DNV·GL

PSV RBI

Pressure Safety Valve RBI - Using Half a Billion Hours of Data

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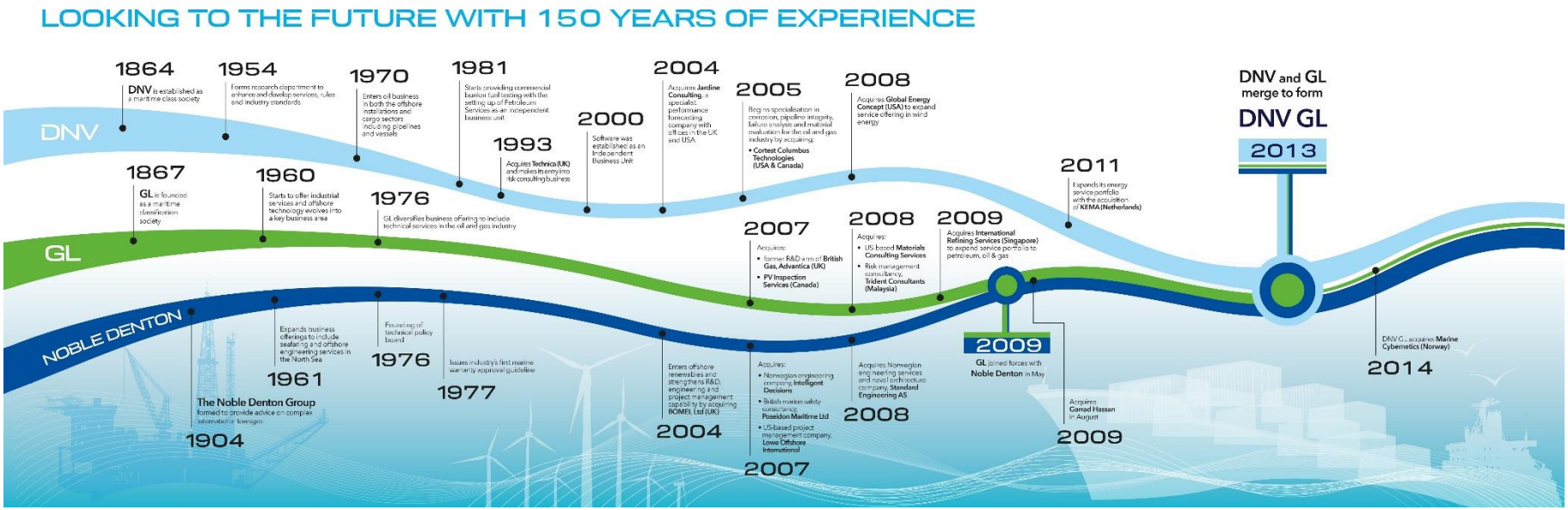
SAFER, SMARTER, GREENER

DNV GL – Our History



- Oil and Gas
  - Verification
  - Engineering Consultancy
- Digital
- Maritime (classification)
- Energy
- Business Assurance

PSV RBI - Agenda

- Pressure Safety Valves
  - Maintenance processes
- RBI
  - Philosophy and approach
  - RBI process
  - Results and benefits
- Other applications
  - BDV
  - EX equipment
  - etc.

