	Management Oversight Risk Tree
MPD	Managed Pressure Drilling
MPO	Managed Pressure Operations
MTO	Man-Technology-Organisation
NTNU	Norwegian University of Science and Technology
P&A	Plugged and Abandoned
PA	Public Announcement
PETEK	Petroleum Technology
POB	Personnel on board
POOH	Pull Out Of Hole
PSA	Petroleum Safety Authority
RCA	Root Cause Analysis
SNA	Snorre A
SOL	Safety through Organisational Learning
STEP	Sequentially Timed Event Plotting

TD	Total Depth
TG	Trip Gas
TNE	Technology and New Energy
USIT	UltraSonic Imaging Tool
WCI	Well Complexity Index
WHP	Wellhead Pressure
XLOT	Extended Leak Off Test

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Appendix A.   BLOWOUT ON SNA

Complete sequence of events

The blowout as presented in its entirety below is extracted from Austnes-Underhaug et. al. (2005) investigation report.

History

From start of operations in 1992 Saga Petroleum ASA was the operator on SNA until Norsk Hydro AS acquired operatorship on the 1st January 2000 and after that Statoil on 1 January 2003.

Two underground production facilities are linked to the installation, which is a tension leg platform.

In the years prior to the blowout there had been high activity on the platform and at the time of the blowout, drilling operations, well intervention and set-up of new well intervention tower were being performed on the platform.

The blowout on SNA occurred on the 28 November 2004 and in the months prior to the blowout SNA had changed drilling entrepreneur from ProSafe to Odfjell Drilling. Odfjell Drilling did acquire 80% of ProSafes crew on board, however, several of the crew members on board were new to the installation as well as this was the first rotation for Statoils Drilling Supervisor.

Well P-31 was drilled as an observation well in 1994; the purpose of this well was to collect geological data to optimize the well trajectory and the wells horizontal section. The sidetrack P-31 A was drilled and completed during spring 1995. P-31 A was originally planned as a production well, but was converted in the beginning of 1996 to an injection well for alternate injection of water and gas (WAG) and was primarily used as a gas injector until shutin in December 2003.

Several issues were encountered when drilling this well and as a result of these the well was graded as a complex well. Factors influencing this were due to reduced integrity as a result of corrosion and leakages, the unconventional well completion using a lot of small completion elements.

Planning of operations: Slot recovery

The operation that resulted in a blowout in November 2004 was a slot recovery operation to prepare the well for drilling sidetrack P-31B.

Planning for the slot recovery started 17th June 2004. To start the process, well history information and Statoil governing documents were collected.

The original plan for slot recovery was finished in September 2004 and had considered the wells integrity issues. This plan stated that the reservoir section should not be tampered with; this meant the reservoir should not be opened and cemented. This plan was according to recommendations from Statoils HQ as of August 2004.

In October 2004, the slot recovery plan was altered due to recommendations from the reservoir SNA RESU (REServoarUndersøkelse = reservoar investigation) team, which was the task force put together for slot recovery purposes. The new plan was to pressure cement the reservoir section in order to avoid communication between the reservoir in P-31A and the new planned sidetrack P-31B. Communication between P-31A and P-31B could lead to poor oil recovery as well as unpredictable/unwanted flow patterns. Drilling and well department of SNA RESU were sceptical to this alteration in the plan due to the fact that it would further complicate the plan and execution of it during slot recovery. However, by the end of October 2004, drilling and well SNA RESU agreed to implement the changes in the revised plan.

The decision was made to alter the sequence of the original plan which was to first cut and pull the 5 ½” production tubing prior to puncturing the tail pipe. By puncturing the tail pipe prior to cutting and pulling the production tubing they could avoid a transition zone between 9 5/8” casing and 5 ½” production tubing, which could show to be problematic for entry with puncture tools.

This plan was risk evaluated concerning the holes in the 9 5/8" casing without any major risk or barrier concerns were identified.

During the last formal planning meeting on the 11th November 2004 both service providers and personell from SNA RESU were present. During this meeting, the wells history was presented as well as presentations and discussions pertaining to every aspect of the each suboperation. A peer assist and risk meeting was planned on the 12th November, but cancelled due to scheduling, and there was therefore never held a proper risk review of the operations plan.

Between 15th -16th November the plan was verified and approved by SNA RESU management and the following operations were approved:

1) Puncturing of tail pipe
2) Bullheading of OBM to replace brine
3) Cutting and pulling of 5 ½" production tubing
4) Cutting and pulling of 7 5/8" scab-liner
5) Cementing of reservoir section
6) Cutting and pulling of 9 5/8" casing.

It was during operation (4) that the blowout occurred.

Operations on P-32 ended earlier than expected, as a result of this the rig was skidded and the slot recovery on P-31B commenced.

The previously delayed peer assist risk review was set to be held on the 19th November 2004 and was cancelled.

Operations

On November 19th 2004, slot recovery operations on well P-31A commenced. Already early in the slot recovery operation at sub-operation number 3) Cutting and pulling of 5 ½" production tubing well control issues were experienced in operations on the 21st November.

