# BOP Risk Model development and applications

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**Abstract:** Deepwater drilling operations typically involve a critical safety system called BOP (Blow Out Preventer), which is latched onto a wellhead and situated on the seabed. It is the final and ultimate line of defense in protecting life and the environment throughout drilling operations. It is thus important to make sure the BOP will function when it is required. When a failure is detected in a certain system or component on the submerged BOP, the industry's typical response is to analyze the possible consequences and perform a risk assessment in order to define risk levels. If the risk level is increased above the certain level, the drilling has to be stopped and BOP needs to be pulled to the surface to fix the problem. To stop the drilling and pull the BOP to the surface for manual inspection is a very costly and timely operation.

To support the BOP pull or no pull decision, there is a need of a risk-informed model which quickly defines the change in operational risks based on the BOP status. This model must be transparent, verifiable and with the subjectivity removed. The BOP Risk Model is realized using traditional risk- and reliability modeling methods. The risk model is made available for drilling rigs staff using a risk monitor interface that can be used for visualizing operational risks.

The paper describes the model development process, involving: (1) identify key BOP functions; (2) establish block diagrams for each function; (3) FMEA; (4) establish fault trees based on the logic block diagrams and FMEA; (5) Integrate the fault tree model into the risk monitor. A case study will be given using the BOP Risk Model for decision making.

**Keywords:** Blowout Preventer (BOP), Risk Model, Drilling, Oil & Gas.

## 1. INTRODUCTION

A Blowout Preventer (BOP) is a critical part of the safety of an offshore drilling, and is often the final line of defense for protecting life and environment. In deepwater and ultra-deepwater drilling operations, a BOP is required to be latched onto a wellhead, situated on the seabed. When a failure is detected in a certain system or component on the submerged BOP, a great challenge for the industry is to decide what to do with the failure [1].

Stopping drilling and pulling the BOP to the surface for manual inspection and reparation is a very costly and time-consuming operation. Some failures are critical and if they happen, the drilling operation must be stopped. Some of the potential failures are not critical to the safety of a drilling rig. There are also levels of redundancy available in the BOP.

The industry is therefore in need of a BOP Risk Model to quickly define changes in the operational risks reflected by the available redundancy for the BOP functions. This model must be fully transparent, verifiable and with the subjectivity removed [2].

The BOP Risk Model is realized using traditional risk- and reliability modeling methods in RiskSpectrum® PSA software. The risk model is then made available for drilling rigs staff using RiskSpectrum® RiskWatcher that can be used for visualizing operational risks.

The paper describes the BOP Risk Model development process, involving: (1) identify key BOP functions; (2) establish block diagrams for each function; (3) FMEA; (4) establish fault trees based on the logic block diagrams and FMEA; (5) Integrate the fault tree model into the risk monitor. A case study will be given using the BOP Risk Model for decision making.

## 2. BOP RISK MODEL DEVELOPMENT

### 2.1. Identify key BOP functions

A BOP is a quite complicated system consisting of a number of subsystems and redundancy in the design. The following figure shows a typical example of BOP functions, and the generic failure modes for these functions.