Pressure Safety Valves

Installed to mechanically relieve pressure

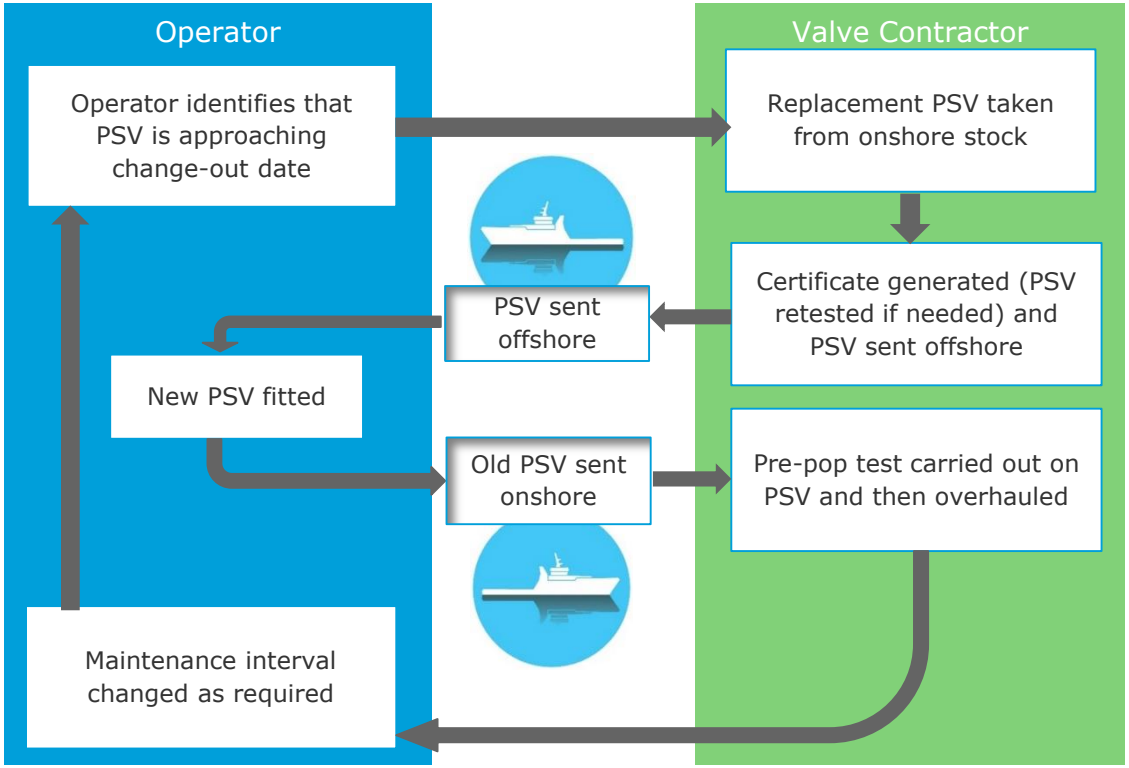
1. From a source such as a well, pump, spec break in pipework
   - PSV often, though not always, sized for full flow i.e. to relieve inflow if the normal pressure outlet is blocked

2. In a fire scenario

3. From thermal changes e.g. solar heating

- Most PSVs offshore are installed for reason (1)
- Across process and non-process pressure containing equipment
- Typically 100s of PSVs on a platform

PSV Maintenance Process



- PSV has hidden failures modes
  - Blockage e.g. wax, corrosion products
  - Drift – gradual change in set-point of the PSV
- Therefore must be tested and maintained
  - Cannot be done in-situ (Trevi testing aside)
- Testing and Maintenance process offshore can be costly (averaging £1,000s per PSV) and have knock-on effects (shutdown driven)
- So it is worth optimising the maintenance interval

Methodologies - API 581 2nd edition Sept 2008

7.8 Nomenclature

A^{prd}	is the orifice area of the
A^{prd}_{total}	is the total installed orif
C_{env}	is the environmental co
$C^{prd}_{f,j}$	is the PRD COF to ope
C^{mild}_{l}	is the consequence of a
C^{prd}_{l}	is the PRD consequenc
C^{so}_{l}	is the consequence of a
C^{mild}_{prod}	is the consequence of l
C_{sd}	is the consequence ass
CF	is the confidence factor
CF_{fail}	is the confidence factor of the test
CF_i	is the confidence fact historical inspection rec
CF_{pass}	is the confidence facto time of the test
$Cost_{env}$	is the environmental co
$Cost_{flu}$	is the cost of the lost flu
$Cost_{inv}$	is the lost inventory or f
$Cost^{mild}_{inv}$	is the cost of lost invent
$Cost^{so}_{inv}$	is the cost of lost invent
$Cost_{prod}$	is the production losses
$Cost^{mild}_{prod}$	is the production losse PRD, $
$Cost^{so}_{prod}$	is the production losses
$Cost_{sd}$	is the maintenance and

D_f	is the damage factor as a function of time f
D_{mild}	is the duration that a minor or moderate PF
D_{sd}	is the number of days required to shut a days
D_{so}	is the duration of a stuck open PRD, days
DR_j	is the demand rate associated with the jth c
DR_{total}	is the total demand rate on a PRD, demand
$DRRF_j$	is the demand rate reduction factor associa
EF_j	is the initiating event frequency associ demands/year
F_{MS}	is the management systems factor
F_a	is the multiple device installation adjustmer
F_c	is the adjustment factor for conventional va
F_{env}	is the adjustment factor for environmental f
F_{op}	is the adjustment factor for overpressure
$F_{op,j}$	is the adjustment factor for the overpressur
F_r	is the recovery factor applied to lost invent
F_s	is the adjustment factor for the presence of
F_{set}	is the adjustment factor for the ratio of oper
$F(t)$	is the cumulative failure density function or
gff_n	is the GFF for the protected equipment ass
gff_{total}	is the total GFF for the protected equipmer
$lrate_{mild}$	is the leakage rate of a mild or moderate le
$lrate_{so}$	is the leakage rate for a stuck open PRD, k
$MAWP$	is the maximum allowable working pressur
$MTTF$	is the mean time to failure
ndc	is the number of demand cases
$P_{f,j}$	is the POF (loss of containment) of th overpressure demand case, failures/year