Mud kicked in to the well containing diesel and gas. This issue was quickly rectified and investigated internally in Statoil.

The operation of puncturing the 2 7/8” tail pipe allowed for reservoir pressure communication with wellbore pressure as well as contact with hydrocarbon bearing layers in the reservoir. At this point, the primary barrier in the well was 1.47 sg brine and then bullheaded to 1.47 sg OBM.

When pulling out the 5 ½” tubing, studies showed that the tubing had only partly been cut and when pulling the tubing, the lower part of the tubing with 4” straddle were also being pulled. The rig was not prepared for this sort of pulling operation and the tools on board were not sufficient to pull this through the BOP.

The onshore service provider had a substantial waiting period before managing to get the tools offshore and therefore other solutions was considered. It was considered to run in hole with the lower part of 5 ½” tubing and the 4” straddle back into the well.

E-mail correspondence between drilling supervisor offshore and program engineer onshore on the 24th November regarding a deviation application for pulling of 7 5/8” scab-liner without BOP rams was responded to by the program engineer stating that he had interpreted that this was not necessary as long as the liner being pulled was not in open hole.

The following day a meeting between the program engineer and the leading drilling engineer in TO RESU (acting supervisor). The agenda for the meeting was to discuss pressure cementing of the reservoir section. As a result of this meeting the plan was revised so that they would puncture a hole in the top of the scab-liner prior to cutting. The purpose of this would be to equalize for potential gas and pressure behind the scab-liner.

This suggestion was implemented in a revised DOP offshore. Risk evaluation of pulling scab-liner through BOP was removed from the DOP as a result of previously mentioned e-mail correspondence.

On 25 November, HAZOPs were completed for two of the sub-operations by the onshore crew. The first was approved and signed by SNA RESU management. The second, however, was never approved or signed by management.

The scab-liner was punctured on the 27th November, after waiting for an hour to observe the well for gas, the crew continued to cut and pull the liner hanger. After this, the operation of pulling the scab-liner out through the PBR commenced.

According to the DOP, the drilling crew were to expect a u-tube effect due to brine in the annulus behind the scab-liner giving a pressure increase of 32 bar in the mud system, however, this effect was not observed, but the crew continued to observe the well periodically for volume changes. Later investigations showed that the reason no u-tube effect had been observed was because the casing spear that connected the drillstring and the scab-liner had no or faulty seal.

Later that evening swabbing was observed for the first time. In the first part of a pulling operation swabbing is consider normal. The scab-liner was then, as a compensatory measure to the swabbing, pulled slowly and periodical observations of the well were made.

On the night of the 28th November the scab-liner had been pulled up to under the BOP and the well was flow-checked prior to pulling the liner through the BOP, the well showed no signs of volume changes. The crew continued pulling the scab-liner through the BOP, blind and shear rams now blocked due to the scab-liner. Swabbing was observed and also mud losses occurred. During this operation the well was periodically flow checked and observed. After each flow check the well was determined stable and pulling proceeded.

During this operation there was continuous communication between the drilling supervisor, Offshore Installation Manager (OIM) and operations manager onshore about the development in the well.

During the discussions mentioned above, the involved personnel only discuss the actual sub-operation and not the affect these may have on later sub-operations.

Well control situation development

At 15.30 on the 28th November the annulus safety valve on the BOP was closed for the first time, as a result of the swabbing. After a short period of pressure buildup in the well, losses occurred.

The progressive issues with the well were the main concern on the installation management meeting at 17.00 and the scheduled emergency preparedness drill was cancelled. At about 18.00, after an attempt was made to reverse circulate the well, backflow of well fluids was observed, developing in an unwanted direction.

In order to gain control of the situation, at 19.00 mud reserves were established with 250m^3 OBM. Neither the shear ram, pipe ram nor kelly cock were accessible. The Kelly cock was covered by the skirts around the top drive and was therefore not operable. In order to put in a kill stand with internal BOP on a pressurized system the Kelly cock must be able to close.

The offshore installation manager called for an emergency meeting at 19.05 between himself, operations manager, production supervisor and safety manager. During this meeting, the decision was taken to mobilise the emergency response management to the emergency response centre. They were mobilised using a silent alarm.

At 19.14, gas was detected in the cooling water returns on the Vigdis subsea processing systems compressors. This was assumed to be an internal leak in the system and without further investigation of the cause of the gas detection the gas detectors were turned off in order to avoid the main power being shut down. The production from both Snorre and Vigdis subsea processing plants was stopped.

As a result of the undefined situation considering well P-31A and all the insecurities surrounding it, the offshore installation manager demanded manual process shut down at 19.30. All non-essential crew, all crew not involved in mitigation of the situation, mustered to the lifeboats. According to standard procedure, the following were alerted of the situation on board: emergency response vessel (Ocean Knarr) and helicopters (on Oseberg and Statfjord B), Statoils command centre at Forus, Rescue coordination centre at Sola (HRS) and PSA.