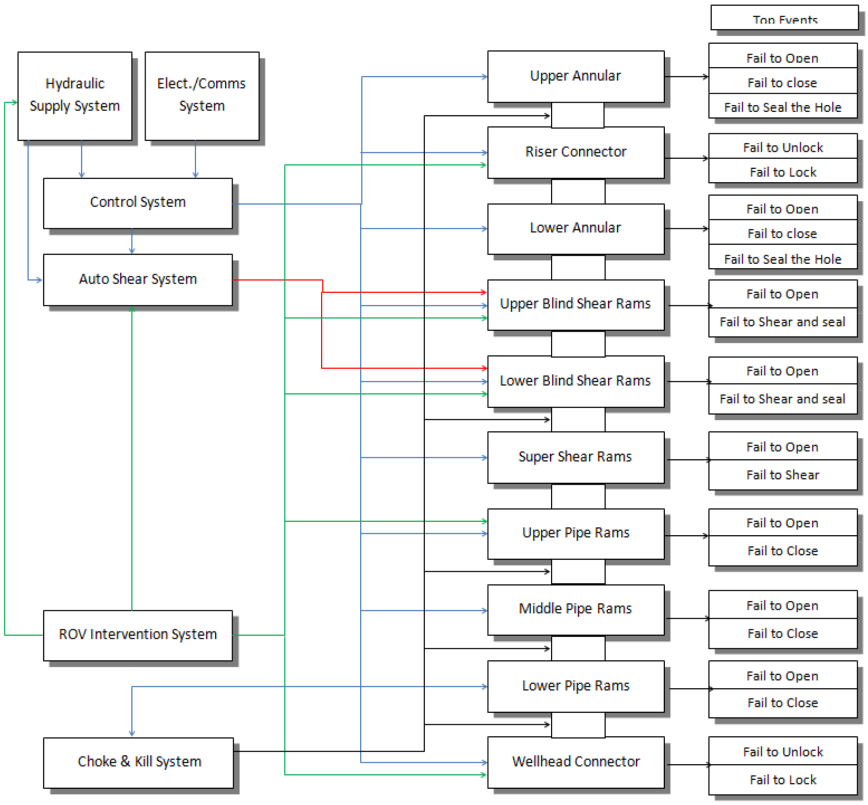


Figure 1. Overall BOP functions (example)

### 2.2. Establish block diagrams

After all critical functions have been identified, logic block diagrams will be built to describe the functions and the needed components and their logics. This is further broken down to each component all the way down until every main, minor, and subcomponents needed for the function are identified

An example of a block diagram for one of the functions is shown in the following figure.

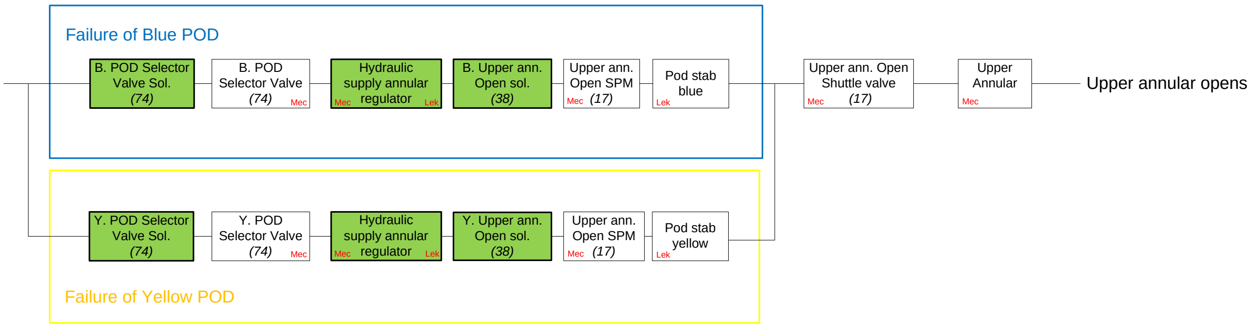


Figure 2. Example of logic block diagram showing components involved in one main function.

### 2.3. FMEA

The Failure Mode and Effects Analysis (FMEA) method is a tool for analysis of risk, through identification of failure modes and corresponding effects (risks) to personnel, equipment and production.

The main intention of the analysis is to identify possible failures of the system, and the consequences of the failures, which are then used as inputs to the BOP Risk Model.

The FMEA is performed by dividing the relevant BOP stack into subsystems and main components, and looking at the functions these subsystems and main components needed to perform in order for the BOP stack to work as intended. It is then assessed how these functions could fail (failure modes) and the effects of these failures. Redundancy in components is also analyzed.

### 2.4. Fault trees

The outputs from logic block diagram and FMEA are used as inputs to build the fault trees. A fault tree is a logical diagram that illustrates the coherence between an undesirable top event in a system and the causes for this event.

An example of fault tree is given in Figure 3. The complete fault tree model is built in RiskSpectrum® PSA software.

