Operational Barrier Elements in Critical Drilling Operations

Understanding failure mechanisms in the control of the primary well barrier

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Abstract

The thesis includes a qualitative human reliability analysis of a operation performed in offshore drilling. The operation is called 'trip out of hole' and constitutes all actions required by rig personnel to retrieve the entire drill-string, bottom hole assembly and bit from the bottom of the well. Maintaining primary well control throughout the operation means ensuring there is a positive pressure differential between the column of mud in the well and the pressure of the fluid inside the pore spaces of the exposed formation. If overbalance is lost, formation fluid will rush into the well and the situation must be controlled by means of a blowout preventer. The thesis makes use of HRA methods to identify and causally represent potential human errors which may cause such an influx to occur. A hierarchical task analysis has been developed, and human error identification performed. Lastly, the relevant errors have been combined with technical faults in a fault tree for the top event 'primary well control failure occurs during trip out of hole'. The fault tree logically depicts the basic events which by themselves, or in combination with other basic events, are sufficient to cause the top event to occur.

Introduction

The Petroleum Safety Authority (PSA) has established barriers as one of their main priority areas in 2014 [2]. The barrier system definition, as presented by the PSA, is holistic and hierarchical. It comprises an envelope of technical, operational and organizational barrier elements. QRA, which is used to estimate major accident risk for offshore facilities, should in line with this definition include operational and organizational elements in the modeling of accident scenarios. Unfortunately, this is currently not standard practice [3]. The nuclear industry has for several decades used Human Reliability Analysis extensively in conjunction with Probabilistic Risk Analysis (PRA) of Nuclear Power Plants (NPPs). The benefit with such a combination of methods is quite obvious; it allows the risk model to measure the human contribution to risk. The overall goal of the work has been to see how HRA methods may be used to include operational barrier elements in the initiating event of a blowout scenario. The thesis therefore includes a thorough introduction into several fields of study which all are relevant for primary well control.

Main Objectives

The work has been aimed at achieving the following objectives:

1. Provide an introduction into the use of, and weaknesses in, QRAs.
2. Discuss the theory and practical use of HRA, both the qualitative and quantitative parts.
3. Discuss the theory of well integrity with emphasis on well barriers and well barrier elements.
4. Present relevant theory of pressure control in conventional drilling.
5. Identify the causes of primary well control failure and how they can be detected.
6. Perform a qualitative HRA case study for 'trip out of hole', including:
   (a) System description.
   (b) Task Analysis.
   (c) Human Error Identification.
   (d) Fault Tree Analysis with top event 'loss of primary well control'.
7. Discuss results of analysis.
8. Discuss applicability of HRA in a QRA context.

Materials and Methods Used

The discussion of theory in QRA, HRA, well integrity and pressure control has been based upon a thorough literature survey. From the information obtained in the survey, it was decided to perform a case study for tripping. The foundation of the case study was laid in a visit to a drilling simulator at Bergen Maritime College, where an experienced driller showed the author how to perform the operation. Based on this visit, and review of a well control procedure by a commercial drilling company, a hierarchical task analysis was performed. The HTA diagram decomposes a task, which is an overall objective or goal state to be reached, into smaller and more manageable units of behavior.