A transcript of the control rooms incident log shows that gas was detected in several modules: W07, W11, P17 and P18. Gas had seeped through the annular preventer in the BOP and out by the bell nipple.

At 20.42, 72 minutes after mustering to lifeboats the evacuation plan and the persons on board list was ready, 47 minutes later than SNAs performance requirement. Evacuation plan was completed after discussion with pilots regarding wind direction and safety of helicopter evacuation.

Between 20.58 and 22.05 the primary phase of the helo-evacuation completed and the crew was now reduced from 216 to 75 crewmembers. Amongst the evacuated crew were also SNAs ROV operators and this decision caused the ROV to be inaccessible on board. The remaining 75 crew members still on board were the drilling personnel included in the killing operation, emergency response management in the emergency response centre as well as emergency response teams which occupied lifeboat #1 in order for quick evacuation or in case they were needed.

There were not many options for killing the well at this point. The only possible well control action that could be taken was to pump mud both through the drillstring med scab-liner and/or down through the annulus. The pressure in the drillstring and the annulus is reduced from 130 bar to 10 bar and 80 bar to 4 bar respectively until 21.00. The skirts around the top drive were dismantled and the Kelly cock was closed at 21.10.

Gas was detected on the exterior of module F11 at 21.20 and several external gas detectors went off in the vicinity of F11 in the minutes that followed. When crewmembers were sent to inspect the area in question they reported back to the emergency response management that the ocean was “boiling” with gas, emergency shutdown (NAS 2) was activated manually; this also results in a main power shutdown. The installation was now operating on emergency power supply which means that large portions of the installation was without power in order to remove sources of ignition. The emergency shutdown process NAS 2 also causes shutdown of ventilation, overpressure and negative pressure, the fire pumps also start automatically when NAS 2 is activated.

For the first time at 21.38, full evacuation of the installation with lifeboat drops was considered as a result of gas to sea.

After NAS 2, low firewater pressure in ring pipes south, east and north was ascertained. Three different common alarms from three different dire pumps were registered in the control rooms alarm list. The shut down of the main power also resulted in a false alarm on the smoke detection unit in the ROV container.

Due to the blowout of gas from the seafloor possibly causing loss of buoyancy and stability of the installation a control room operator was set to continually keep an eye on the tension force in each leg. The official reports state that no change in tensile force was observed on any of the legs.

At 21.25, drilling module also started to run on emergency power. This resulted in decreased efficiency of the well control operations due to substantially reduced power supply to drawworks, rotation of drillstring and mud pumps. Until midnight they were unable to achieve sufficient pump rates to counteract the influx.

Several alternative solutions were now being discussed in order to regain control of the well, among these were complete cementing of the well. The cement pumps run on diesel engines and are therefore independent of the main power supply. This operation, however, posed a safety threat due to the fact that the diesel engine and cement module is ventilated by taking in air from underneath the installation and this could potentially lead to suction of gas into the cement module and diesel engine. Actions were implemented in order to reverse the intake of air for the diesel engine.

At approximately 21.45 a short recess in the helo-evacuation was taken whilst evaluating the possibility of gas on the helo-deck. Due to favourable wind direction and conditions it was concluded that helo-evacuation could continue.

Manual pressure relief of the well commenced at 21.50.

At 22.45 the decision was made to restart the main power supply in order to achieve enough power to continue with the killing operation. When this decision was made the emergency response management had two options, either to fully evacuate the installation or to turn the main power supply back on. At this point gas had not been detected since 21.33, which was the basis for the decision. However, the emergency response management still looked at this action as critical.

The vessel Normand Mjølne was in the vicinity of SNA and set in high alert with regards to FIFI-emergency response (fire-fighting) together with another vessel, Ocean Knarr. FIFI-emergency response entails that the vessels kept there main engines running so that the time taken to get full effect of the FIFI-monitors was reduced from 12-14 minutes to 2-3 minutes to ensure a short response time in case the gas was to ignite.

The crew which had mustered to lifeboat #1 from 19.30 were given the opportunity to collect warm blankets and so on, they were also affected by the high noise generated by the fire pumps and emergency generators which made it difficult to hear the PA messages in the lifeboat. At 22.50 the crew was moved to lifeboat #4 after observations of a lot of gas in the sea beneath lifeboat #1.

The critical operation of rebooting the main power supply commenced at 23.52. Simultaneously, the wind direction changed due west and diminished so that by midnight there was almost no wind. For the second time this night SNA was again prepared for quick evacuation of personnel and requested high helicopter response alert.

Statoil request an expanded safety zone from Ptil. The safety zone is now expanded to a radius of 2000m and height of 3000ft.

When the main power supply had been shutdown the ventilation had done the same, this meant that the local supply rooms were without ventilated air and the doors had been kept open to avoid overheating. Some of the rooms also lost their overpressure protection. The remaining crew on-board did rounds to monitor these areas.