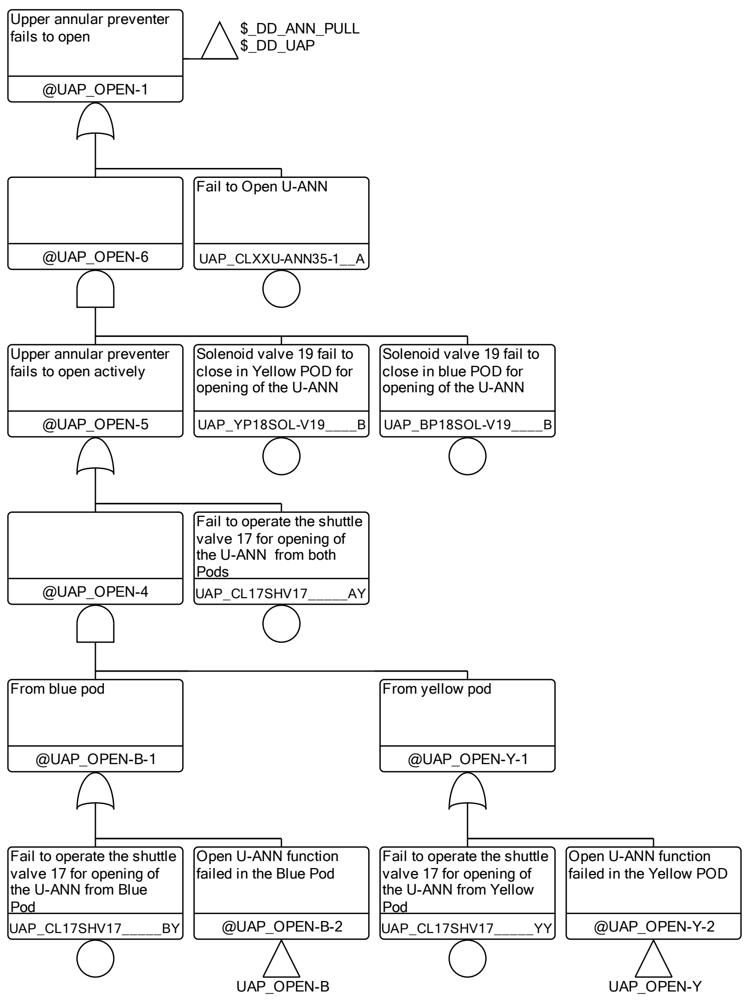


Figure 3. An example fault tree in the BOP model

### 2.5. Realize the BOP Risk Model in RiskWatcher software.

In addition to the fault trees, the system/subsystem/component information is also added to the BOP Risk Model.

The model is finally implemented in RiskWatcher, a risk monitor software in RiskSpectrum family. This program is unique in that the operator interface is easily navigable and does not require experience in risk analysis or fault tree modelling.

The BOP risk levels can be assessed easily, by comparing the remaining available redundancy of the BOP capabilities with the minimum requirements in the company policy, industry standards and the regulatory regulations. The minimum requirements are identified and verified by the experienced BOP experts. These requirements are the basis for the “Pull” or “No Pull” suggestion from the BOP Risk Model.

For the drilling rigs operated in the Gulf of Mexico, the following regulatory and industry requirements are relevant:

- CFR 250
- API 16D
- API Standard 53

The applicable requirements will need to be investigated for the drilling rigs operated in the other areas, e.g. NORSOK requirements for Norwegian Continental Shelf.

Four colours are introduced in the RiskWatcher software to indicate the different risk level based on the applicable requirements and the 'real-time' BOP status:

- RED Red on the top level means that critical functions cannot be operated and that the BOP is under the minimum requirements. Critical functionality less than 100 %
- ORANGE Orange means loss of redundancy. Detailed risk assessment of the failure taking into account the actual risk of the drilling operation must be performed.
- YELLOW Yellow means that at least one component in the BOP has failed, maintenance is needed at the next available opportunity
- GREEN Green means all fine, no problems. This must be the colour when the stack is deployed and after landing

An example of the defence-in-depth structure can be seen in the pictures below.

