Optimizing the testing policy for the Blowout Preventer

RAMS Seminar

Danilo Colombo
Visiting PhD

Data: 09/02/2022

Danilo Colombo

- Bachelor’s degree in Mechatronic Engineering by USP in 2012
- Petroleum Engineer professional specialization at University of Petrobras – 2013
- Field Experience (Onshore and Offshore) – 2014/2015
- CENPES (Petrobras R&D Center – since 2015)
- Executive MBA in Finance Management – 2017
- Master’s degree in Production Engineering at UFF – 2018
- PhD Candidate – 2019
- Certified as Reliability Consultant by RELIASOFT - 2020
- Advisor in Reliability and Risk Analysis at PETROBRAS

Danilo Colombo

- R&D projects in Well Integrity, Reliability of Equipment and Plug and Abandonment of Wells
- Member of SPE – Society of Petroleum Engineers
- Member of ABRISCO – Brazilian Association for Risk Analysis, Process Safety and Reliability
- Master's Thesis – A Markov model to support integrity risks management of subsea wells
- Several papers and book chapters published in the last few years

Ph.D. Project

- Title:

Forecasting the reliability performance of well safety barriers under different conditions using machine learning

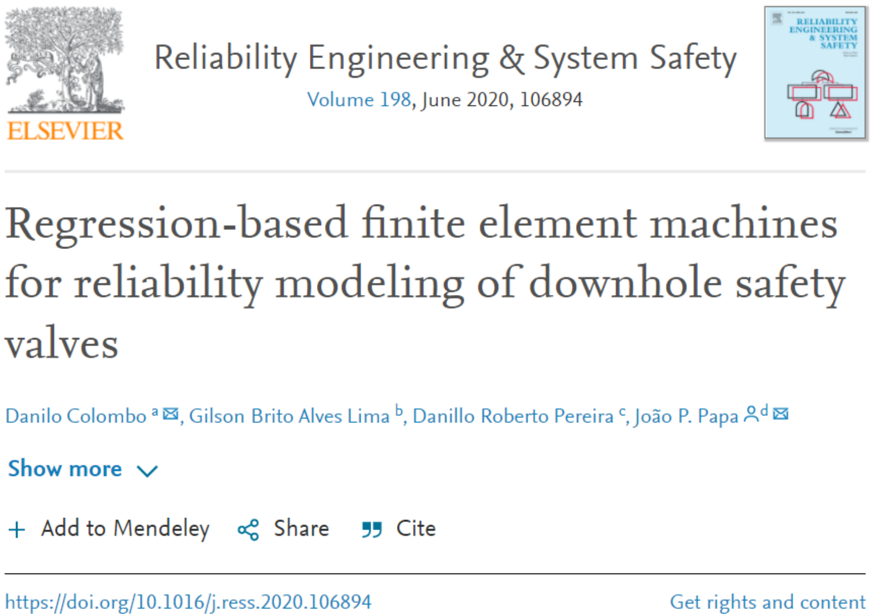
- University:

UFF - Universidade Federal Fluminense

- Academic Supervisors:

Gilson B. A. Lima - Risk supervisor

João P. Papa - Machine Learning supervisor



ELSEVIER

Reliability Engineering & System Safety

Volume 198, June 2020, 106894

Regression-based finite element machines for reliability modeling of downhole safety valves

Danilo Colombo [a], Gilson Brito Alves Lima [b], Danillo Roberto Pereira [c], João P. Papa [d]

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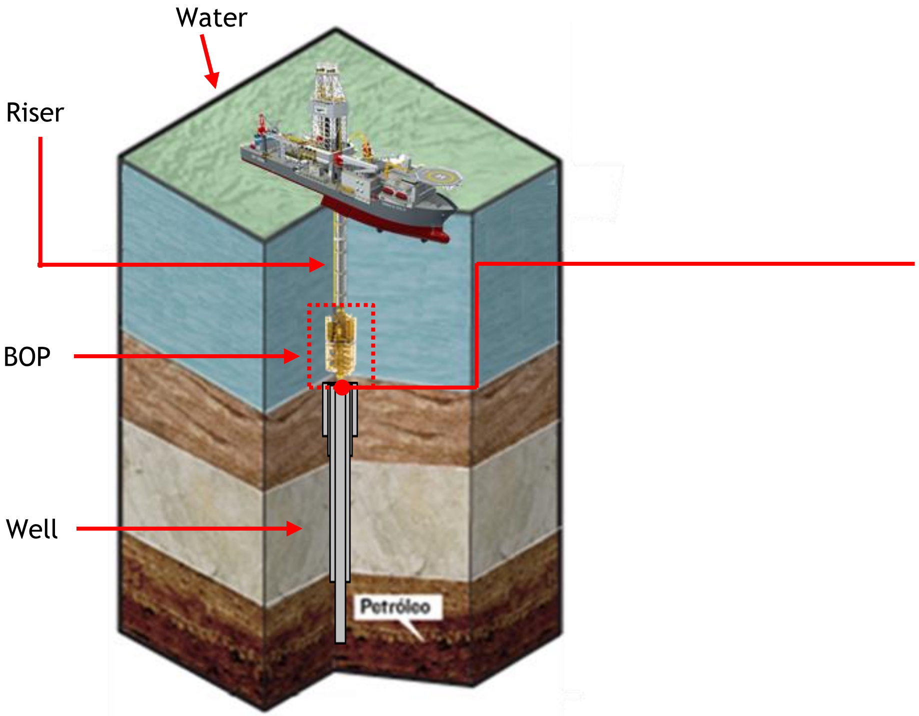
Agenda

1. What's the Blowout Preventer
2. BOP reliability Project
3. Testing the BOP
4. Optimizing the test plan
5. Paper ESREL 2022
6. Next developments

BOP in Images



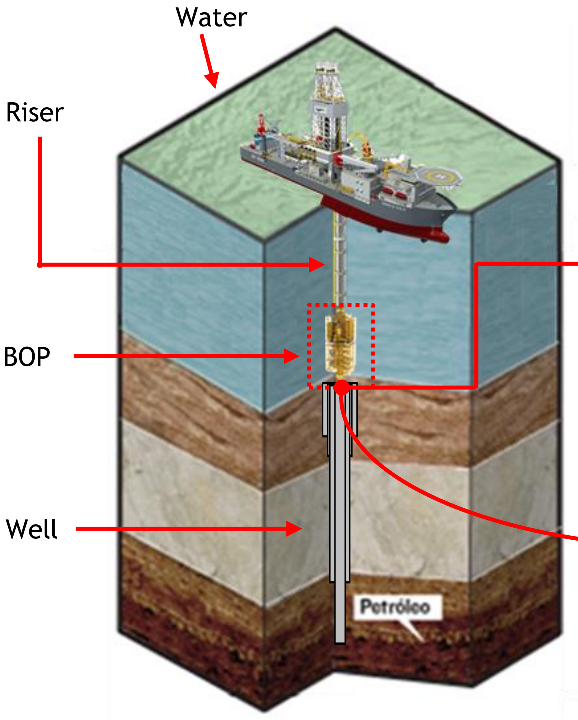
- The Blowout Preventer is a large (up to 20 meters tall) and heavy (400 tones) safety equipment to avoid oil spills (*"blowouts"*)

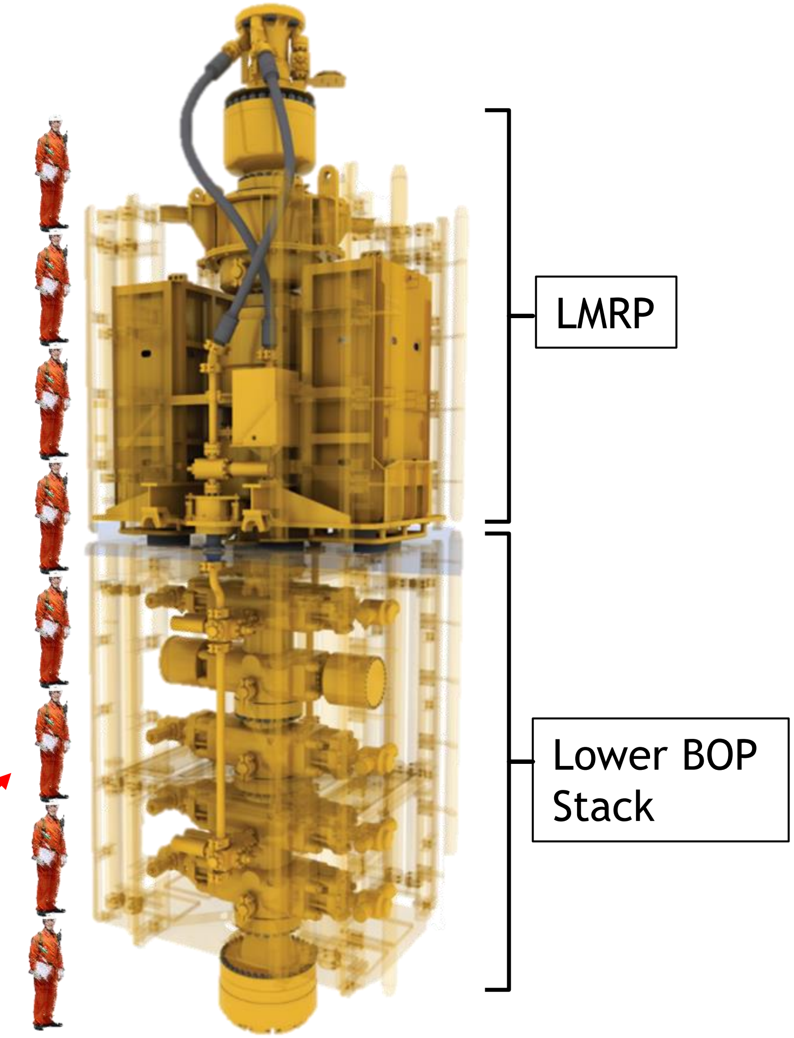
- It's installed on the top of the wellhead and connects the rig through the drilling riser

- The BOP is the most important safety equipment in a rig

What's the Blowout Preventer

BOP in Images





BOP in Images

- The failure of BOP can be catastrophic, leading to accidents called blowouts

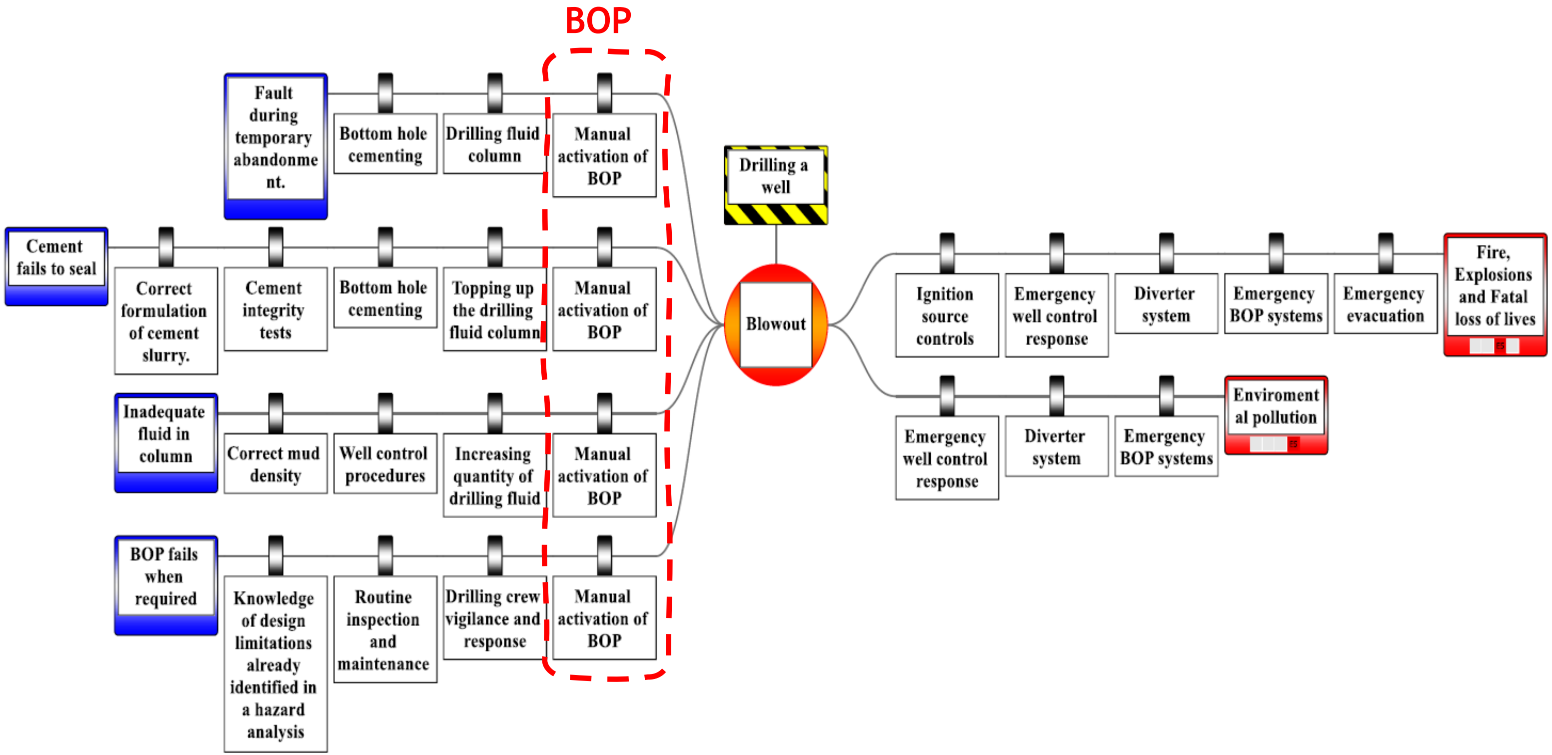
- The Macondo blowouts was started due to a well cement failure, but the failure of the BOP leads to a blowout.