Between 01.25 and 01.30 another 40 crewmembers were evacuated in 3 helo-lifts. The team, which had been waiting in lifeboat #4, was now evacuated after 6 hours in a lifeboat. There was at this point now only 35 people left on-board the installation.

At 01.00 OBM was bullheaded into the well and pressure decrease was observed until 02.30, at this time there was no more pre-mixed OBM mud left, including the reserves. The drilling crew mixed another $80m^3$ of OBM between 02.30 and 04.00, since the reserves were empty the only action they could do whilst mixing mud was to observe the well. The pressure increased to 120bar inside the drillstring and 84bar in the annulus.

A confirmation of the extinguished flare was logged at 03.15.

By 03.30 the wind had once again changed direction to south/south-west and forces increased to 17-10knots.

80 m^3 OBM was confirmed mixed at 0400 and was bullheaded into the well until the reserves were once again empty. After 0530 there was no more OBM left on board and due to the gas conditions in the sea and in the vicinity of the installation, supply vessels with mud were not an option. At this time the following pressure readings were recorded: 32 bar inside the drillstring and 55 bar in the annulus.

Several possible actions were discussed and considered: Cementing, use of seawater or mixing of emergency mud using the additives available on the installation. The decision was made to go for the latter option and water based mud (WBM) was mixed using water, barite and bentonite. Between 0400 and 0915 the crew mixed $160m^3$ WBM having a specific density of 1.8, whilst continually observing the well.

The emergency response management saw this operation using WBM as the final attempt to stop the influx into the well. The purpose of waiting prior to starting bullheading, using WBM, was that it was desirable to have sufficient volumes of WBM during this last attempt.

Prior to starting the bullheading operation with WBM at 0900 a heightened evacuation response was for a 3rd time requested from the installation.

The pressures recorded prior to bullheading with WBM were 156 bar in the drillstring and 72 bar in the annulus. Bullheading started and at 1022 the crew confirmed 0bar pressure in the drillstring and 0bar pressure in the annulus. At this point only $8\text{-}10m^3$ WBM was left in the tanks.

Observations

Table 8 - Observations SNA interpreted during the present thesis from Austnes-Underhaug (2005), Nygaard and Skoland (2011) and Schiefloe et. al. (2005).

No.	OBSERVATION
1	Operatorship changed from Hydro to Statoil in 2003 - altering operating philosophy and steering documentation
2	Establishing a functioning RESU unit has been time consuming
3	Implementation of Tampen RESU unit has caused confusion in the Snorre organisation
4	Deviation between audit (2004) and planning of P-31 A
5	Method used in internal audits do not reveal insufficient compliance with governing documents
6	Milestones during planning not according to governing documents
7	Planned with insufficient barriers
8	Consequences of alterations in plans not analysed
9	Inadequate experience transfer related to well integrity
10	Planned with inadequate well barrier during cutting of scab-liner
11	Pulling of scab-liner planned without consideration to the overall risks involved
12	Compensating measures not implemented with regards to blocking BOP in open position
13	Inadequate management involvement with respect to prioritization of peer assist
14	Approval routines not according to governing documents
15	Signature page not in compliance with governing documents
16	Overall risk evaluation meeting cancelled during planning
17	Inadequate experience transfer regarding previous incidents
18	Inadequate understanding of deviation processes
19	Lack of understanding related to terms used in governing documents
20	Inadequate approval of executed HAZOPs
21	Result of HAZOPs not communicated to executing crew
22	Previous incidents not taken into consideration in risk assessments regarding swabbing
23	Insufficient job description and responsibilities
24	Drilling contractor not involved in planning of operations
25	Statoil changed drilling contractor short time prior to the accident, several personnel new to the installation as well as Statoils own drilling supervisor
26	Working methods do not include implementing competency from principal environments in the organisation
27	Program engineer was a hired consultant left to plan mainly for himself
28	Poor prioritization of resources from management
29	Low prioritization of planning meetings from involved personnel

No.	OBSERVATION
30	Compensating measures not implemented regarding securing the secondary barrier after puncturing tailpipe
31	Stop of operation not initiated as a result of insufficient barrier status, communication with reservoir.
32	Principal personnel do not evaluate the overall risk of altering program
33	Risk contributions taken out of DOP
34	Pressure testing of secondary barrier not performed
35	Preparation for a well control incident not according to drilling contractors "golden rule"
36	Compensating measures not implemented when pulling scab-liner through BOP
37	Kelly cock valve blocked when well control incident developed and annulus valve in BOP was closed
38	Accident severity downgraded by onshore management, later upgraded to severity RED
39	Communication issues between emergency preparedness line 2 and PSA due to wrong telephone number
40	Statoil unaware of who to contact regarding expanded safety zone
41	ROV container experienced several smoke alarms, false alarms as a result of the container being classified as temporary despite being onboard for several years
42	Offshore emergency personnel contacted directly by PSA and HRS, this communication should have gone through line 2
43	Emergency personnel exposed to unnecessary danger while sitting in lifeboat #1 for 6 hours
44	Startup of operations initiated earlier than planned
45	High activity on installation at time of accident
46	Rig unprepared for pulling operation
47	ROV operators evacuated
48	Crew on lifeboat #1 unable to hear messages given on PA due to external noise
49	Drilling management offshore underestimated the risks involved and a risk assessment was not completed prior to each activity/DOP

Appendix B. WELL CONTROL INCIDENT ON GFC

Complete sequence of events

The well control incident as presented in its entirety below is extracted from Talberg et. al. (2010) investigation report.