$P_f(t)$	is the POF (loss of containment) of the protected equipment, failures/year
$P^{prd}_{f,cond}$	is the conditional POFOD, failures/demand
$P^{n}_{f,j}$	is the POF (loss of containment) of the protected e with the jth overpressure demand case, failures/year
$P^{prd}_{f,j}$	is the POF of a PRD associated with the jth overpres
$P^{prd}_{f,prior}$	is the prior POFOD, failures/demand
$P^{prd}_{f,wgt}$	is the weighted POFOD, failures/demand
P_{fod}	is the PRD POFOD, failures/demand
$P_{fod,j}$	is the PRD POFOD associated with the jth overpres
P^{prd}_{l}	is the PRD probability of leakage, failures/year
$P^{prd}_{l,wgt}$	is the weighted probability of leakage, failures/demand
P_o	is the overpressure likely to occur as a result of a PRD failing to open upon demand, kPa (psig)
$P_{o,j}$	is the overpressure likely to occur as a result of a PRD failing to open upon demand, associated with the jth overpressure demand case, kPa (psig)
$P^{prd}_{p,prior}$	is the prior probability of passing on demand, failures/demand
P_s	is the storage or operating pressure of the protected equipment, kPa (psig)
P_{set}	is the set pressure of the PRD, kPa (psig)
$Risk^{prd}$	is the total risk for a PRD, $/year
$Risk^{prd}_{f}$	is the risk of a PRD failure to open, $/year
$Risk^{prd}_{f,j}$	is the risk of a PRD failure to open associated with the jth overpressure demand case, $/year
$Risk^{prd}_{l}$	is the risk of PRD leakage, $/year
$R(t)$	is the risk as a function of time, m²/year (ft²/year) or $/year
t	is time, years
$t_{dur,i}$	is the actual duration between inspections associated with the ith historical inspection record, years

t_{insp}	is the inspection interval, years
$Unit_{prod}$	is the daily production margin on the unit, $/day
W^{prd}_{c}	is the rated capacity of a PRD, kg/hr (lb/hr)
β	is the Weibull shape parameter
η	is the Weibull characteristic life parameter, years
η_{def}	is the Weibull characteristic life parameter based on the default service severity chosen for a specific PRD, years
η_{mod}	is the Weibull characteristic life parameter modified to account for installation factors, design features, overpressure and environmental factors, years
η_{upd}	is the Weibull characteristic life parameter updated to account for inspection history, years

Methodologies

Semi-Quantitative

Probability of Failure	Consequence of Failure		
	HIGH	MED	LOW
HIGH	24	36	60
MED	36	48	72
LOW	48	60	96

IP Model Code of Safe Practice for Pressure Vessels (part 12)

Maximum maintenance interval:

– Grade 0	2 years	No data
– Grade 1	3 years	Some Data
– Grade 2	6 years	Good data

Methodologies are either very **complex**, or very **simple**

DNV GL RBI APPROACH

- Modelling is extremely difficult and needs a massive amount of data to prove
- DNV GL use a **combination** of quantitative and qualitative methods

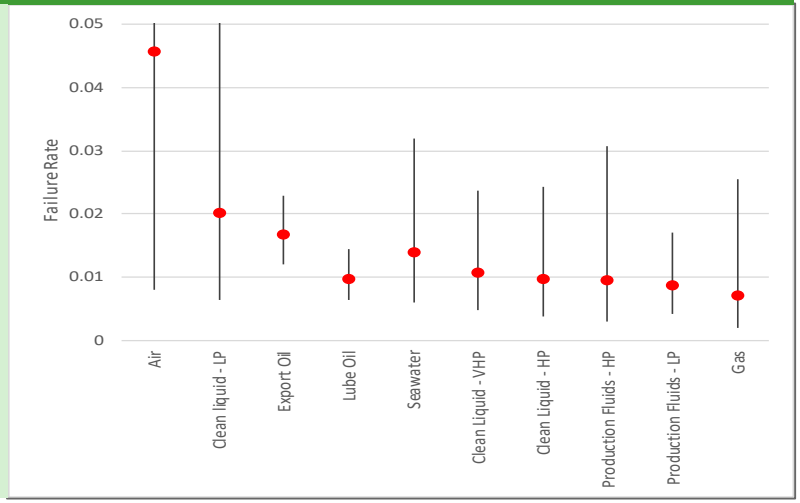
FAILURES, QUANTATIVE AND QUALITATIVE APPROACHES

Random Failures	• Failures can occur anywhere • May be different failure rate for different PSVs services • May be due to unknown factors • Inspection interval set such that residual risk of failure is acceptable	• More amenable to quantitative approach ($\lambda T/2$)
Systemic Failures	• A specific cause gives a large number of failures in a particular area • Cause may be clear and temporary, or unknown, or permanent	• More amenable to qualitative approach