- The Macondo accident has several consequences: deaths, injuries, oil spill, material losses, environmental damage, etc.

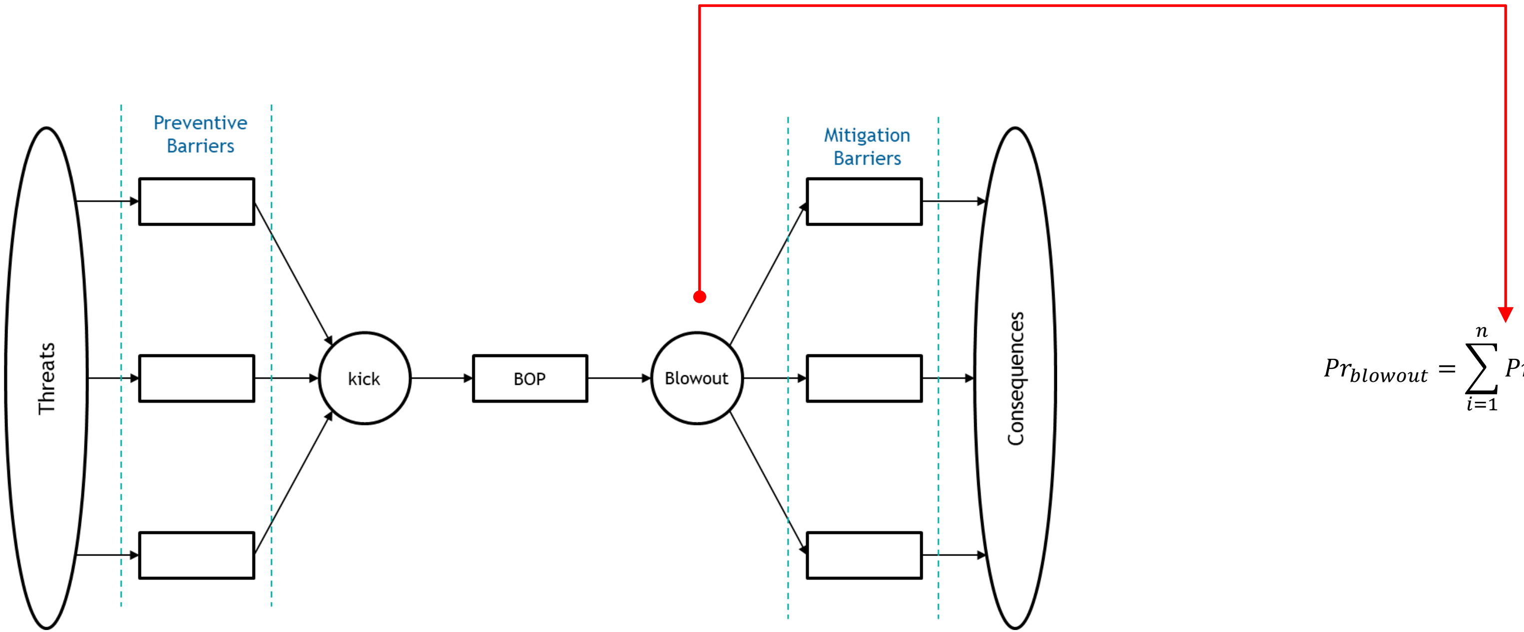
BOP in Images

- Besides the safety impact of the component, it has significant impact in the operation uptime.
- The BOP unavailability is the main cause of downtime in rigs, costing dozens of millions of dollars
- To repair the BOP, it is necessary to pull out the BOP, repair on surface, run and land the BOP again, connect to the wellhead and test.

BOP and Risks

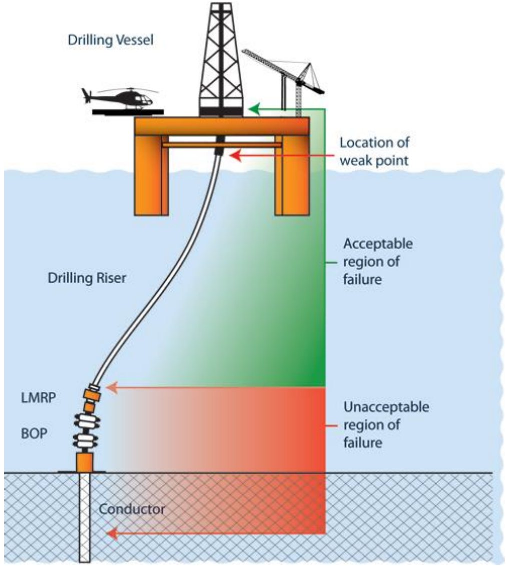


BOP and Risks



$$Pr_{blowout} = \sum_{i=1}^{n} Pr_{kick} * PFD_{BOP}$$

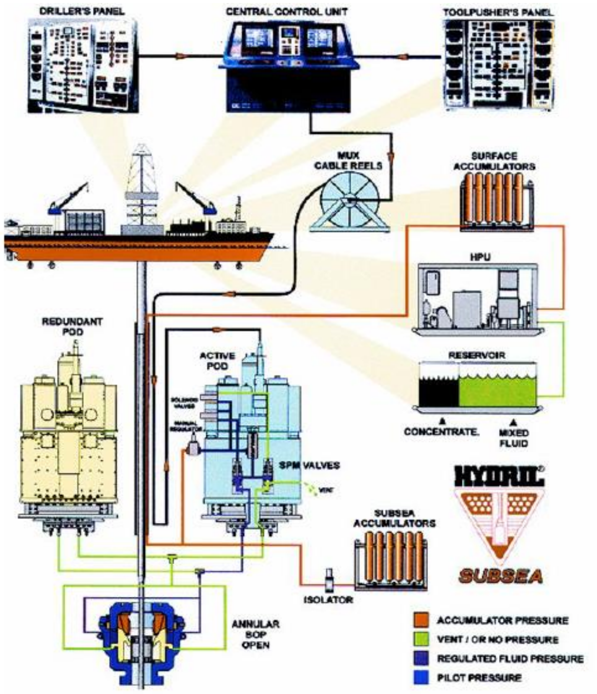
The BOP is a complex system



Functions

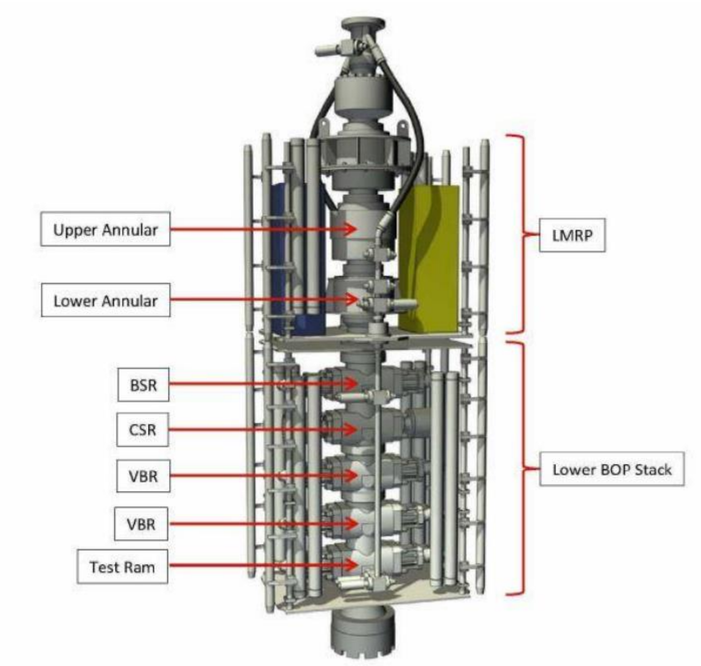
- Close and seal the well;
- Provide means of fluid circulation into and out the well
- Kill the well
- Regulate and monitor wellbore pressure
- Hang-off and stripping the drillpipe
- Disconnect the rig from the well in emergency situations

The BOP is a complex system



- Control System
- Electrical and hydraulic lines
- Hydraulic accumulators
- Control PODs (Yellow and Blue)
- Wellhead connector
- LMRP connector
- Riser connector
- Riser
- Emergency Systems (Acoustic, Hot Stab, DMAS, EDS)
- Electronic Controls
- Kill and Choke lines
- Several RAMS

The BOP is a complex system



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R&D Portfolio over 100 Millions NOK

- Aviation reliability
- Condition-Based Maintenance of BOP
- MyBarrier BOP
- Full-electric BOP
- Accelerate Life Testing Facility
- New pressure regulator valve
- Real time EDS

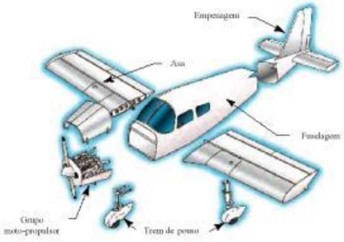
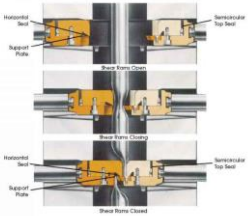
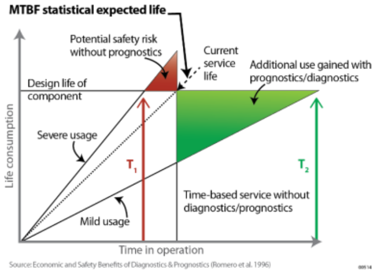
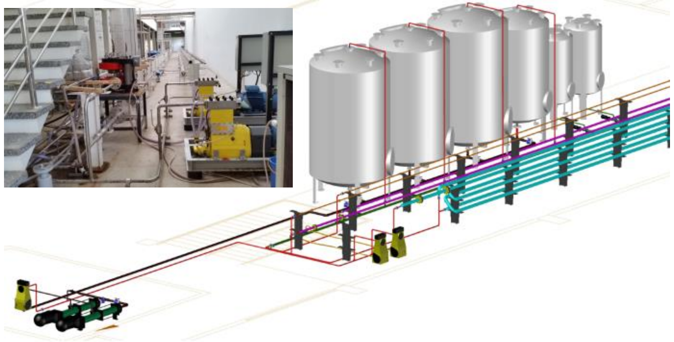


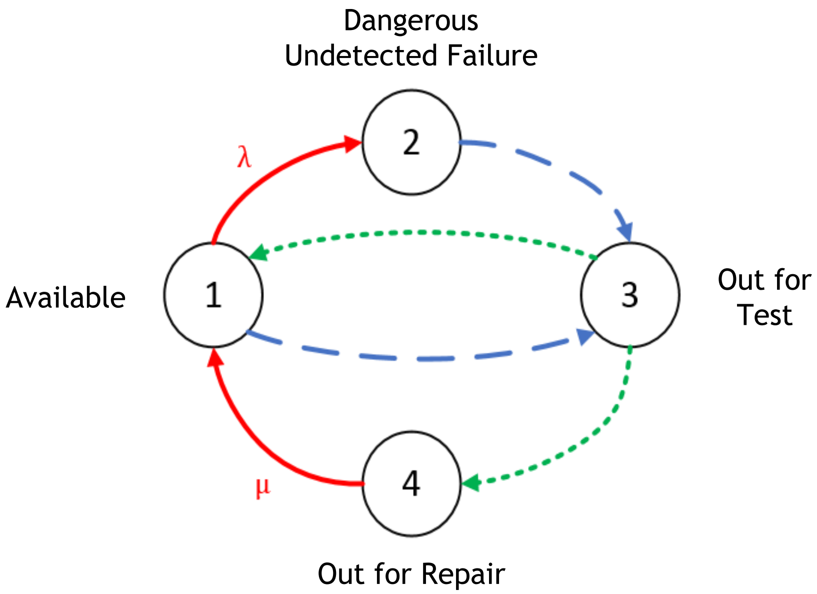
Figure 1 - Example of Results of the Qualitative Assessment







Operational states of BOP



Multi-phase Markov Chain

1. The system is available just in state “1”
2. The failure and repair transitions are random and continuous events that depend on the rates of failure and repair of BOP components
3. The testing or repair decision are discrete events
4. The system is unavailable in states “2”, “3” and “4”
5. However, in state “3” and “4” the system is safe, and the unavailability affects the nonproductive time, an economic issue.
6. In state “2” the BOP operator doesn’t know that the system is unavailable and in case of a demand for well control, there will be an accident, a safety issue.