History

Well C-06 was drilled in 1991. In 2008 production seized and the well was plugged back in 2009 in order to drill the sidetrack C-06A. C-06 is a well without gastight threads in 13 3/8" casing, as well as poor cement towards the 20 " casing. Hydrocarbons have been present in the B- and C- annulus.

September 30th 2009 the drilling program for conventional drilling of C-06A is approved with the following main risks:

- Drilling in to high pressure zone
- Unable to get 9 5/8" x 10 ¾" extension tubing to planned depth
- Small window between pore and fracture pressure
- Unexpected pore pressure, undrillable well and unplanned mobilization of MPD
- Difficulty regarding good cement job on 7" tubing

During November 2009, well C-06 is plugged and abandoned (P&A) and pore pressure at the top of the Shetland group was measured at 1,72 s.g. A USIT-log was run and the 13 3/8" casing and cement evaluated. The results of the USIT log showed 14% general wear throughout the casing, variable cement bond quality behind the 13 3/8" casing, dislocation of logging tool between 1420 and 1430 mMD indicating possibly larger wear in this area.

Operations

Drilling of 12 ¼" x 13 ½" section in well C-06A commences. The plan is to stop drilling and set the 9 5/8" casing far enough above the high-pressure zone in the Shetland Gp. On December 23rd the well experiences a kick as well as loss of mud to formation. The kick came from the Lista formation, with pore pressure above 1,70 s.g. The formation at the 13 3/8" shoe leaks off at 1,68 s.g. whilst the prognosed fracture pressure was at 1,85 s.g. As a result of this incident a compensatory action is to execute an XLOT in order to find the minor horizontal stress.

On December 28th this incident is classified as severity Red level 1 (actual), however, it is not investigated according to regulations for such a classification. It is classified as qualitatively red and HSE-wise yellow.

By the end of January 2010 the well is secured by setting cement and mechanical plug inside the 9 5/8" liner. Due to the incident the 10 ¾" x 9 5/8" liner was set at 2427 mMD compared to planned depth of 2704 mMD. Planning of the further operations on C-06A starts.

Conventional drilling on C-06A resumes on March 1st, with a smaller drilling window than previously assumed. After the incident stated above the maximum pore pressure has increased from 1,72 s.g. in the Shetland formation to 1,73 s.g. in the Lista formation. Estimated fracture pressure is now 1,83 s.g. at the 9 5/8" shoe.

Drilling of C-06A ceases on March 9th whilst drilling of C-06AT2 commences.

Three days later C-06 AT2 is plugged back as a result of losses while drilling out of shoe. Total lost is 85 m^3 mud with a mud weight of 1,72 s.g. at the 9 5/8" shoe.

An XLOT performed at 2420 m MD on March 13th shows 1,79 s.g. in reopening pressure, which is lower than the 1,83 s.g. prognosed formation strength. Drilling starts on C-06 AT3 using a 8 ½" x 9 ½" BHA before drilling is ceased on March 19th and fractures caused by the XLOT are cemented.

Between March 13th to 20th alternative solutions are considered, due to the new pressure prognoses, and the decision is made to continue drilling using MPD techniques. This decision is made without regarding the effect this change to the operation will have on the drilling program or risk register is documented or approved. The transition from conventional drilling to MPD implies the following alterations:

- New drilling method (MPD)

- New requirements due to common barrier elements
- Altered conditions regarding relief well
- New safety margins
- Change in kick margin
- New requirements regarding training

The decision to drill a 2300 m long reservoir section is made with the following starting point:

- MPD operations are to be executed using 1,52 s.g. mud, approximately 42 bar back pressure and maximum allowed variation in well pressure of ± 2,5 bar.
- Conventional part of operation to be executed using 1,75 s.g. mud.

At this point the highest pore pressure in the well is 1,73 s.g. (1740 mTVD) and measured fracture pressure is 1,79 s.g. (1644 mTVD), this implies that:

- The MPD-operation has a margin of ± 0,85 bar towards losses and influx, as well as the presupposed operational window of ± 2,5 bar.
- Requirements to margins against kicks for the conventional part of the MPD operation, which is 4 m^3 in a 8 ½" hole, are not met.

The static mud weight of 1,52 s.g. is lower than the prognosed collapse pressure of the formation (1,55 s.g.)

The Final Well Report (FWR) for well C-01 including MPD operational experience is at this point not prepared and the experiences/learnings are not available.

When starting to drill C-06 AT4 on March 20th losses of 8 m^3 are experienced as well as an influx of 440 litres during an hour.