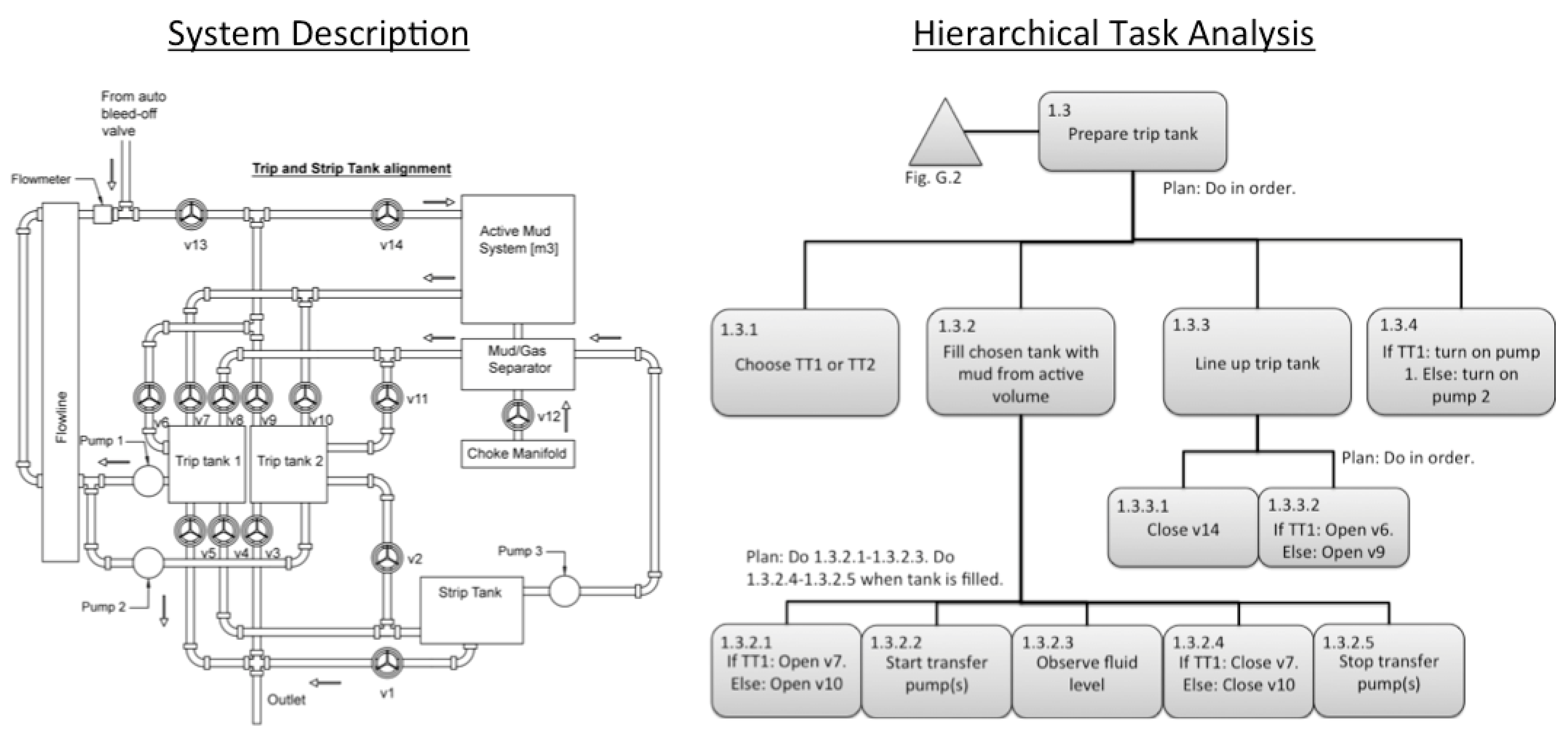

Figure 1: Excerpt from the hierarchical task analysis. Preparing trip tank for trip out of hole.

When the decomposition reaches a level at which so-called action or diagnosis activities are located, further decomposition is stopped. A diagnosis is a '*cognitive assessment of the state of the system*' [1], whereas an action is '*the observable result (often a bodily movement) of a person's intention*'[1]. Guide-words are then systematically applied to each element in the HTA. Each guide word prompts the analyst to consider deviations from expected performance. Examples of such guide words include 'operation omitted', 'operation incomplete' and 'right operation on wrong object' [4]. This is the method by which potential human errors are identified. The errors are divided in the categories (1) kick occurrence, (2) kick detection and (3) secondary well control, according to their consequences. The human errors relevant for kick occurrence have been modeled in a fault tree. The fault tree does not contain only the applicable human failure events, but also technical failures in the trip tank system.