QUANTITATIVE ANALYSIS (II) – Failure rates

DNV GL & Repsol-Sinopec data

- ½ **billion** service hours
- 10,311 tests, 544 failures
- Failure rate of 2.7% (though less without air)
- Intervals 6 months (rare) to 6 years (with 4 years being most common)



OREDA2009

- ⅔ **million** hours
- 1.2% failure rate

QUANTITATIVE (III) – Risk assessment

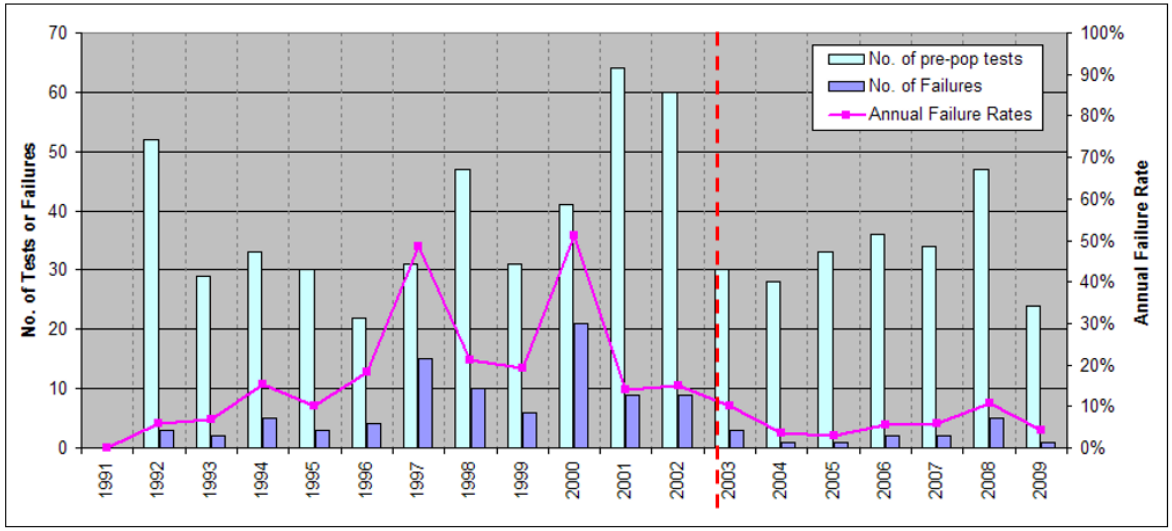
- QRA assessment uses:
  - Fixed demand rates on each class of PSV *(D)*
    - Thermal / Pressure / Fire
  - PSV Failure rate (λ)
  - POB

- Range of consequences from minor mechanical failure to full, ignited rupture *(N)*
  - Size of equipment protected
  - Set pressure
  - Fluid phase
  - Fluid flammability

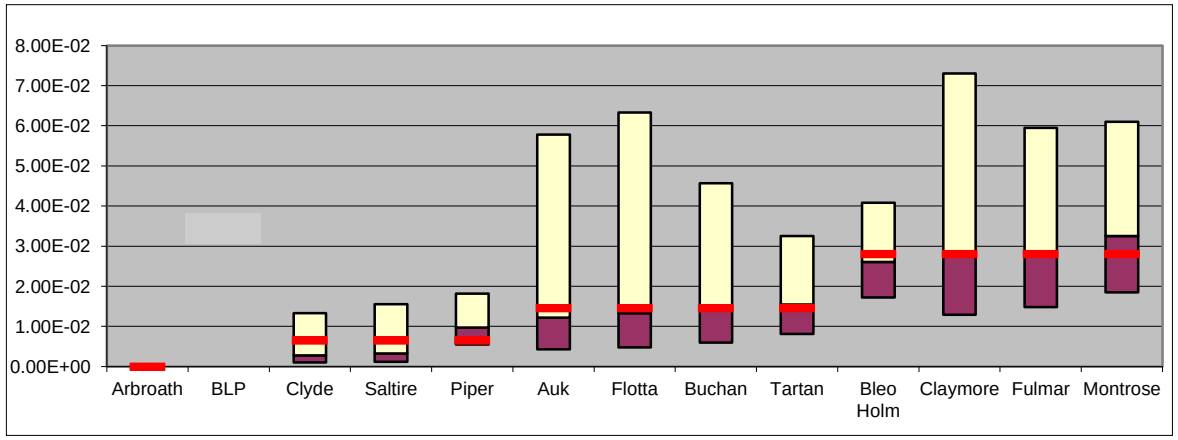
$$PLL = \frac{1}{2} \lambda \times T \times D \times N$$

- PSV failure rate is compared to a Potential Loss of Life *(PLL)* limit (10^{-5})
- Results in an upper interval limit *(T)*