BOP Test

- Factory test/ body test / shell test
  - BOP 10k psi or more … 150%
  - BOP 5k or less … 200%

- Acceptance test / pre-spud test
  - Ram: 100% of working pressure
  - Annular: 70% of working pressure

- Periodic test:
  - Ram: greater than the maximum anticipated pressure
  - Annular: not exceed 70% of working pressure

- Rule of thumb: function test must be done at least one time per week

Regulations about BOP periodic test frequency

CFR § 250.737

Function – Weekly (7 days)
Pressure – Each 14 days (21 days under special conditions)

NORSOK D-010

Function – Weekly (7 days)
Pressure – Each 14 days

API S53

Function – Weekly (7 days)
Pressure – Each 21 days

PETROBRAS

Function – ~~21 days~~ 28 days
Pressure – ~~21 days~~ 28 days

Just periodic tests of annular, pipe rams and subsea valves

Previous studies – Argonne Report

	Impact of an Extension of the Time-Based BOP Pressure Test Interval		
Factor	**Operational Economics**	**Operational Safety**	**Component Reliability**
Description	*A significant amount of rig downtime is necessary to prepare for and perform BOP pressure tests, which adds to the costs associated with offshore drilling.*	*BOP pressure testing requires significant downhole and on rig operations and system reconfigurations.*	*The BOP pressure test is primarily a proof test of the following components:* • *BOP wellbore sealing elastomers* • *Choke/kill lines and valves*
Analysis Results	*An economic analysis found average industry wide cost savings over the next ten years of:* • *$410 Mil/year for 21 day* • *$600 Mil/year for 28 day*	*Reduction in risks associated with the following factors:* • *Downhole operations* • *High pressure rig operations* • *Potential for system misalignment*	*A qualitative and quantitative reliability analysis demonstrates that there is minimal net impact on component reliability due to an extension of the time based pressure test interval.*
Conclusion	**Significant Benefit**	**Significant Benefit**	**Minimal Impact**

Argonne National Laboratory. 2019. Examination of Blowout Preventer Pressure Test Frequency. Report prepared for the Bureau of Safety and Environment Enforcement. Chicago, USA.

Previous studies – Argonne Report

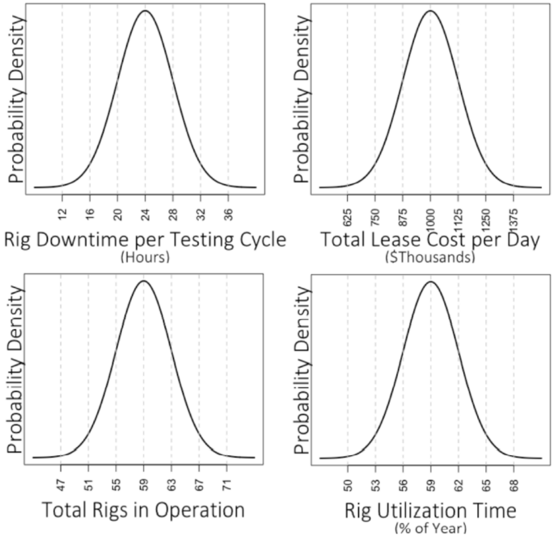


Figure 3-1: Economic Model Input Parameter Uncertainty Distributions

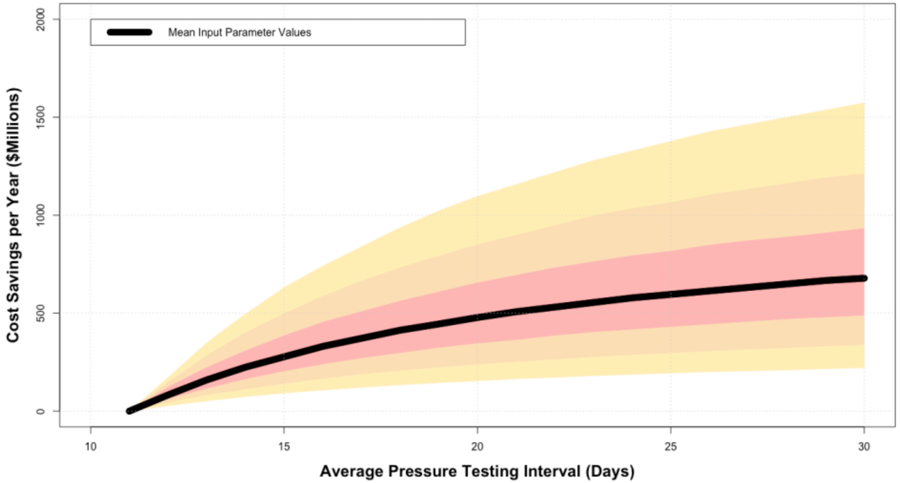


Figure 3-2: Economic Model Results

Argonne National Laboratory. 2019. Examination of Blowout Preventer Pressure Test Frequency. Report prepared for the Bureau of Safety and Environment Enforcement. Chicago, USA.

Previous studies - Argonne Report

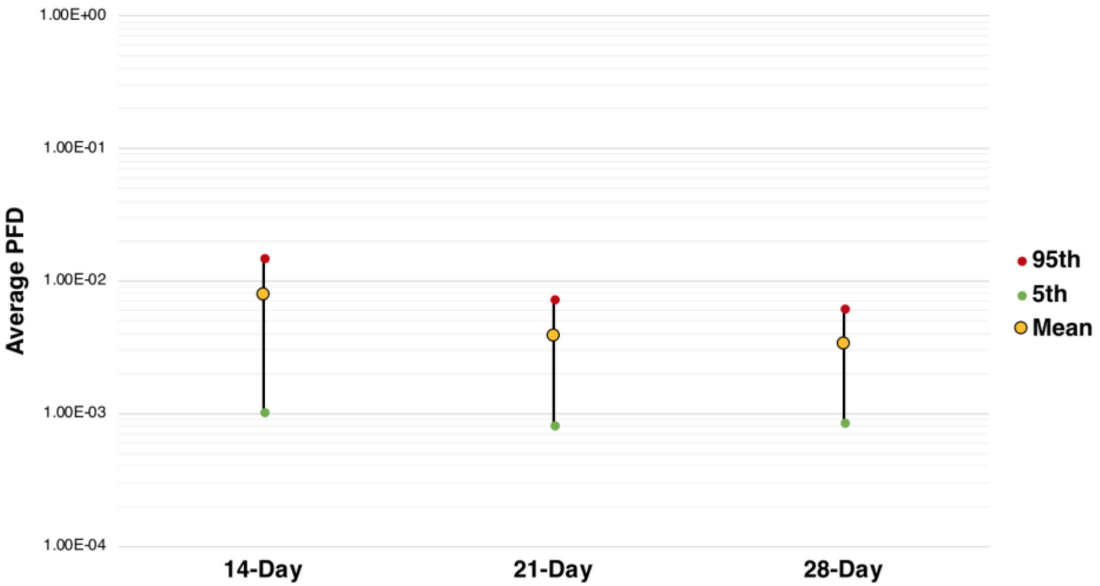


Figure 4-7: Annular – Average PFD with Varying Time-Based Pressure Test Interval[25]

Argonne National Laboratory. 2019. Examination of Blowout Preventer Pressure Test Frequency. Report prepared for the Bureau of Safety and Environment Enforcement. Chicago, USA.

Previous studies – My own paper

Brazilian Journal of Development | 103985
ISSN: 2525-8761

Análise do impacto da frequência de testes na disponibilidade do BOP utilizando um modelo markoviano multifásico

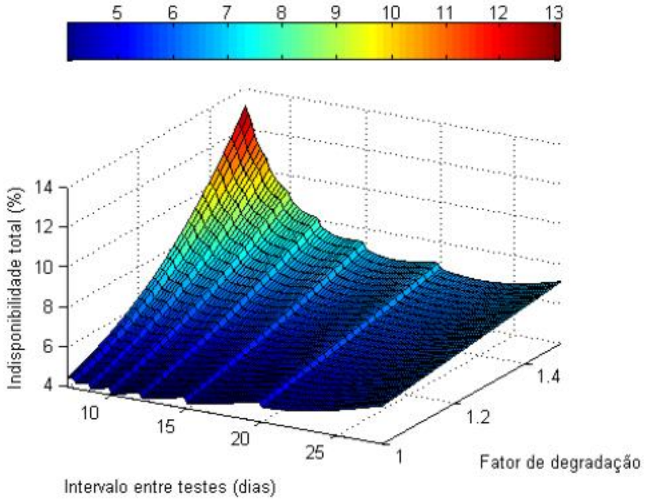
Analysis of the impact of test frequency on BOP availability using a multiphase markov model

DOI:10.34117/bjdv7n11-156

Recebimento dos originais: 12/10/2021
Aceitação para publicação: 10/11/2021

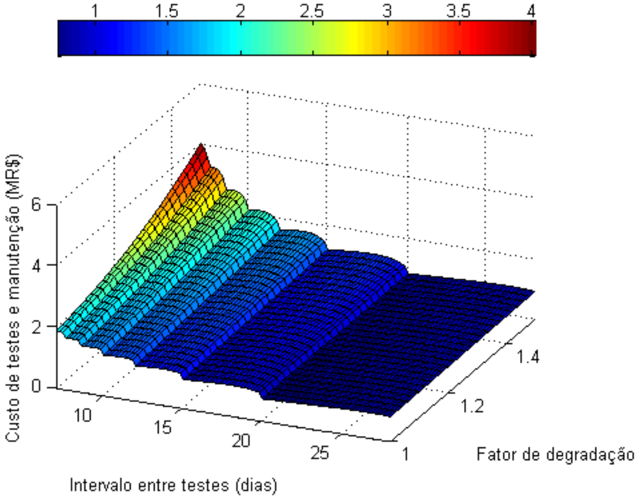
Previous studies – My paper

Figura 6. Indisponibilidade total do BOP em função do intervalo entre testes e fator de degradação



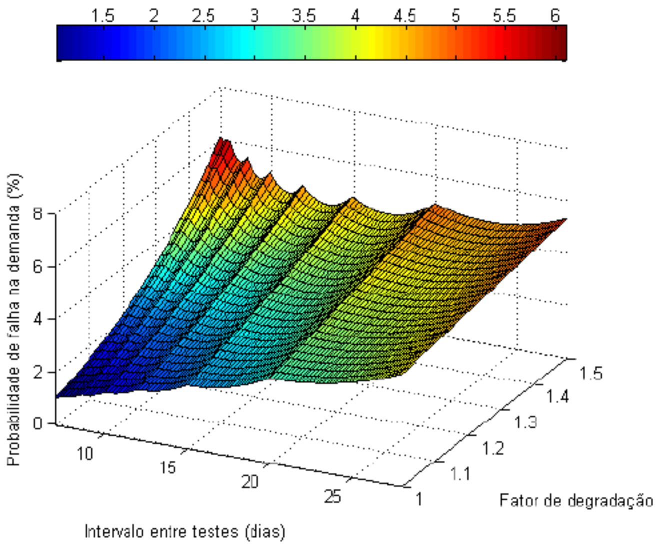
Previous studies – My paper

Figura 7. Custo de testes e manutenção em função do intervalo entre testes e fator de degradação