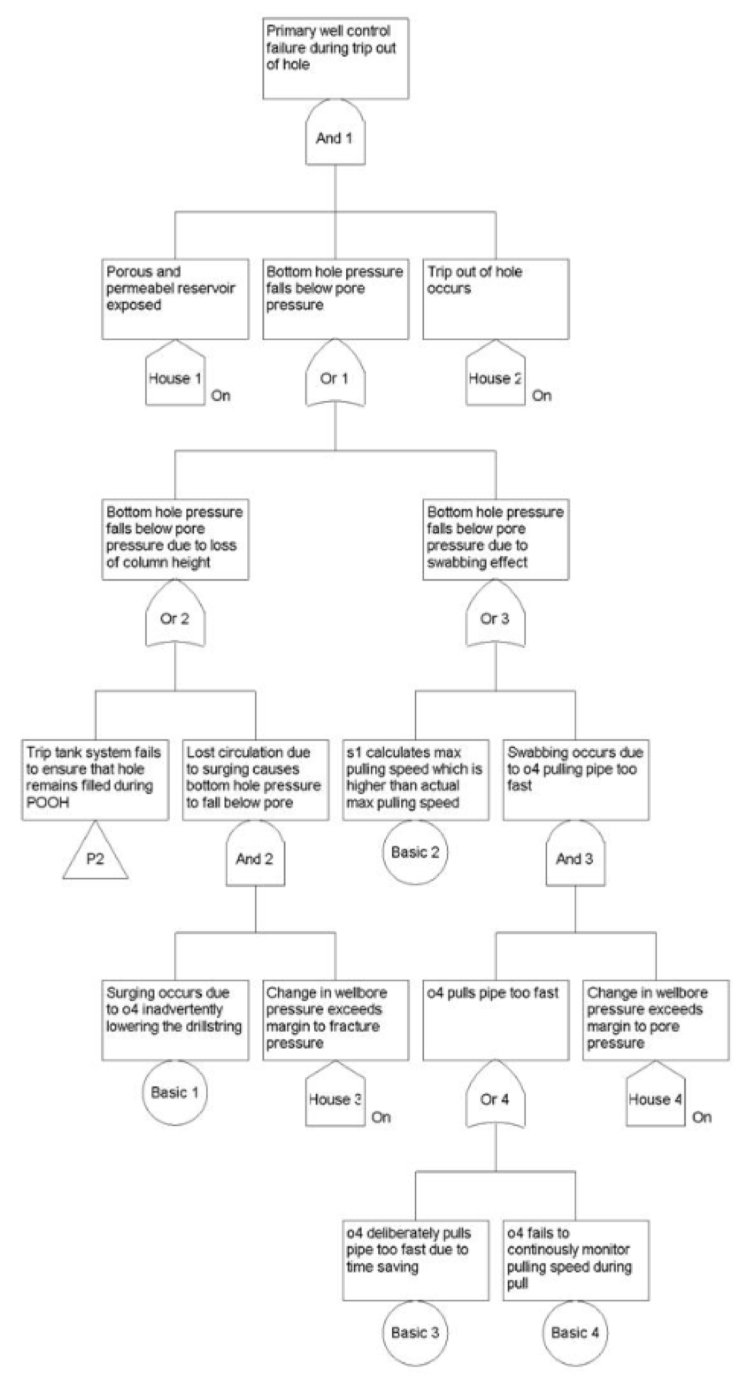

Figure 2: Fault Tree Model: Page 1.