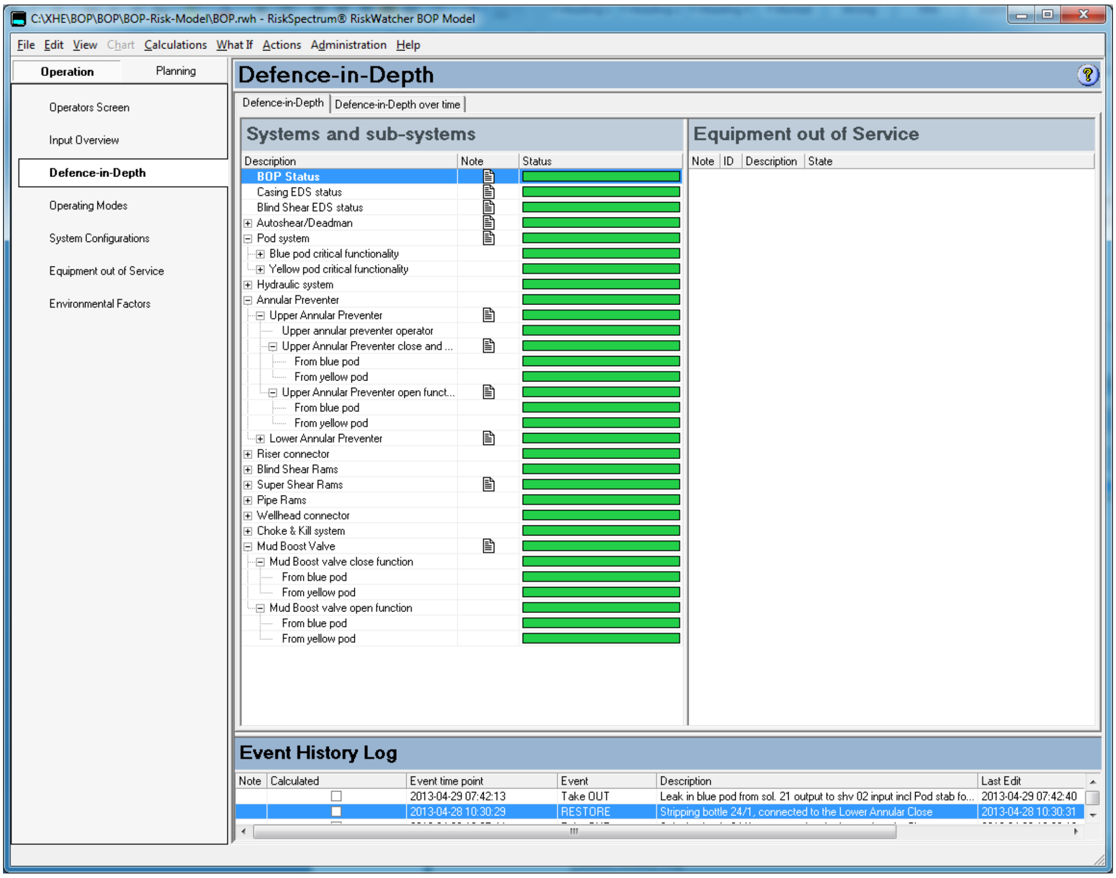


Figure 4. An example interface in the BOP Risk Model

As can be seen from the picture, in addition to the overall status of the BOP, the status of each of the functions and sub-functions is represented by a status bar.

## 3. A CASE STUDY

An offshore drilling rig developed several simultaneous leaks. Most of the leaks by themselves were minor issues; however the sum total made the personnel uneasy and need to decide on continuing with operations, pull the LMRP, or to pull the entire BOP stack.

Over the next few days, a number of teleconferences were organized between the drilling manager, his staff and shore-based experts to discuss issues and to clearly identify the root causes. The following failures were identified:

- Leak on mud boost valve open function from blue pod
- Leak on the lower annular open function
- Leak on surge-stripping accumulator bottle on upper annular which rendered the upper Annular inoperative