Previous studies - My paper

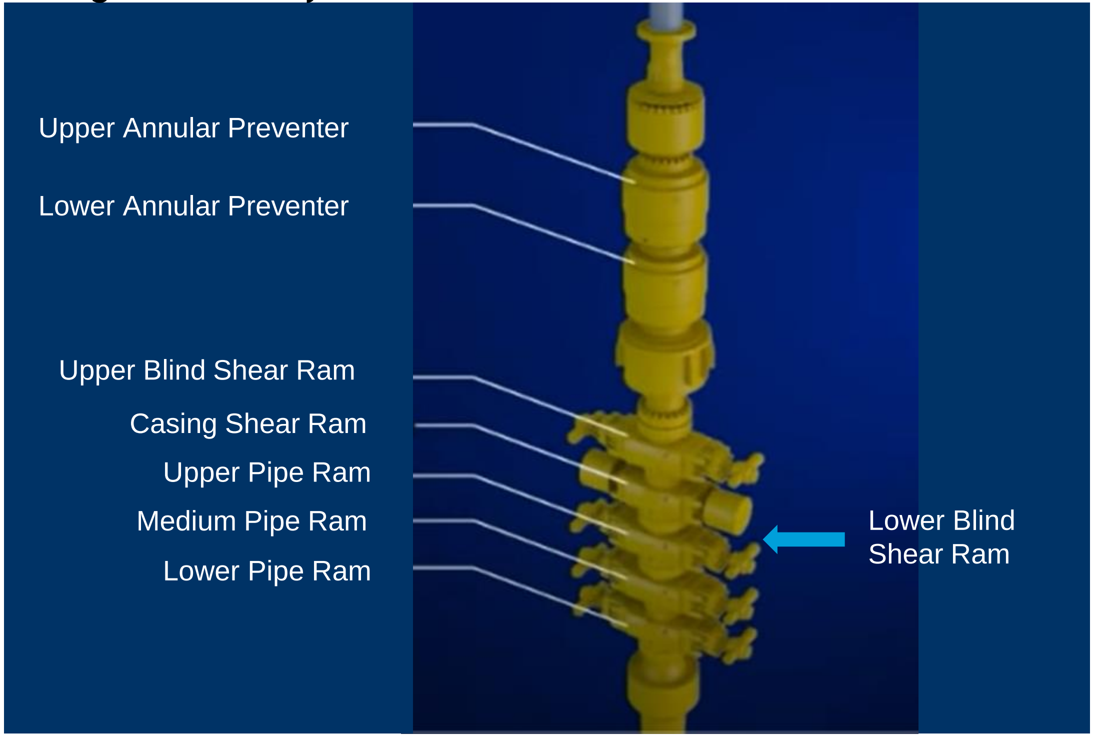
Figura 8. Probabilidade de falha na demanda em função do intervalo entre testes e fator de degradação



Previous studies - PETROBRAS/DNV MyBarrier BOP

- Two annular preventers
- Two blind shear rams
- One casing shear ram
- Three pipe rams

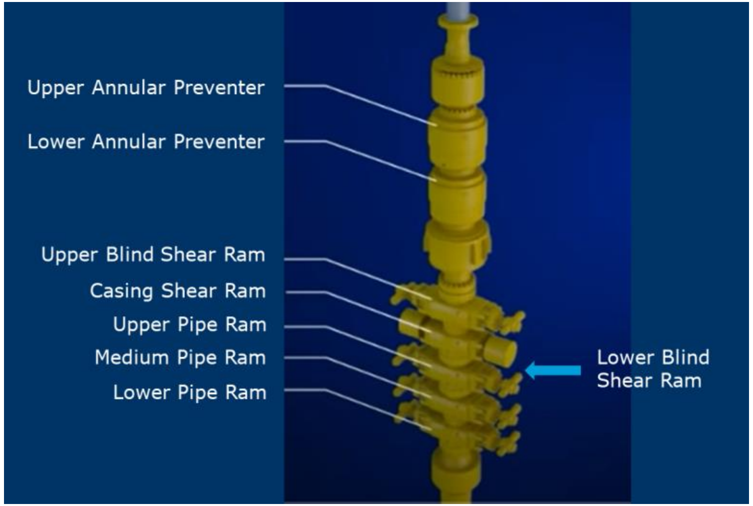
Configuration analyzed



Previous studies - PETROBRAS/DNV MyBarrier BOP

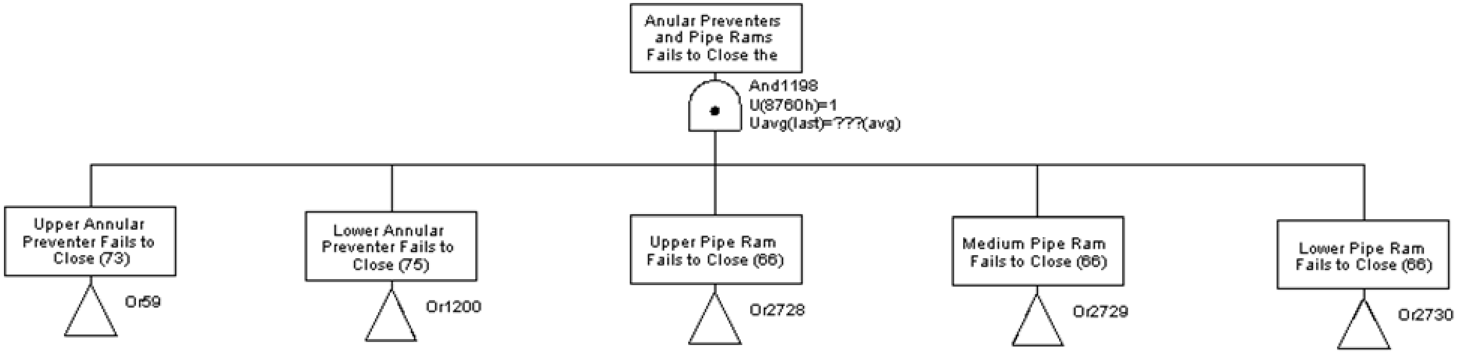
- **SF 1** — Closing and holding against pressure by UBSR
- **SF 2** — Closing and holding against pressure by UAP
- **SF 3** — Closing and holding against pressure by AP & PR

The assessed BOP Safety Functions



Previous studies - PETROBRAS/DNV MyBarrier BOP

Fault Tree for SF3: Closing and Holding Against Pressure by AP & PR



Previous studies - PETROBRAS/DNV MyBarrier BOP

Acceptance Criteria

Norwegian Industry document OLF-070 (2018)

BOP main safety functions must comply with SIL 2

070 – NORWEGIAN OIL AND GAS

APPLICATION OF
IEC 61508 AND IEC 61511
IN THE NORWEGIAN PETROLEUM
INDUSTRY
(Recommended SIL requirements)

Norskolje&gass

June 2018

SIL concept defined in international standard IEC 61508

PFD_{avg}

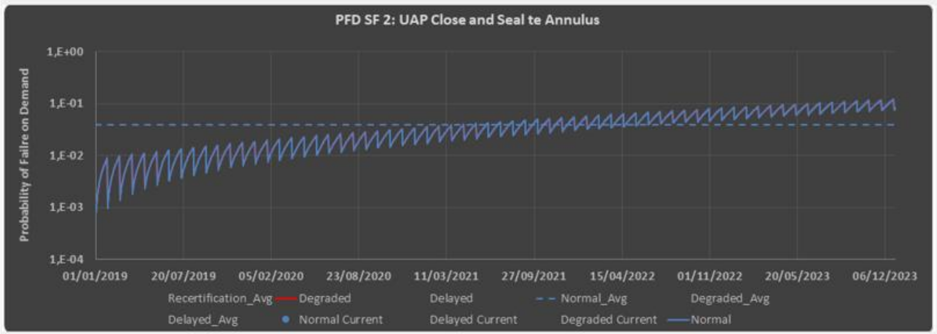
PFD = 1 in 100

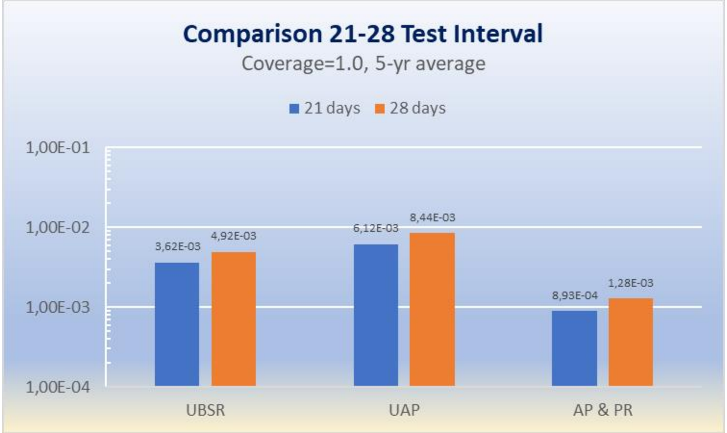
PFD = 1 in 1000

Max	Min	
1E-1	1E-2	SIL 1
1E-2	1E-3	SIL 2
1E-3	1E-4	SIL 3
1E-4	1E-5	SIL 4

Previous studies - PETROBRAS/DNV MyBarrier BOP

Results





Results – PFDavg for 5yr period						
Test	UBSR	Increase in PFDavg (%)	UAP	Increase in PFDavg (%)	AP PR	Increase in PFDavg (%)
21 dias	3,62E-03		6,12E-03		8,93E-04	
28 dias	4,92E-03	35,91	8,44E-03	37,91	1,28E-03	43,34

Previous studies - PETROBRAS/DNV MyBarrier BOP

New approach for BOP test planning – The MyBarrier BOP – Operational campaign based on reliability

Campaign Planner

First Campaign

Edit Campaign

Status: Planning
Start Date: 2020-01-01 00:00
End Date: 2020-03-20 18:00

Compare Selected 0 of 1 selected

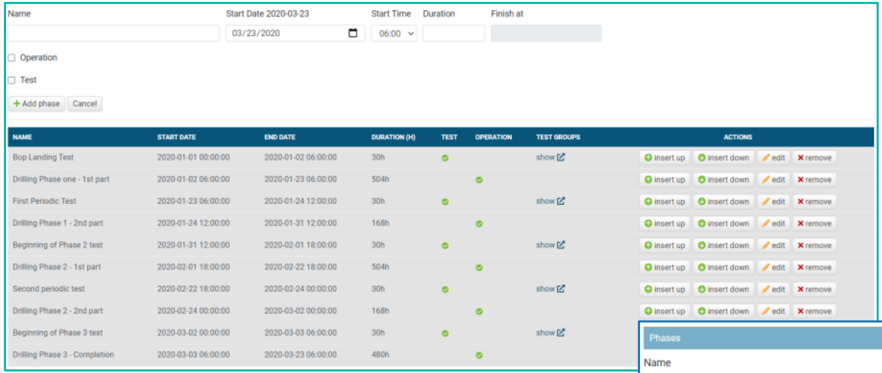
+ Add New Schema

SCHEMA	TYPE	OPERATIONAL SCHEMA	BASE SCHEMA	START DATE	END DATE	ACTIONS
28 day test schema	Operation	✓		2020-01-01 00:00	2020-03-20 18:00	
21 Days test	Planning			2020-01-01 00:00	2020-03-23 06:00	