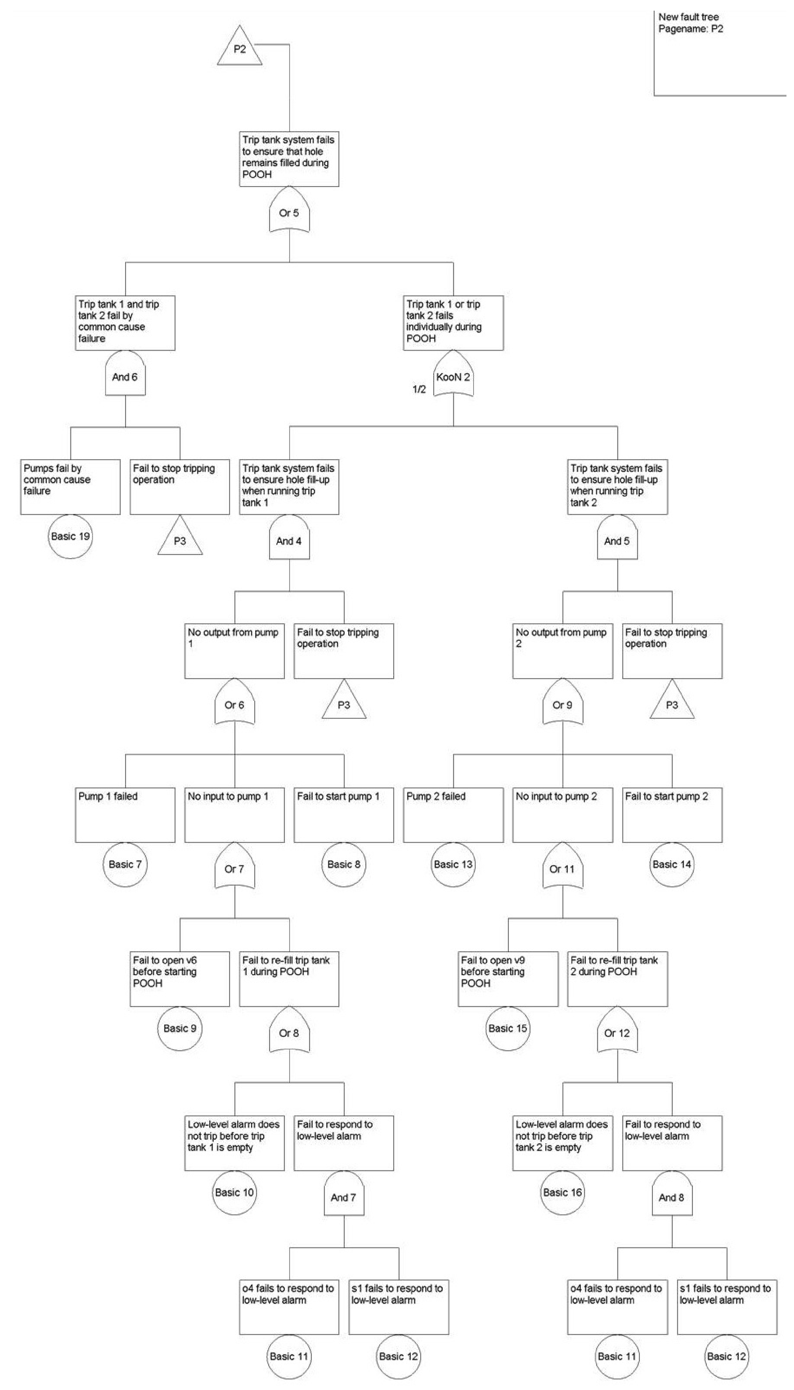

Figure 3: Fault Tree Model: Page 2.

Results

The fault tree model produces four minimal cut-sets of first order. House events representing breach of pressure margins are not included. All of these basic events are human errors. The errors relate to swabbing and surging, which are dynamic pressure changes in the mud due to drill string movement. The other minimal cut-sets are of fifth and sixth order. They contain errors pertaining to the trip tank system, which is the system used to ensure that the well remains full of mud while the drillstring is being removed.

Cut-set no.	Basic Event(s)	Description
1	{Basic 1}	Surging occurs due to driller inadvertently lowering the drillstring
2	{Basic 2}	Mud logger calculates max pulling speed which is higher than actual max pulling speed
3	{Basic 3}	Driller deliberately pulls pipe too fast due to time saving
4	{Basic 4}	Driller fails to continuously monitor pulling speed during pull

Table 1: Minimal cut-sets of first order.

Conclusions

- Loss of primary well control during tripping is likely to be dominated by surging/swabbing.
- Improper hole fill-up has marginal effect on top event probability, due to considerable human redundancy.
- The analysis demonstrates that human error can be systematically identified, represented and combined with technical failures.
- QRA as a tool for risk-informed decision support would benefit from modeling human error explicitly.
- Frequencies for events where human errors lie in aggregated form does not provide a platform from which to propose error reduction measures.

References

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