A successful pressure test is executed on March 24th of the 13 3/8" and 10 ¾" x 9 5/8" casings to 83 bar for 10 minutes. In accordance with best practice in the Statoil organisation, it is applied for a dispensation from requirements regarding two independent barriers in the crossover from conventional to MPD operations. It is sought for dispensation despite the fact that there is acceptance in APOS for a common barrier element during MPD operations.

Rig up of the MPD equipment starts on March 23rd by Halliburton. The dispensation application is approved on March 31st with the risk assessments presented. Casing and cement as a common barrier element is not included in these assessments.

Another successful pressure test of 13 3/8” casing and 9 5/8” x 10 ¾” liner to 83 bar for 10 minutes is executed on April 5th, as well as successful inflow test in MPD mode using 1,52 s.g. WARP mud.

Trip gas of 7,3% is experienced whilst circulating bottoms up (BU) at 2360 mMD on April 7th.

On the following day, April 8th, the wellhead pressure (WHP) is set at 119 bar (295 bar standpipe pressure (SPP)), most likely due to operating error.

Drilling out of the cement is finished on April 13th and ready to sidetrack C-06 AT4. 82 m^3 have now been lost since April 11th.

C-06 AT5 is drilled in MPD-mode starting on April 13th. Five days later on the morning of April 19th trip gas of 7,1% is experienced, increasing the target ECD to 1,77 s.g. which again results in even more gas (TG=9,5%), this effect is referred to as ballooning[8]. The ballooning effect indicates that the well cannot withstand the target ECD of 1,77 s.g. A draw-down test is executed later that day in the Lista formation at 2664 mMD showing a pore pressure of 1,73 s.g. This coincides with the previously assumed pore pressure.

During the time period from April 22nd to the 29th a pressure increase in the C-annulus occurs from 12 to 18 bar resulting in a weakened barrier envelope. C-annulus pressure is normally registered once every 24 hours by production operator, however, this pressure increase is not detected.

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[8] A phenomenon in which fluids are lost to the rock during over-pressured operations, such as found in increased pressures from equivalent circulating density operations, and then flow back when pressure is reduced. This may be confused with a kick (SPE E&P glossary 2012).

The well experiences underbalance on April 22nd whilst changing the PCD packing element due to leakage through stripper annular. This does not allow the well to stay within the ± 2,5 bar margin.

Whilst changing the PCD packing element on April 24th, the volume on the trip tank is increased, the stripper annular is leaking and the WHP decreases from 43,34 to 5,71 bar (underbalance). Gas is circulated out of the well.

Despite the fact that the issues related to the PCD packer element causes underbalance in the well, operations proceed as planned without implementing sufficient compensatory measures.

Between April 30th and May 1st the well is displaced to 1,75 s.g. prior to POOH. A kick is experienced (350 litre) with consequent well control situation when pulling drillstring out of hole. This incident is registered in Synergi with severity Yellow level 3 (Possible). Operations continue without implementing compensatory measures.

Another increase in the C-annulus occurs between May 10th and 18th from 12 to 20 bar again weakening the barrier envelope. The pressure change is not detected.

During the period from May 5th to the 19th the is drilled to TD (4800 mMD) with periodical challenges with both the well and tools experienced:

- Change of PCD packer element with simultaneous leakage in stripper annular
- Problems regarding backpressure, feeding and cement pumps
- Uncertainty whether the hole opener has worked
- Several incidents of loss and influx
- Periods of underbalance
- Leakage in mud system and difficulties shearing mud.

Well control situation development

The well control incident that occurred on well C-06 AT5 happened on May 19th 2010.

At 11:39 the suction pressure is lost on the back pressure pump as well as all other pumps used in operation. The MPD-choke pressure decreases from 45 to 33 bar at 12:32 (underbalance in the well for 8 minutes) and then increases to 43 bar. Due to changing of the PCD packer element the drillstring is pulled off bottom and is now standing with the BHA in a shale zone.

Between 12:23 and 13:14 the well is shut in using the rig annular, whilst the back pressure pump is being repaired.

At 13:32, using the cement pumps, 800 lpm is pumped into the well with 800 lpm in return. 14 minutes later at 13:46 the back pressure decreases from 45 to 13 bar over the MPD choke and it is no longer a possible to maintain the back pressure. This occurs in conjunction with pulling the PCD packer element. 800 lpm are pumped without returns over the MPD choke confirming loss to formation. At this point, one of the wells common barrier elements is broken. The 20” shoe loses its integrity and fluids are injected into the formation. 13 bar + 1,52 s.g. static coincide with LOT at 20” shoe.

The backpressure stabilizes at 13 bar after 20” shoe is broken. The well is losing mud, taking influx from the reservoir and the drillstring is possibly packed off. The mud weigh (1,52 s.g.) plus 13 bar is lower than the pore pressure in the Lista formation and Shetland Gp.

There is here an incident with potential for underground blowout that baffles both the on- and offshore crew.