A PETROBRAS and DNV development

Testing the BOP

Previous studies - PETROBRAS/DNV MyBarrier BOP



Name | Start Date 2020-03-23 | Start Time | Duration | Finish at

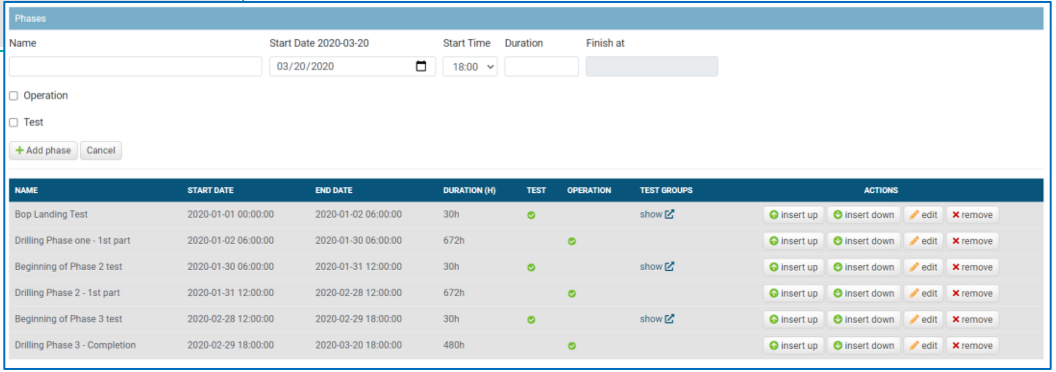
03/23/2020 | 06:00

Operation

Test

Add phase | Cancel

NAME	START DATE	END DATE	DURATION (H)	TEST	OPERATION	TEST GROUPS	ACTIONS
Bop Landing Test	2020-01-01 00:00:00	2020-01-02 06:00:00	30h	✓		show	insert up, insert down, edit, remove
Drilling Phase one - 1st part	2020-01-02 06:00:00	2020-01-23 06:00:00	504h		✓		insert up, insert down, edit, remove
First Periodic Test	2020-01-23 06:00:00	2020-01-24 12:00:00	30h	✓		show	insert up, insert down, edit, remove
Drilling Phase 1 - 2nd part	2020-01-24 12:00:00	2020-01-31 12:00:00	168h		✓		insert up, insert down, edit, remove
Beginning of Phase 2 test	2020-01-31 12:00:00	2020-02-01 18:00:00	30h	✓		show	insert up, insert down, edit, remove
Drilling Phase 2 - 1st part	2020-02-01 18:00:00	2020-02-22 18:00:00	504h		✓		insert up, insert down, edit, remove
Second periodic test	2020-02-22 18:00:00	2020-02-24 00:00:00	30h	✓		show	insert up, insert down, edit, remove
Drilling Phase 2 - 2nd part	2020-02-24 00:00:00	2020-03-02 00:00:00	168h		✓		insert up, insert down, edit, remove
Beginning of Phase 3 test	2020-03-02 00:00:00	2020-03-03 06:00:00	30h	✓		show	
Drilling Phase 3 - Completion	2020-03-03 06:00:00	2020-03-23 06:00:00	480h		✓		



Phases

Name | Start Date 2020-03-20 | Start Time | Duration | Finish at

03/20/2020 | 18:00

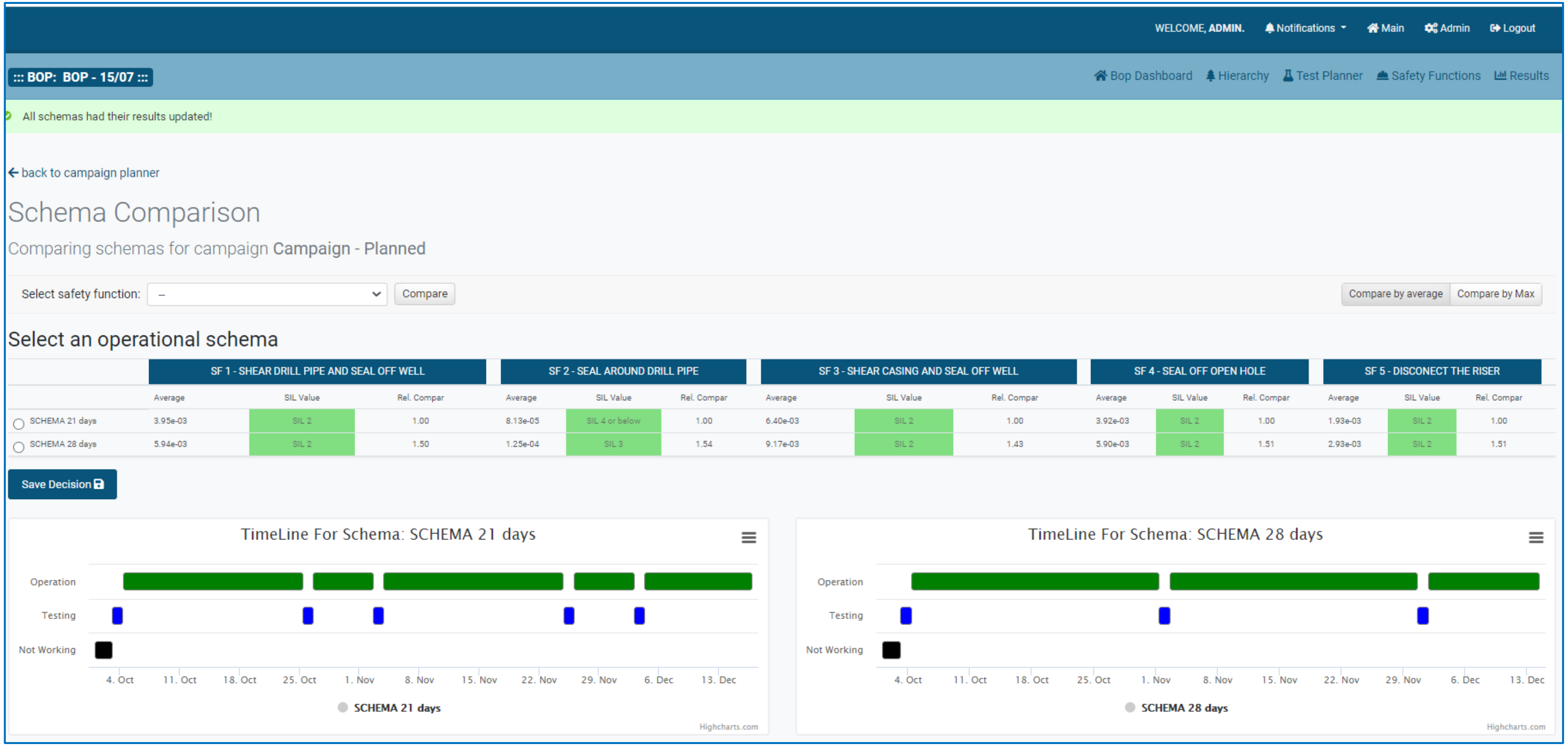
Operation

Test

Add phase | Cancel

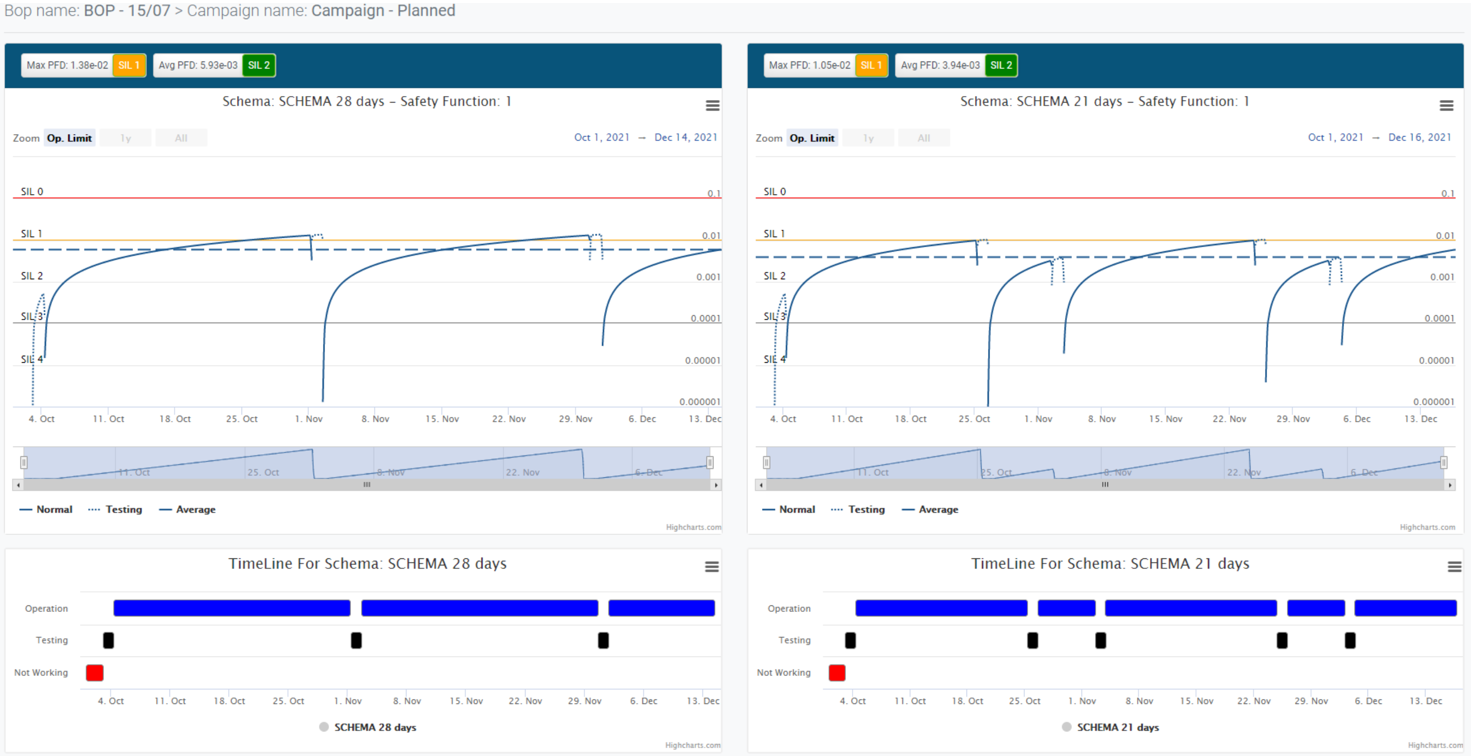
NAME	START DATE	END DATE	DURATION (H)	TEST	OPERATION	TEST GROUPS	ACTIONS
Bop Landing Test	2020-01-01 00:00:00	2020-01-02 06:00:00	30h	✓		show	insert up, insert down, edit, remove
Drilling Phase one - 1st part	2020-01-02 06:00:00	2020-01-30 06:00:00	672h		✓		insert up, insert down, edit, remove
Beginning of Phase 2 test	2020-01-30 06:00:00	2020-01-31 12:00:00	30h	✓		show	insert up, insert down, edit, remove
Drilling Phase 2 - 1st part	2020-01-31 12:00:00	2020-02-28 12:00:00	672h		✓		insert up, insert down, edit, remove
Beginning of Phase 3 test	2020-02-28 12:00:00	2020-02-29 18:00:00	30h	✓		show	insert up, insert down, edit, remove
Drilling Phase 3 - Completion	2020-02-29 18:00:00	2020-03-20 18:00:00	480h		✓		insert up, insert down, edit, remove