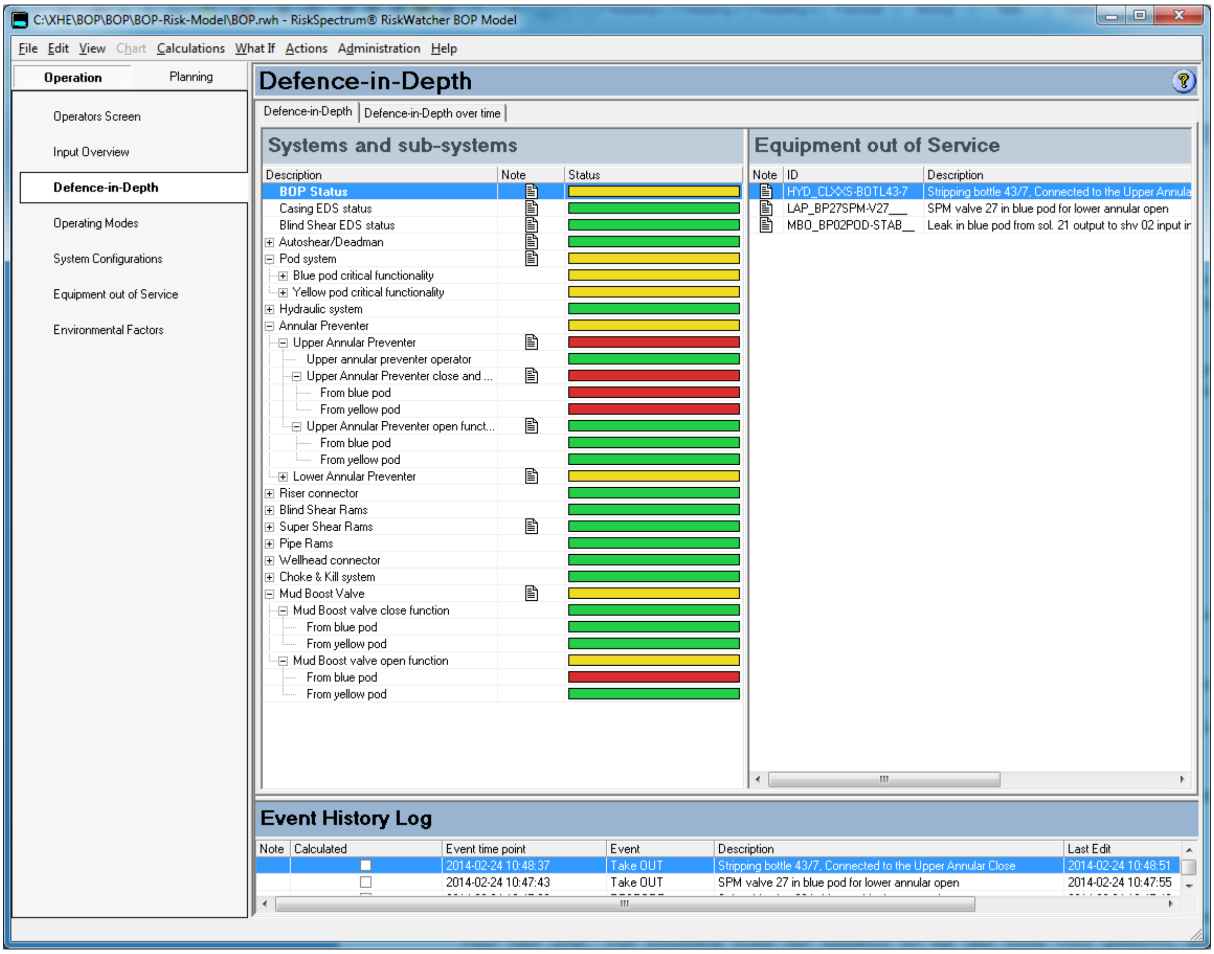


Figure 5. An example interface in the BOP Risk Model with the identified component failures

The overall BOP status for this particular BOP in this particular case is yellow from the BOP Risk Model and drilling is able to continue without pulling BOP. The reasons that the BOP was able to avert pulling include:

- The leak in the lower annular open function could be controlled by closing a valve.
- Lower annular can close
- Lower annular can open by itself (rubber memory) as long as close pressure is vented
- Mud boost valve function is not critical for safety

## 4. WEB VERSION BOP RISK MODEL

A web version RiskWatcher software for BOP Risk Model is currently under development. The web version software can open the model through the web browser. Any users with authorized user name and password can open the model within the company intranet.