Quantitative (IV) – Data consistency



- The history of each failure class is examined to determine improving or worsening behaviour
- Confidence limits assessment is carried out

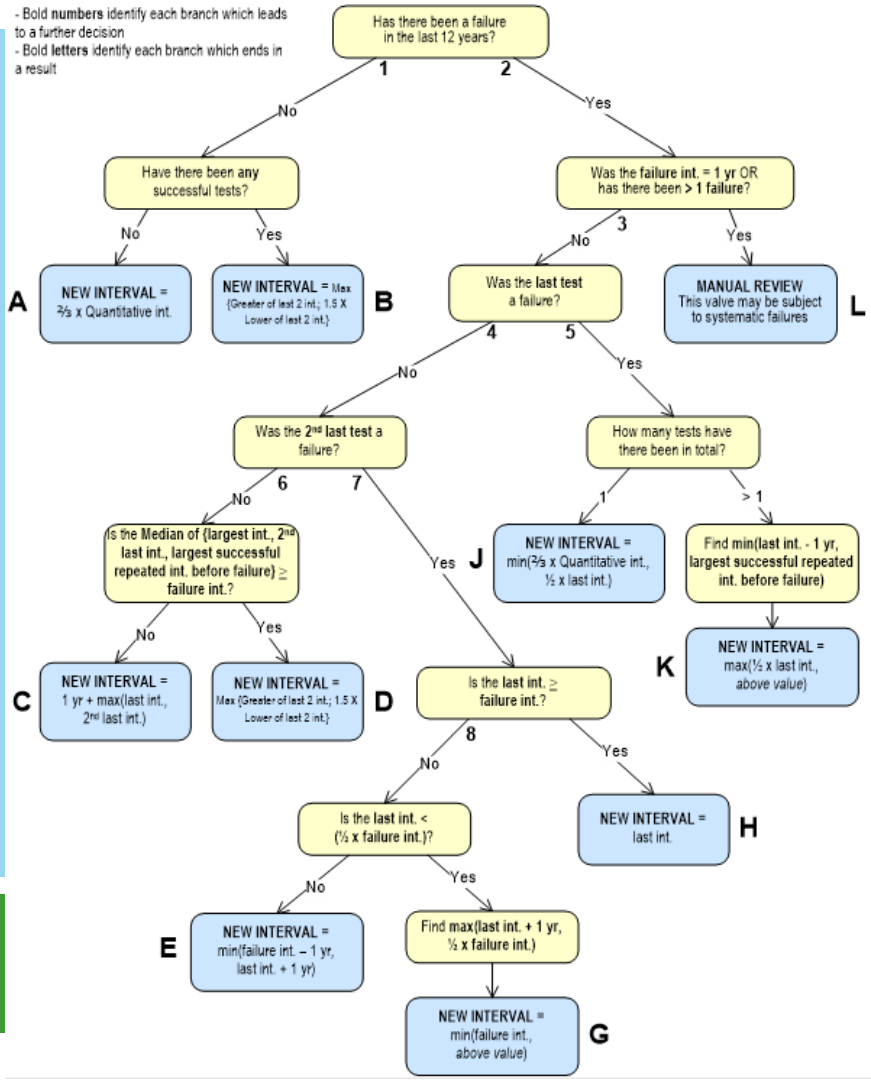


- Data from similar assets are merged to prevent small differences in data leading to differences in interval
- Avoids 3.49 and 3.51 becoming 3 and 4 years respectively

QUALITATIVE – Individual PSVs

- Three basic rules
  1. **Halve** the interval if a **failure** occurs (e.g. 4F→2 years)
     - CAUTIOUS - If all failures were "random", there would be no need to do this
  2. **Add 50**% to interval if repeated **good** history (e.g. 2P, 2P→3 years)
     - Takes longer to increase interval than decrease it
  3. Require repeated good history to move past a failure (e.g. 4F, 2P, 2P, 3P, 3P, → 4), though may never move past 3