Previous studies - PETROBRAS/DNV MyBarrier BOP



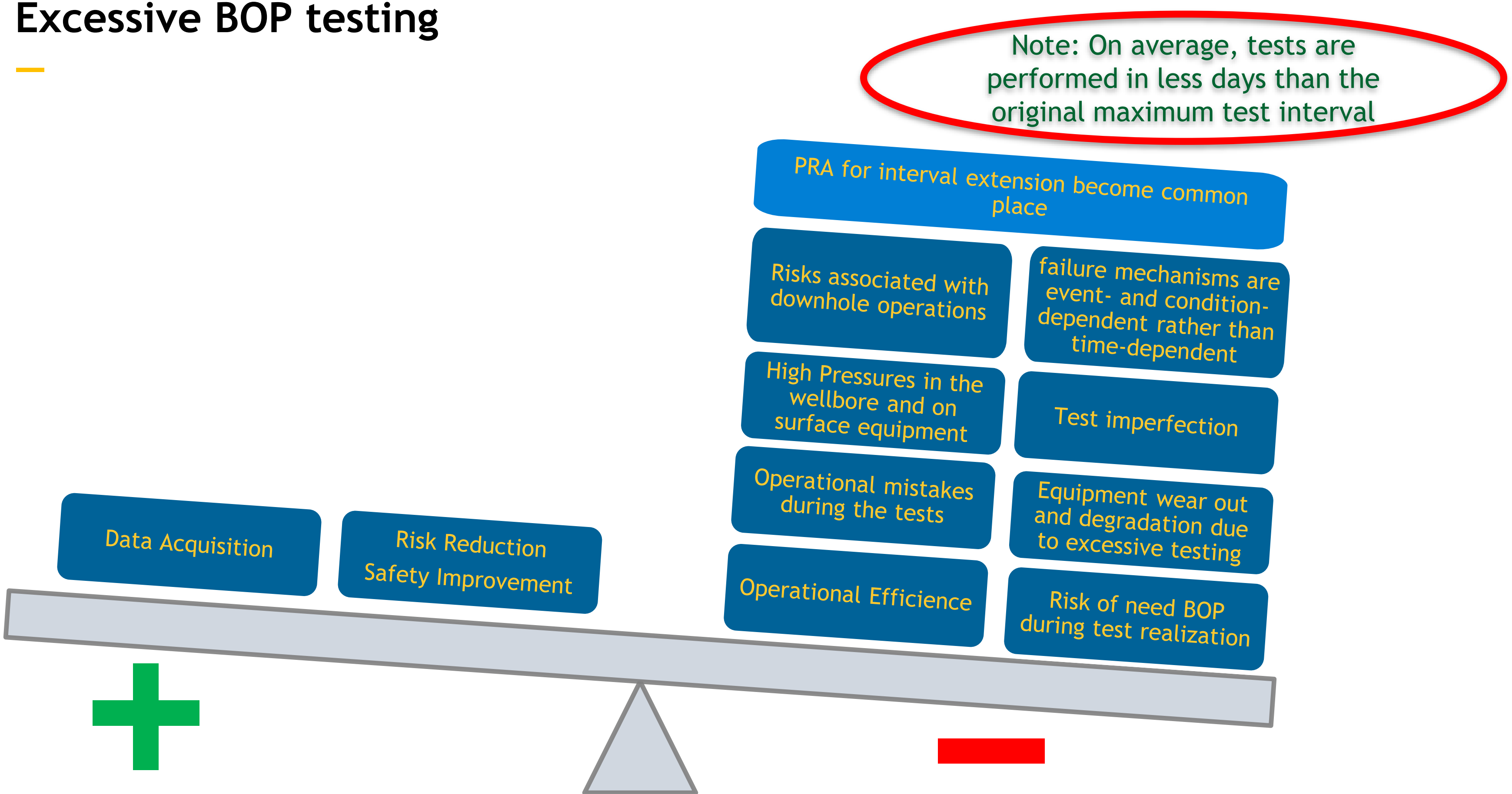
	SF 1 - SHEAR DRILL PIPE AND SEAL OFF WELL			SF 2 - SEAL AROUND DRILL PIPE			SF 3 - SHEAR CASING AND SEAL OFF WELL			SF 4 - SEAL OFF OPEN HOLE			SF 5 - DISCONECT THE RISER		
	Average	SIL Value	Rel. Compar	Average	SIL Value	Rel. Compar	Average	SIL Value	Rel. Compar	Average	SIL Value	Rel. Compar	Average	SIL Value	Rel. Compar
SCHEMA 21 days	3.95e-03	SIL 2	1.00	8.13e-05	SIL 4 or below	1.00	6.40e-03	SIL 2	1.00	3.92e-03	SIL 2	1.00	1.93e-03	SIL 2	1.00
SCHEMA 28 days	5.94e-03	SIL 2	1.50	1.25e-04	SIL 3	1.54	9.17e-03	SIL 2	1.43	5.90e-03	SIL 2	1.51	2.93e-03	SIL 2	1.51

Previous studies - PETROBRAS/DNV MyBarrier BOP

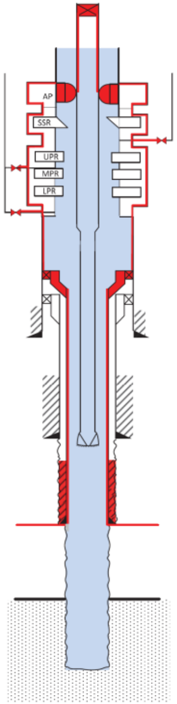


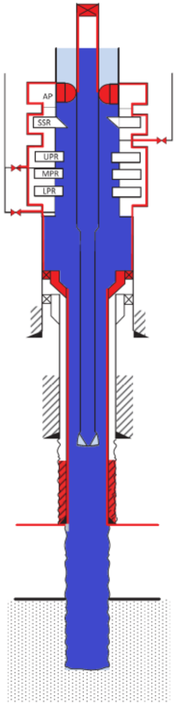
Optimizing the test plan

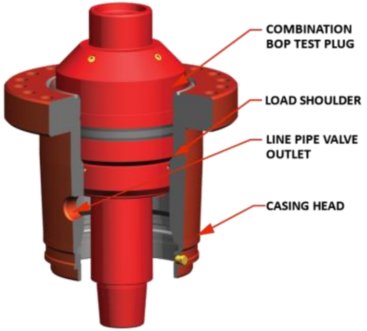
Excessive BOP testing

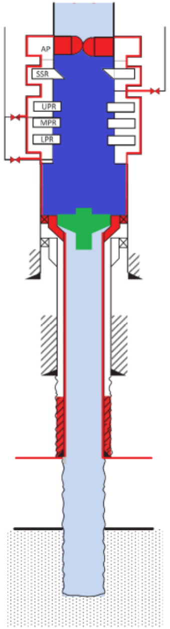


Problems with High Pressure Testing









Understanding the PFD of the BOP

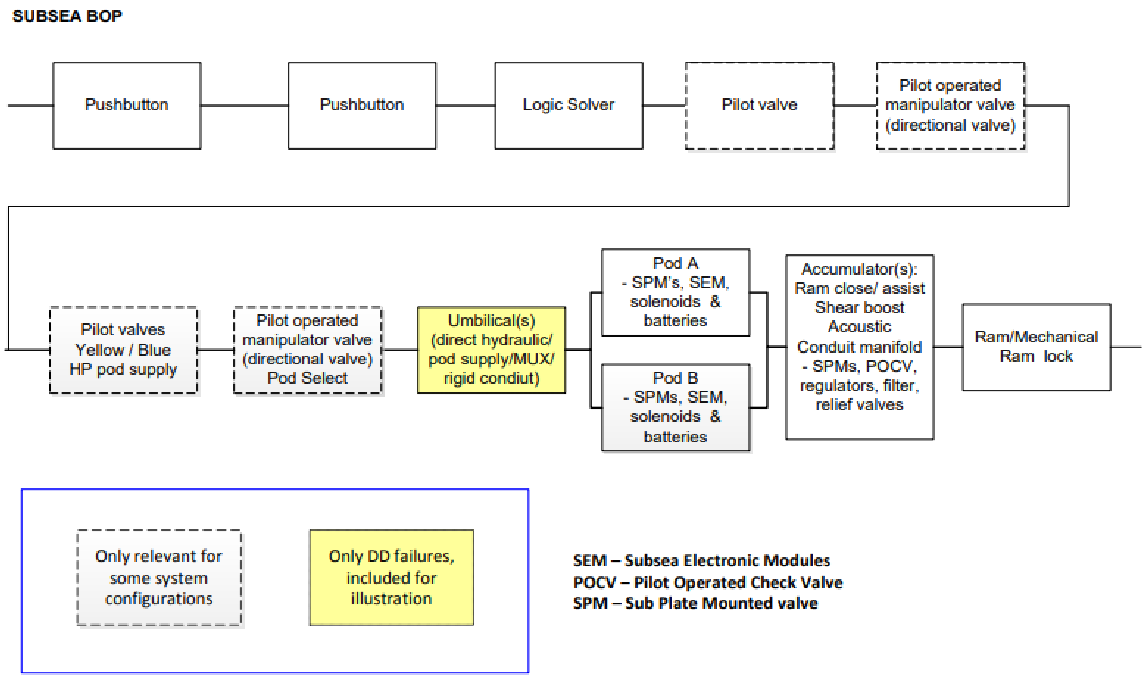
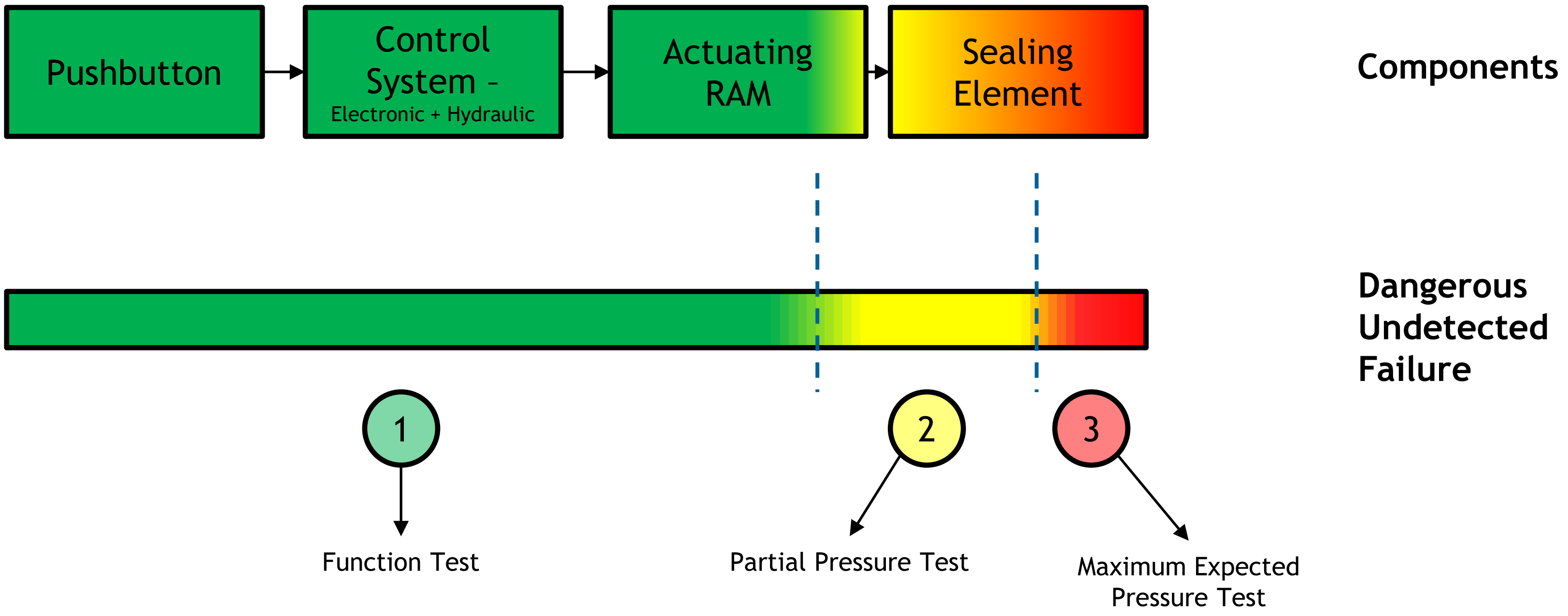
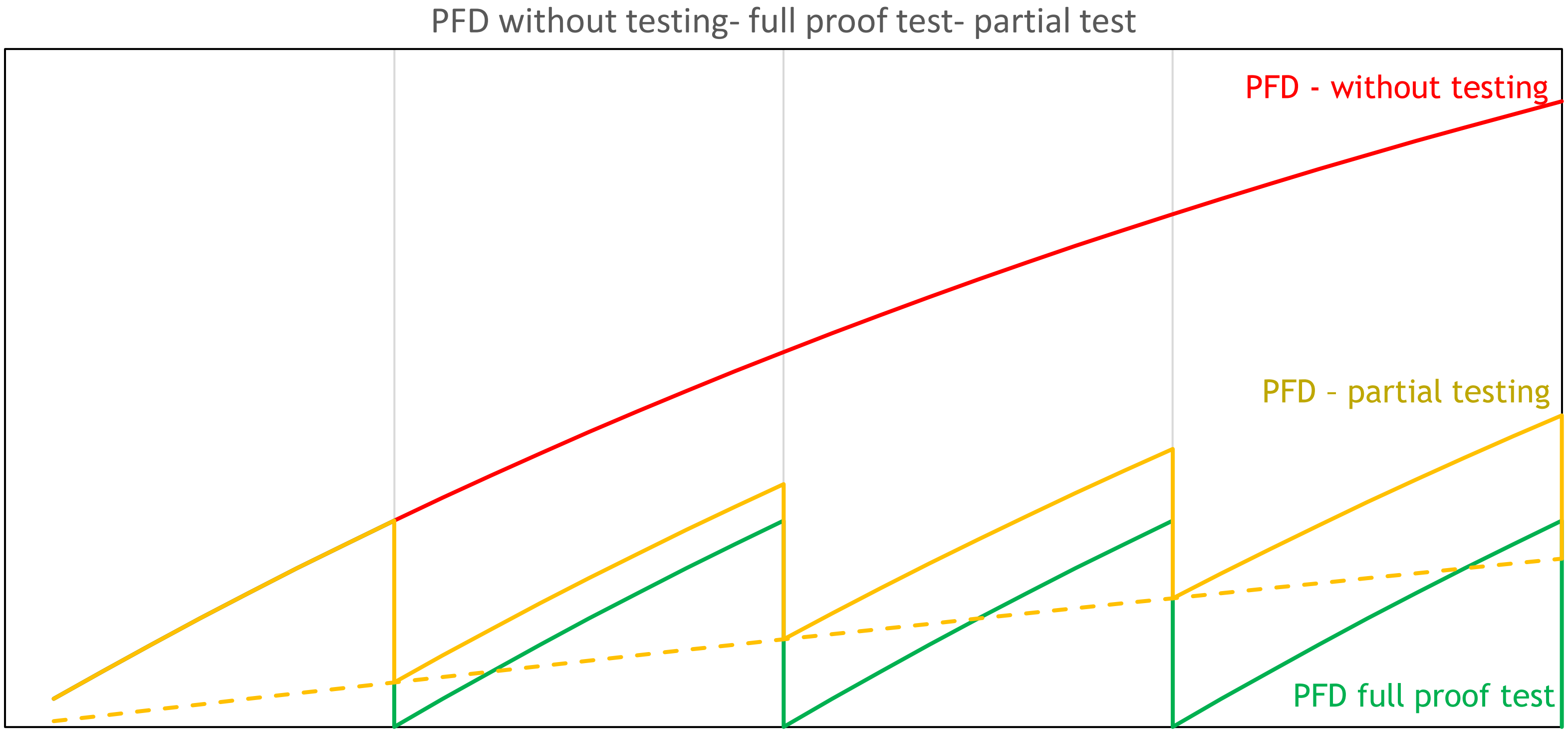