All the model information, the event history including equipment out of service, restoration, etc. will be saved in the server and available for all the users. Multiple users are able to open the same model and check the up-to-date BOP status.

## 5. RELIABILITY OF THE BOP CRITICAL FUNCTIONS

BOP Risk Model is different from the traditional BOP monitor. The traditional BOP monitor could be an advanced feature of BOP control system where the real time BOP equipment status could be monitored. While BOP Risk Model is built on the logic block diagram and fault tree model and it is able to help decision maker to decide the current BOP risk level to make BOP pull or no pull decision.

BOP Risk Model can also be used to evaluate the reliability of the BOP critical functions in the future. In some countries/regions, there are specific safety integrity level (SIL) requirements for BOP critical functions. An example is the requirement in the OLF 070:

- As a minimum the SIL for isolation using the annulus function should be SIL 2 and the minimum SIL for closing the blind/shear RAM should be SIL 2

SIL2 means the probability of failure on demand is between $10^{-3}$ and $10^{-2}$.

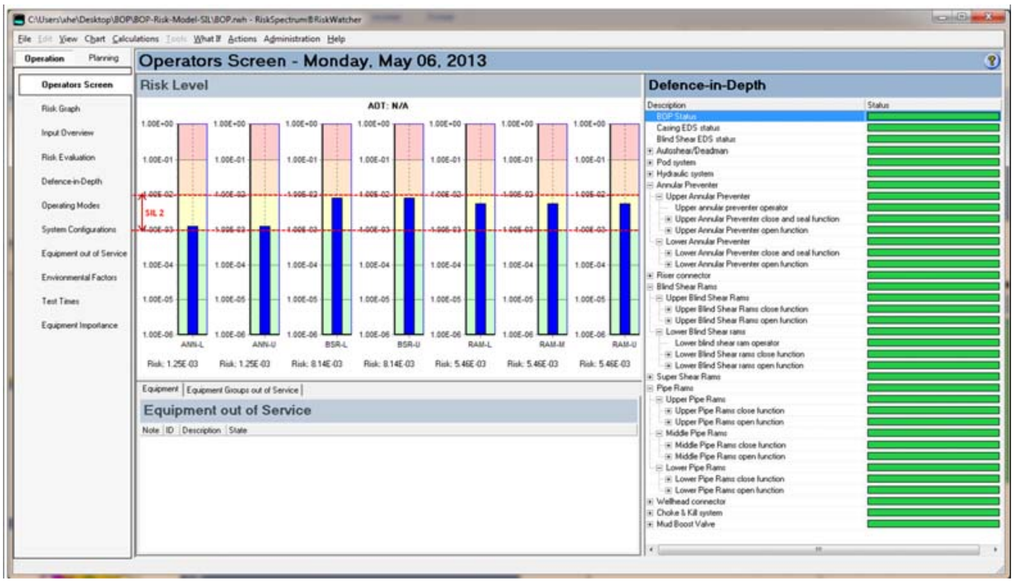


Figure 6. Reliability of the BOP critical functions (example)

## 6. DISCUSSIONS AND CONCLUSIONS

BOP Risk Model projects have been successfully implemented in a number of offshore drilling rigs. Positive feedbacks are received from the regulatory body. The model provides a good common platform for different parties including operator, drilling company, regulatory body to look at the BOP risk level. It helps to get accurate logic decision and fasts the decision making process.

Additional advanced features are under evaluation based on feedbacks and the project experiences. One big challenge is the fault identification in the BOP system. This may be solved using the available functions in the existing BOP control system as well as the other diagnosis technologies.

**References**

[1] Jeff Sattler, WEST Engineering Services. *"Pull Your BOP Stack-Or Not? A Systematic Method to Making This Multi-Million Dollar Decision"*, SPE/IADC 119762. SPEIIADC Drilling Conference and Exhibition held In Amsterdam, The Netherlands, 17-19 March 2009.

[2] I. A. Alme, X. He, T. B. Fylking, et, al. *"BOP risk and reliability model to give critical decision support for offshore drilling operations"*, 11th International Probabilistic Safety Assessment and Management Conference and The Annual European Safety and Reliability Conference, Helsinki, Finland, 25–29 June 2012.