- Complexity added to above given some complex history

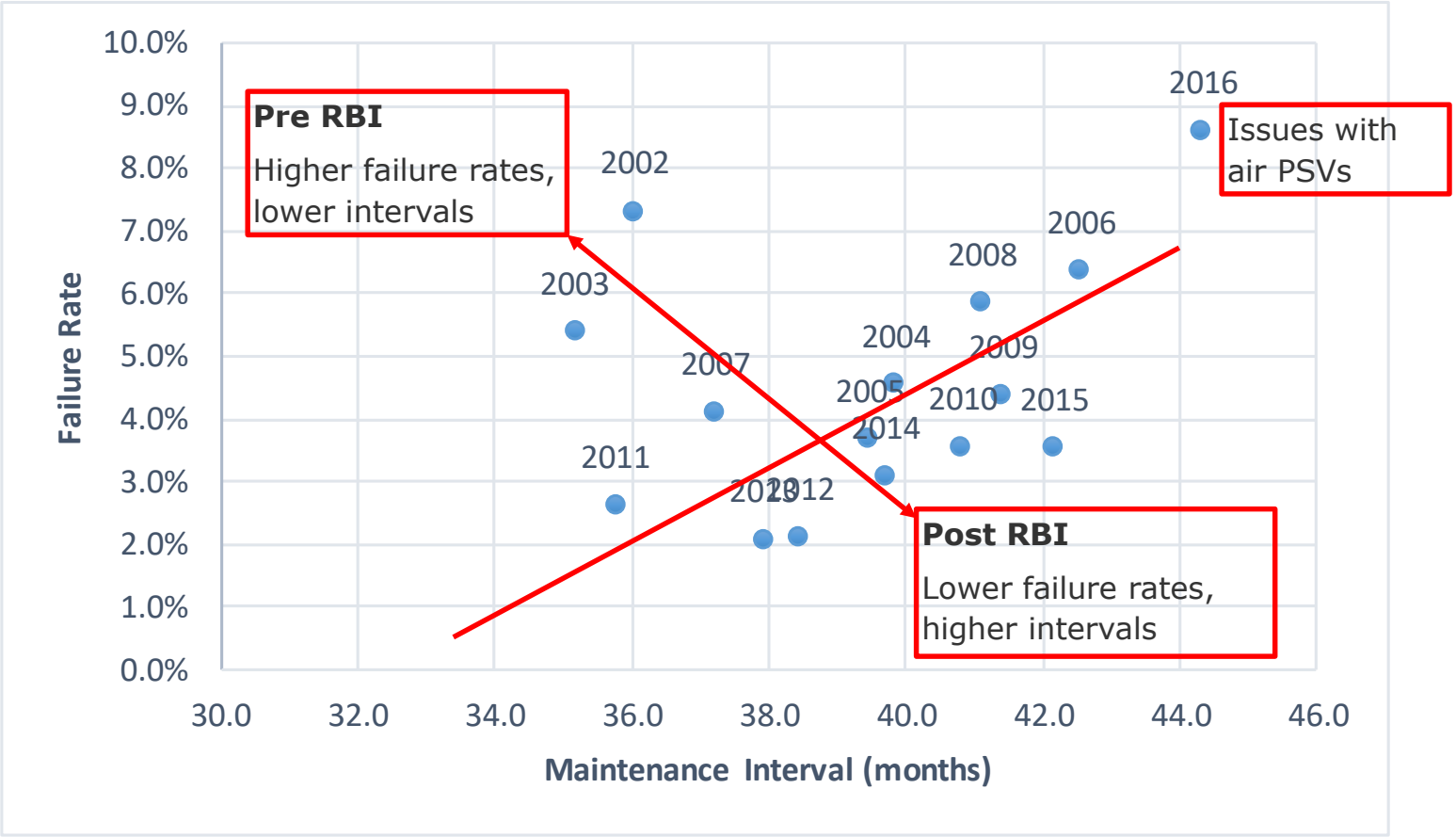


QUALITATIVE – Grouping PSVs

- A "group" is a set of PSVs under identical conditions
  - Same pressure
  - Same fluid
  - Same part of the process (almost guaranteed by two points above)
- PSVs are grouped with identical service and location for optimising credit from combined performance history, or considering adverse impact of a failure in the group.
- Gives confidence that the single failure is "random" and the interval can be 60 months (could be higher if failure had not occurred)

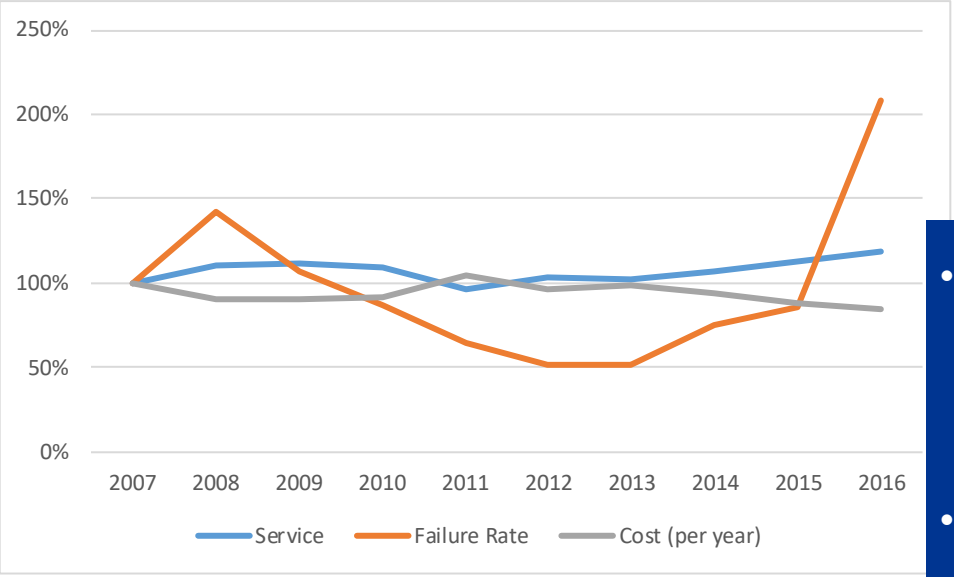
PSV Tag	PSV Tag history				
2-PSV-1005K	3p	3p	2.8p	2.9p	5p
2-PSV-1005L	3p	4.9p	5p		
2-PSV-1005N	2.4p	5p	5p		
2-PSV-1005O	2.4p	3p	2.9p	3p	5.1p
2-PSV-1005P	2.3p	3.5p			
2-PSV-1005Q	3p	3p	2.9f	2p	3p
2-PSV-1005R	2.3p	5p	5p		