Figure A.14.1 Generic RBD for subsea BOP comprising shear seal ram function and mechanical lock function.

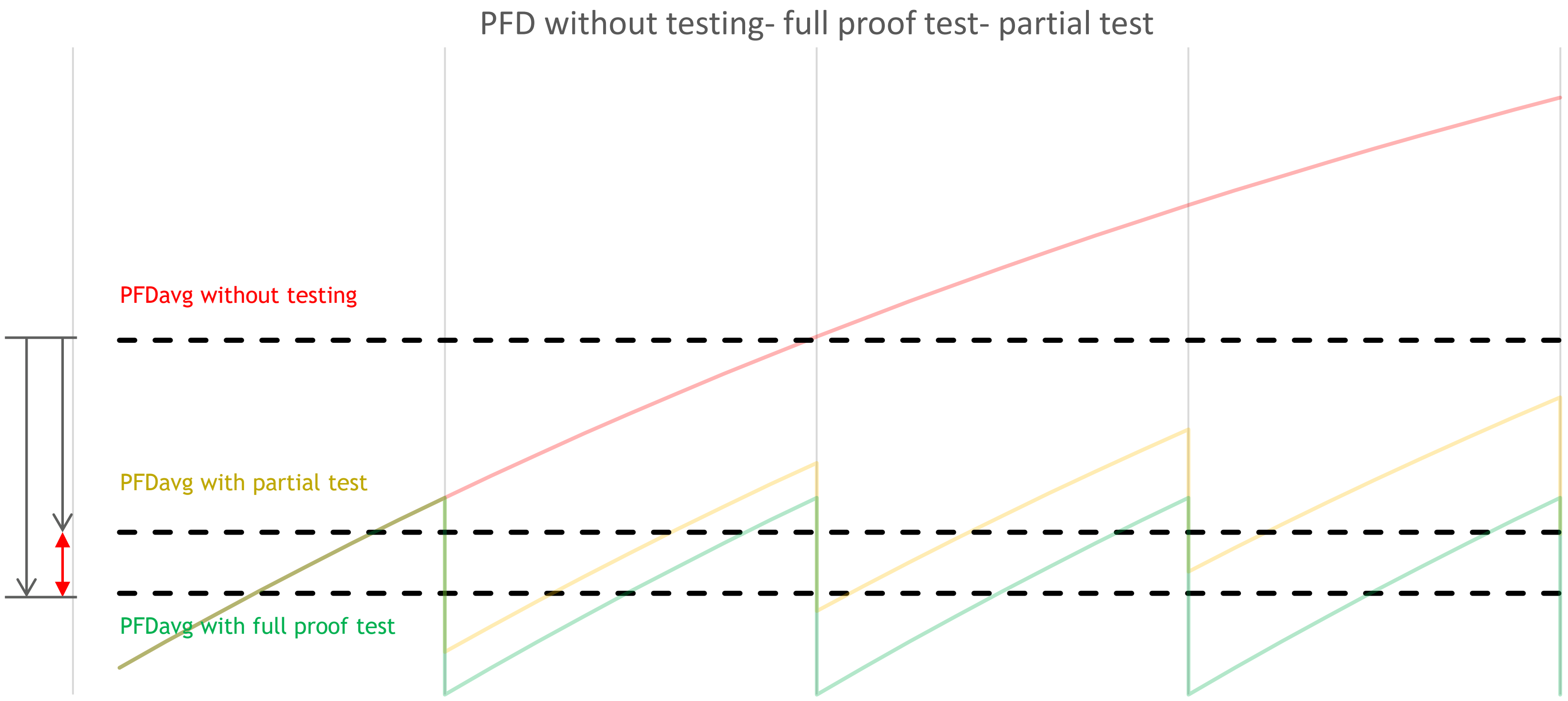
Understanding the PFD of the BOP



Understanding the effect of testing in the PFD



Understanding the effect of testing in the PFD



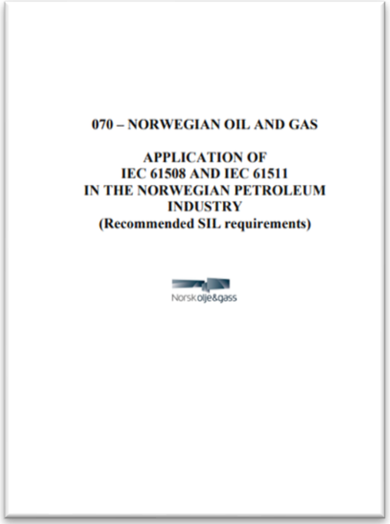
Optimizing the test plan

Proof Test Coverage - Some data sources


IADC IOGP

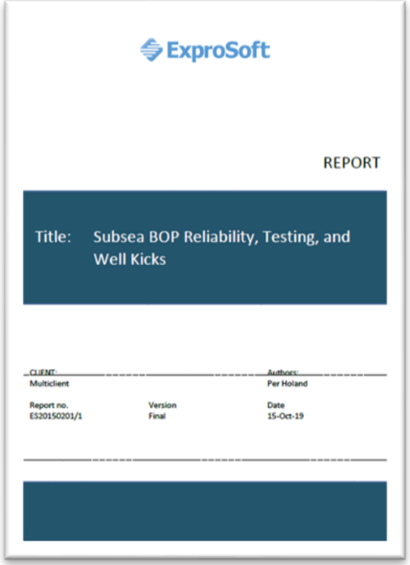
RAPID-S53

Reliability and Performance Information Database for the Well Control Equipment (WCE) covered under API S53.


070 – NORWEGIAN OIL AND GAS

APPLICATION OF
IEC 61508 AND IEC 61511
IN THE NORWEGIAN PETROLEUM INDUSTRY
(Recommended SIL requirements)

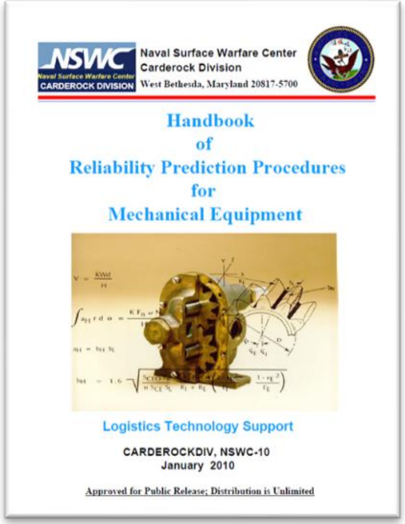
Norsk olje&gass


ExproSoft

REPORT

Title: Subsea BOP Reliability, Testing, and Well Kicks

CLIENT: Multiclient		Authors: Per Holand
Report no. ES20150201/1	Version Final	Date 15-Oct-19


NSWC Naval Surface Warfare Center CARDEROCK DIVISION

Naval Surface Warfare Center
Carderock Division
West Bethesda, Maryland 20817-5700

Handbook
of
Reliability Prediction Procedures
for
Mechanical Equipment

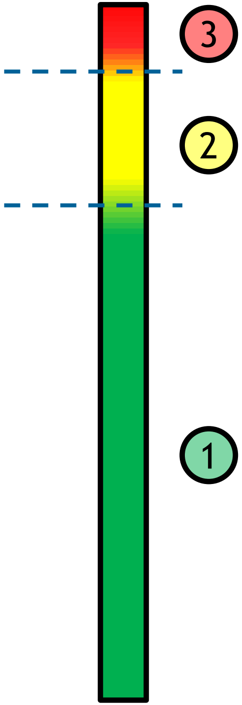
Logistics Technology Support

CARDEROCKDIV, NSWC-10
January 2010

Approved for Public Release; Distribution is Unlimited

OREDA

Proof Test Coverage



#	BOP test	Type	Why?	PTC
1	Function Test	Partial Test	Restrictions in the test scope	$PTC_{FT} = \frac{\lambda_f}{\lambda_{DU}}$
2	Partial Pressure Test	Imperfect Test	Constrains in the test conditions	$PTC_{PPT} = \frac{\lambda_f + \lambda_{lp}}{\lambda_{DU}}$
3	Maximum Expected Pressure Test	Proof Test	All DU expected to be revealed	$PTC_{PPT} = \frac{\lambda_f + \lambda_{hp}}{\lambda_{DU}} = 1$

Proof Test Coverage - Functional x Pressure

Source	Function	Sealing
Original OLF-70	85%	15%
Adapted OLF 70	57%	43%
MyBarrier BOP UBSR LCP	82%	18%
MyBarrier BOP UAP LCP	74%	26%
IADC RAPID S-53	67% to 84%	33% to 16%

Table A.14.1 PFD input for safety function "shear seal ram" / "casing shear ram"

Component	Voting	PFD per component	Total PFD
Pushbutton	2oo2	$5.0 \cdot 10^{-5}$	$1.0 \cdot 10^{-4}$
Single programmable safety system	1oo1	$3.5 \cdot 10^{-3}$	$3.5 \cdot 10^{-3}$
Control system (incl. pilot valves, DCV, HP pod supply, pods, shuttle valves, etc.)	1oo1	$8.4 \cdot 10^{-4}$	$8.4 \cdot 10^{-4}$
Shear seal ram (incl. ram lock)	1oo1	$7.7 \cdot 10^{-4}$	$7.7 \cdot 10^{-4}$
Total for function			**$5.2 \cdot 10^{-3}$**

Proof Test Coverage – Different Pressures

$$\lambda_{SE} = \lambda_{SE,B} \bullet C_P \bullet C_Q \bullet C_{DL} \bullet C_H \bullet C_F \bullet C_V \bullet C_T \bullet C_N$$

Where:

λ_{SE} = Failure rate of a seal in failures/million hours

$\lambda_{SE,B}$ = Base failure rate of seal, 2.4 failures/million hours

C_P = Multiplying factor which considers the effect of fluid pressure on the base failure rate (Figure 3.8)

C_Q = Multiplying factor which considers the effect of allowable leakage on the base failure rate (See Figure 3.9)

C_{DL} = Multiplying factor which considers the effect of seal size on the base failure rate (See Figure 3.10 or Figure 3.11)