From 13:57 the rigs BOP is closed using annular preventer and efforts are being made towards the demanding well control incident with underbalanced mud in the hole, which the crew is not prepared to handle.

From 15:57 gas is detected in the mud processing area with consequent automatic general alarm and mustering. POB is OK after 23 minutes, meeting the 25 min requirement.

Vaktsentralen is alerted by crew on GFC who, according to procedure, alert line 2. During the following conversation between emergency response leader on GFC and emergency response manager line 2 the emergency response leader perceives the conclusion to be that line 2 are to muster, whilst line 2 understands that this is not necessary at this point.

Between 16:19 and 18:41 the north and south shaft on GFC are shut down.

New gas detection takes place in the mud processing and drilling area at 17:51 with automatic initiation of general alarm.

From 19:15 to 19:27 the south shaft is again up and running without the crew being aware of the pressure build up in the C-annulus, this has now increased from 20 to 38 bar from May 18th to the 20th. No pressures are read on May 19th.

At 20:00 an attempt is made to pull the drillstring. The drillstring is stuck with the bit at 4573 mMD.

The following day, May 20th, the organisation is made aware of the pressure increase in the C-annulus, this has been read at 05:00 showing 38 bar.

Production is shut down from 18:13 to 21:03 and personnel without emergency preparedness tasks are demobilized. D&W establish an emergency preparedness organisation onshore.

The first cement plug is set on May 31st between 3290 and 4573 mMD in order to isolate the reservoir from the Shetland Gp.

Cement plug number two is set on June 7th to stop the flow from the Lista formation and Shetland Gp into the well, it is set inside shoe until 9 5/8” liner at 2427 mMD.

A hole in the 13 3/8” casing from 1408 to 1420 mMD is localised on July 10th. Cement plug number three is set on top of the mechanical plug (set at 2043 mMD) between 1848 to 2043 mMD.

On July 14th a 10 ¾” tieback is installed, sealing the hole in the 13 3/8” casing against the well. The well barriers are re-established and the normalisation phase is ceased.

Observations

Table 9 - Observations GFC interpreted during the present thesis from Gundersen et. al. (2010), Nygaard and Skoland (2011) and Talberg et. al. (2010).

No.	OBSERVATION
1	Merger between Statoil and Hydro in 2007 created many personnel challenges, including harmonizing work processes and governing documents
2	Access to installation specific competency lacking as a result of the 58+ exit package
3	Management underestimated the technological complexity of GF field
4	GF organisation is seen as rigid and difficult to manage, do things their own way without consideration of governing documents
5	Complex governing documents when integrating DocMap and APOS
6	Contingency plans do not cover loss of common barrier element in a well control incident
7	Planned with insufficient pressure margin
8	Inadequate risk evaluation regarding use of 13 3/8" casing with inadequate technical integrity
9	Risk assessments not completed according to governing documents
10	Risk coordinator not appointed in compliance with governing documents
11	Risk assessment group not composed of necessary expertise
12	The need for different analyzes had not been assessed. (Ex. HAZID, HAZOP, impact study etc.)
13	Risk reviews conducted did not reflect the wells complexity and risk category
14	Higher levels of risk definition efforts in relation to the high WCI were not implemented
15	Well planned as a standard well without increased attention to risks associated with altering the plan or incidents during operations
16	Inadequate risk assessment regarding corresponding well drilled using MPD techniques (C-01)
17	Risk analyses were not completed and risk reducing measures implemented according to ALARP principles
18	Risk register did not reflect the risk analyses and discussions in the planning group
19	Risks related to circulation of heavy fluids/cement did not reflect the results from simulations
20	Experiences related to kicks/losses while pulling out during MPO were not included in the risk review
21	Assessment and approval of rest risks in the risk register (yellow and red risks) were not signed according to governing documents on several accounts
22	Risk register did not include all the minimum information requirements.
23	Most documentation from risk review lack list of participants according to governing documents

No.	OBSERVATION
24	Drilling of 8 1/2" hole and cementing of 7" liner were treated in several documents in the risk register, however with different risks identified and different evaluation of the risks identified
25	Planning personnel not aware of requirements regarding process related to execution of risk reviews
26	Planning personnel unclear as to who was required to be present/involved in risk analysis - risks analyses executed without involving principal personnel
27	Insufficient capacity in the organisation to plan both conventional and MPD operations simultaneously prior to start up of operations
28	Individual reporting in DBR regarding quality of reporting. Insufficient in instances regarding collecting experiences from previous incidents/operations
29	Lack of evaluation of previous experiences relating to the possibility of higher pressure above Shetland
30	Lack of evaluation of experiences relating to kicks in wells B-30 and A-36
31	Experiences regarding poor cement in previous wells were not addressed
32	Lack of operational experience with MPOs in the planning organisation
33	Involved personnel had relatively short experience with the Gullfaks field
34	Personnel with operational experience regarding MPOs on Gullfaks were not involved in planning
35	Inadequate use of peer assist/Peer Review in conjunction with planning
36	Learning processes, including "workshops", were not used during planning
37	Gullfaks organisation chose not to utilize competence outside their organisation despite principal personnel on well integrity and MPOs had offered their assistance
38	The MPD principal community in Statoil were in a small or to no degree involved prior to the final stage where it was decided to used MPD techniques
39	Pressure development in Shetland/above Shetland was inadequately monitored regarding the development of good and precise pressure prognoses
40	MPD community were not involved in PETEKs decision regarding drillability or classification of wells drilled using MPD techniques
41	MPD was not planned as an actual alternative for the majority of the planning phase
42	Elements relating to well execution were insufficiently examined prior to operations
43	Risk analysis did not compensate for the complexity of primary barrier and challenges relating to common barrier element. Alternatives relating to loss of barriers were not planned for
44	Requirement regarding competence related to MPOs were not implemented. Very few of involved personnel had taken the required e-learning courses, safety training and simulator training
45	Planning department experienced communication issues between principal personnel within GF and MPD competent personnel in TNE