Results
Failure Rate Comparison



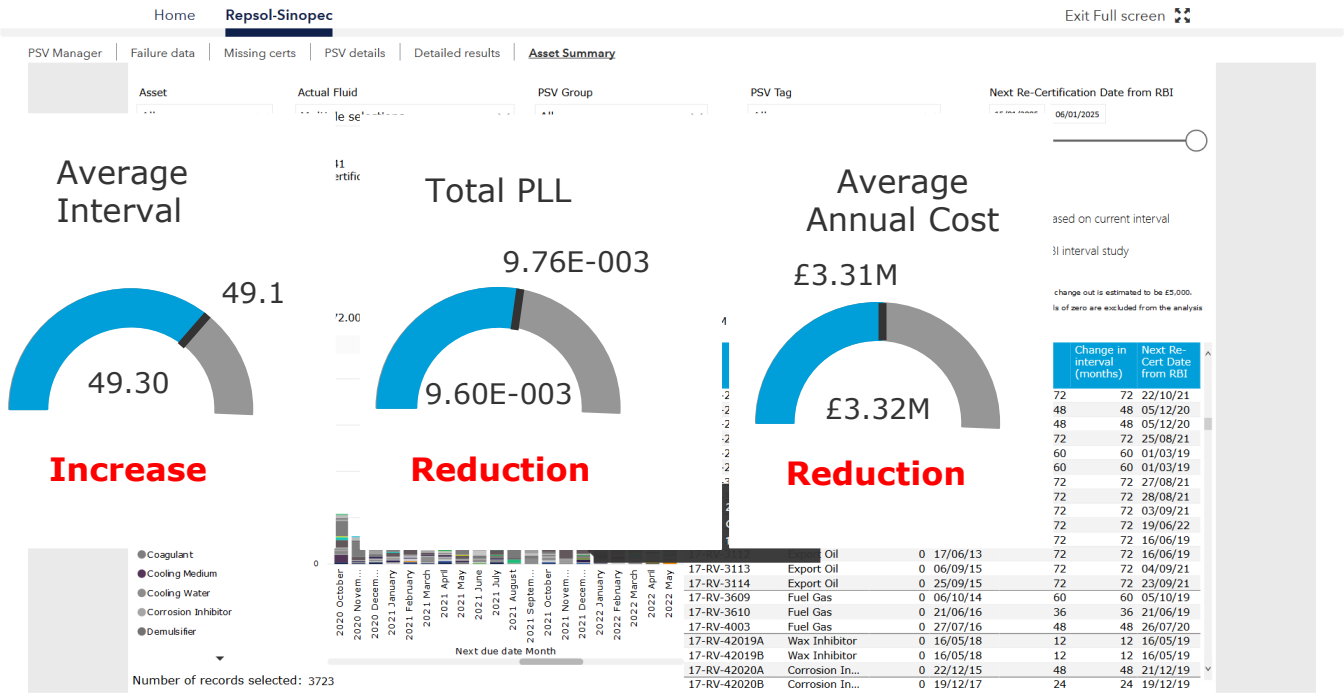
Positive validation of methodology, though at a high level

RESULTS AND BENEFITS – Cost savings & safety improvements



- Average maintenance interval has changed from 37 months to 44 months
- Failure rate has dropped (apart from recent air failures – previously no testing done on these valves)
- For an average PSV maintenance cost of a few £1,000, the total cost reduction is from £6.5m per year to £5.4m per year **(£1.1m saving)**