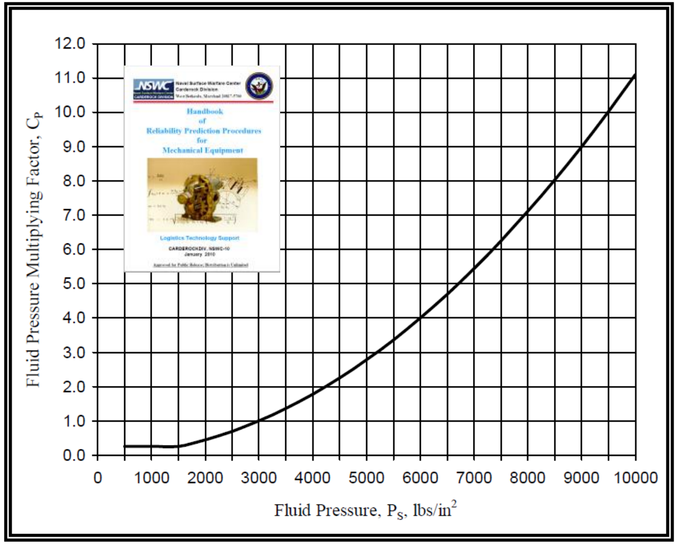
C_H = Multiplying factor which considers the effect of contact stress and seal hardness on the base failure rate (See Figure 3.12)

C_F = Multiplying factor which considers the effect of seat smoothness on the base failure rate (See Figure 3.13)

C_V = Multiplying factor which considers the effect of fluid viscosity on the base failure rate (See Table 3-3)

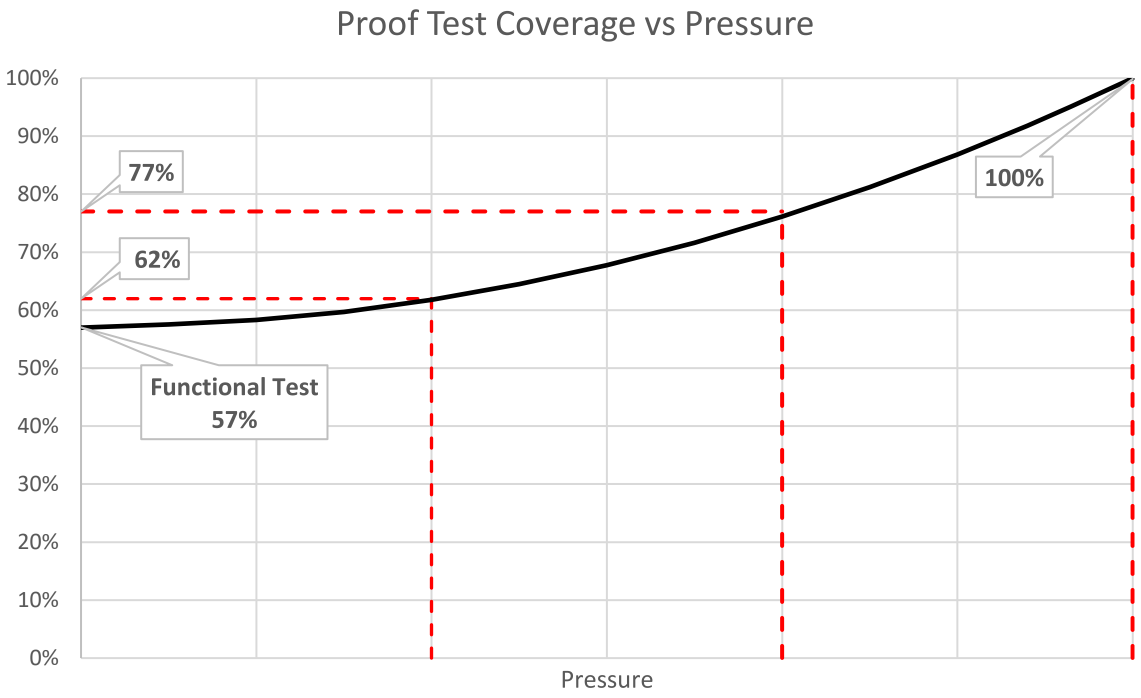
C_T = Multiplying factor which considers the effect of temperature on the base failure rate (See Figure 3.14)

C_N = Multiplying factor which considers the effect of contaminants on the base failure rate (See Table 3-4)



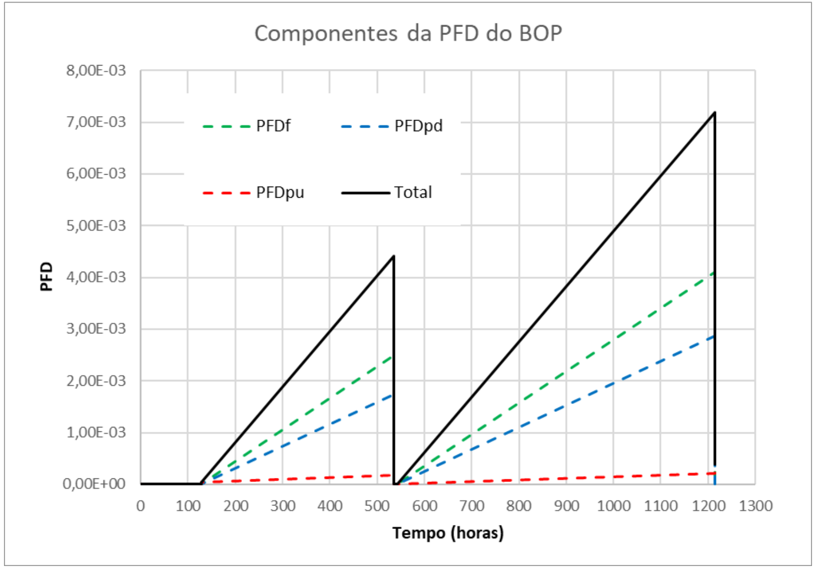
Optimizing the test plan

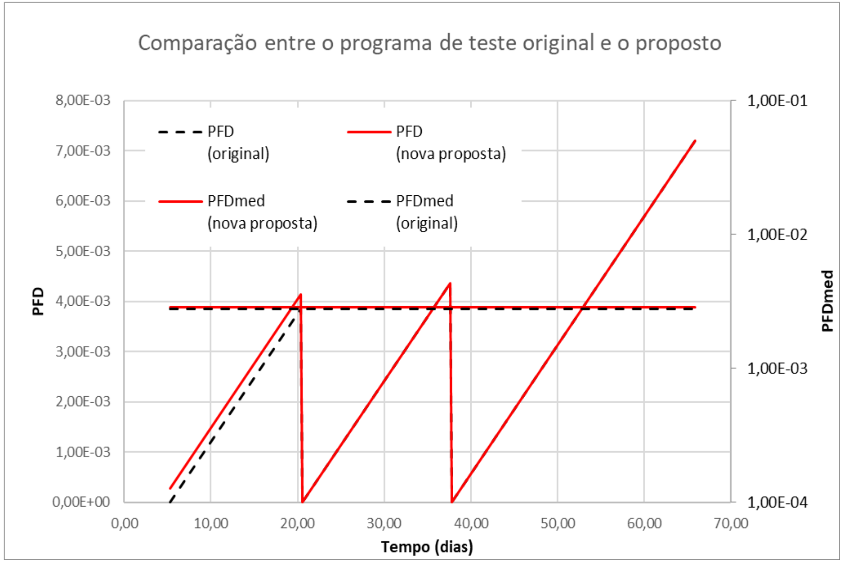
Proof Test Coverage



Optimizing the test plan

Analysis performed in a specific wells





ESREL 2022 - Special Session

S.01: Advances in Well Engineering Reliability and Risk Management

Organised by:

- Marcio das Chagas Moura (marcio.cmoura@ufpe.br) and Isis Didier Lins (isis.lins@ufpe.br) Federal University of Pernambuco, Brazil
- Danilo Colombo (danilo.colombo@petrobras.com.br) and Feliciano Silva, (feliciano@petrobras.com.br), Petrobras, Brazil
- Enrico Zio (enrico.zio@polimi.it) MINES ParisTech, France and Politecnico di Milano, Italy
- Enrique Lopez Droguett (eald@g.ucla.edu), University of California, Los Angeles (UCLA)

Motivation: The world energy balance has been changing, and the oil and gas industry is facing an ultimate challenge: how to be sustainable, resilient in the next years with deep cost reduction and almost zero environmental impact and human exposure? In this scenario, Well Engineering (especially, subsea) needs to be reinvented and pushed for developing brand new, disruptive solutions in all activities. This comprises autonomous and remote offshore activities by using digital twins for production management, the development of robots for unmanned operations, prognostic and health management for predictive maintenance and real-time integrity management, and electrification. Indeed, the latter is an enabler for the adoption of most of the other initiatives due to its potential cost reduction. All those efforts are linked to digitalization in the oil and gas industry allowing for data availability and integrated databases to improve well design, technical specification, maintenance, and operational decisions.
Given that, reliability and risk management play an important role to address the above mentioned challenges. Indeed, machineries, which are installed in deepwater oil wells, are typically exposed to quite harsh conditions such as high temperature and high pressure. In spite of that, they need to be fit to function without failures for long time periods. Otherwise, the maintenance costs are exorbitantly high in a way that it may even result in the early abandonment of faulty oil wells. These challenges are commonplace for most of the oil and gas operators around the world and, then, are of special interest for scholars and reliability practitioners who have dealt with them.

Objective: This special session welcomes papers that bring up innovative solutions for reliability and risk management within the Well Engineering field, which includes different aspects in each phase of a wellbore development (especially, subsea wells), from well construction and operation to abandonment. Scientific approaches and practical studies are expected, encompassing autonomous and remote offshore activities, real-time integrity management and electrification.

ESREL 2022 - Special Session

$$PFD_{avg} \cong \frac{1}{\beta_f}\left(\lambda_f \frac{1}{\frac{1}{T_f}+\frac{1}{T_{lp}}+\frac{1}{T_{hp}}}\right)^{\theta_f} + \frac{1}{\beta_{lp}}\left(\lambda_{lp} \frac{1}{\frac{1}{T_{lp}}+\frac{1}{T_{lp}}}\right)^{\theta_{lp}} + \frac{1}{\beta_{hp}}\left(\lambda_{hp} T_{hp}\right)^{\theta_{hp}}$$

- **Optimize** the functional, low-pressure and high-pressure tests
- Investigate more detailed the **coverage factor** as a function of pressure being applied during the test – possible use of Accelerated Failure Time models (AFT)
- Create the **cost function**
  - Input the cost of each test – functional < l-pressure < h-pressure
  - Input the cost of failure – rig downtime maintenance cost – pulling out, repair and running the BOP
  - Input the cost of accident – blowout x probability

Future Work

Journal paper

Including:

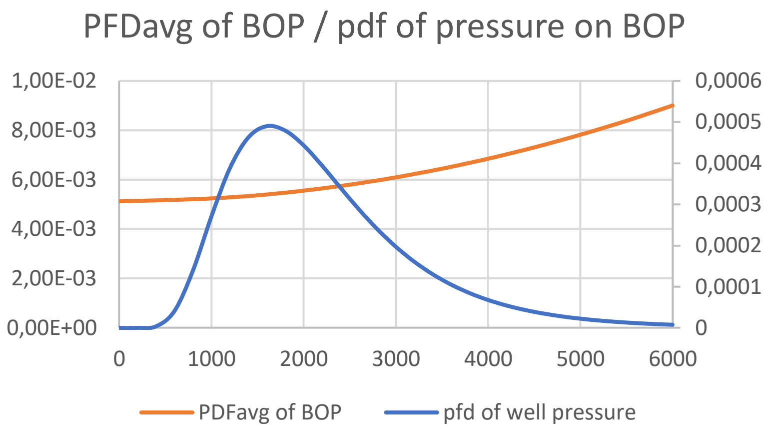
- Redundancy

- Test planning updating according to partial failures of BOP

- Probability of heaving a well control situation with some pressure

- Include the days since last overhaul (renewal) – aging effect

- Degradation model – to compute the damage input by the pressure test



Review of current regulation

Pressão máxima esperada	5400	Coloque a máxima pressão esperada
Pressão de teste desejada	5200	Coloque a pressão em que se pretende testar o BOP
Fator de Cobertura do teste de pressão	92,7%	

	Taxa (/h)	Intervalo de Teste	PFDmed	
Sistema de Controle				
Funcional	6,10E-06	21	1,54E-03	Coloque o período de teste funcional
Total de Pressão	4,60E-06			
Teste na Pressão Desejada	4,27E-06	56	2,87E-03	Coloque o período de teste na pressão desejada
Teste na Máxima Pressão	3,34E-07	168	6,74E-04	Coloque o período de teste na máxima pressão
Total do Sistema	1,07E-05	**40**	**5,08E-03**	

Seria o período equivalente de teste do BOP

Resultado
SIL2
5,08E-03