No.	OBSERVATION
46	General insecurity about the definition of key concepts in governing documents
47	Inadequate documentation of decisions and basis for them, including method choice and risk assessments
48	Lack of compliance with requirements related to managements job description. This includes requirements seeing to that the operation is planned and executed according to company requirements, HSE policy and strategy
49	Statoil still has challenges relating to the companys ability to involve necessary principal personnel during planning and risk assessment even after putting in a lot of work into bettering the situation after blowout on SNA
50	The existing plan for relief well at the time of operations start-up could not have been used if needed looking at the formation conditions
51	Calculated kick margin of 2,4 m3 does not comply with requirement for kick-margin for MPD which is 1 m3
52	Lack of monitoring and control of C-annulus pressure
53	Drilling supervisor and tool pusher perform shift change at the same time
54	Continued operation despite complications with PCD equipment
55	Continued operations despite experiencing kick
56	Drillstring used in MPD operations was not checked out according to governing documents relating to well integrity
57	Change log not updated or signed according to governing documents, unable to read from the log whether the changes were implemented or not
58	Responsible personnel were not made aware of the results, conclusions and recommendations following the assessment after loss of well control in the well during December 2009
59	Several people thought that the incident in December 2009 should have been investigated more thoroughly
60	Lower pressure than pore pressure during inflow tests after having observed a pore pressure of 1,73 s.g. during a previous inflow test further up in the well
61	Shear ram not certified according to cutting of the drillstring being used
62	Miscommunication between drilling supervisor and on-duty staff manager line 2 regarding mustering of the emergency preparedness organisation
63	Severity of the situation underestimated by line 2 organisation

Appendix C. RESULTS TABLES

Table 10 - Explanation strength HF

	SNA		GFC		COLLECTIVE	
Procedures	2,43	9 %	4,95	16 %	7,38	12 %
Organisational culture	1,62	6 %	5,22	17 %	6,84	11 %
Organisational change	1,44	5 %	3,15	10 %	4,59	8 %
Design error	3,24	12 %	2,88	9 %	6,12	10 %
Management and supervision	6,12	22 %	3,96	13 %	10,08	17 %
Training and competence	**8,01**	**29 %**	**6,12**	**19 %**	**14,13**	**24 %**
Communication	3,96	14 %	4,68	15 %	8,64	15 %
Fatigue	1,26	4 %	0,45	1 %	1,71	3 %
Total	28,08		31,41		59,49	

Table 11 - Explanation strength per subclass [%]

	SNA	GFC	COLLECTIVE
PROCEDURES			
Inadequate planning procedure	4 %	2 %	3 %
Inadequate safety procedure	3 %	12 %	8 %
Inadequate reporting procedure	1 %	2 %	2 %
ORGANISATIONAL CULTURE			
Safety culture	6 %	9 %	7 %
Guiding safety principle	0 %	4 %	2 %
Inflexible organisation	0 %	4 %	2 %
ORGANISATIONAL CHANGE			
Inadequate change process	2 %	8 %	5 %
Integrating HF	0 %	2 %	1 %
Inadequate evaluation of change	3 %	0 %	1 %
DESIGN ERROR			
Planning error	7 %	5 %	6 %
Equipment design error	4 %	4 %	4 %
MANAGEMENT AND SUPERVISION			
Lack of management prioritization	3 %	0 %	1 %
Inadequate auditing	5 %	0 %	2 %
Inadequate follow-up of operations	4 %	7 %	5 %
Inadequate resource management	10 %	6 %	8 %
TRAINING AND COMPETENCE			
Lack of competence	18 %	14 %	16 %
Lack of procedural training	9 %	5 %	7 %
Inadequate task analysis	1 %	0 %	1 %
COMMUNICATION			
Poor quality of information	4 %	3 %	4 %
Poor quality of communication	3 %	8 %	6 %
Inadequate application of information	7 %	3 %	5 %
FATIGUE			
External fatigue factors	4 %	1 %	3 %
Personal fatigue factors	0 %	0 %	0 %