RESULTS AND BENEFITS – Overview



Various gains offset by poor air performance

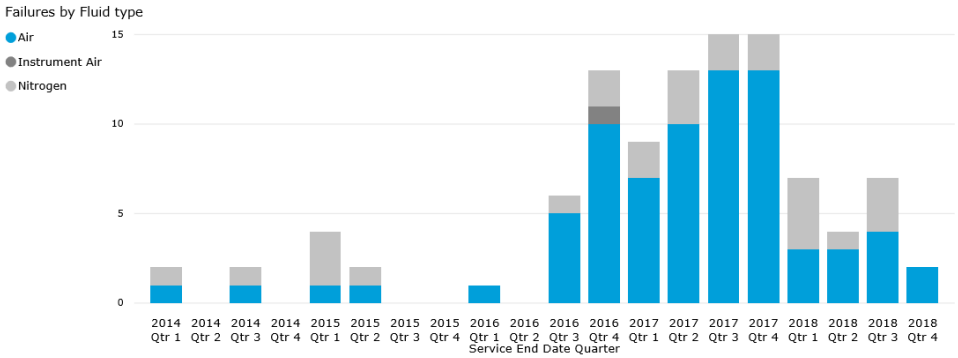
Intervals more static after many years of running analysis

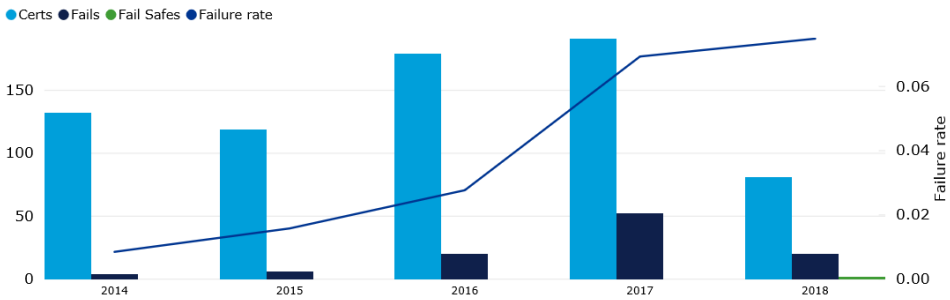
RESULTS AND BENEFITS – Trending

Home | Repsol-Sinopec | Exit Full screen

Failure data | Missing certs | PSV details | Detailed results | Asset Summary

Asset: All | Fluid Class: Air | Actual Fluid: All | PSV Tag: All | Service End Date: 01/01/2014 – 26/12/2018





PSV service records

Asset	2014	2015	2016	2017	2018
Arbroath					
Air					
14-BB-PSV8190				5.2P	
14-BB-PSV8200				5.2P	
14-CE-PSV6082		4.3P			
14-CE-PSV60900			4.7P		
14-CE-PSV60908		4.3P			
14-DB-PSV60710					6.1P
Auk					
Air					
16-RV-1006		1P			
16-RV-1007		1.1P			
16-RV-1009	4.3P				
16-RV-7090					6.1F
16-RV-9875		0P			
Nitrogen					
16-RV-59103A		2.8P			
16-RV-59103B		2.6P			
Bleo Holm					
Air					
BH-340-PRV-6004	2P			3F	
BH-370-PRV-4000				3.7P	
BH-370-PRV-6012			4.1P		
BH-370-PRV-6014				3.1P	
BH-370-PRV-6054		2P			3.1P
BH-371-PRV-4007				4.1F	
BH-371-PRV-4008				4.1F	
BH-371-PRV-4009				1.1P	
BH-371-PRV-4041	4P				
BH-371-PRV-4042	4.1P				
BH-371-PRV-4045				4.1P	
BH-371-PRV-6004				1.7P	
BH-371-PRV-6024				1.7P	
BH-375-PRV-001				4.3P	

Trends easily seen and correct action taken where required – air in this case

RESULTS AND BENEFITS – Readily available information

Home | **Repsol-Sinopec** | Exit Full screen

Failure data | Missing certs | PSV details | **Detailed results** | Asset Summary

Asset: Bleo Holm
PSV Group: All
PSV Tag: All
Next Re-Certification Date from RBI: 15/01/2005 – 06/01/2025
Fluid Class: All
Actual Fluid: Diesel
Change in Interval (months): All
Comment: All

Average Interval: 36.00 (0.00 – 72.00)
Total PLL: 3.75E-005 (0.00E+000 – 7.50E-005)
Average Annual Cost: £11.67K (£0.00K – £23.33K)

Value based on current interval
After RBI interval study

Note: Cost of a single PSV change out is estimated to be £5,000.
Valves with current intervals of zero are excluded from the analysis plots.

Asset	Tag	Failure Class	PSV Group	System Fluid	Current Interval (months)	Latest WO Date	4th Latest Cert	3rd Latest Cert	2nd Latest Cert	Latest Cert	Quant Result (months)	Final RBI Result (months)	Change in Interval (months)	Next Re-Cert Date from RBI	Comment
Bleo Holm	BH-340-PRV-60...	BH-CLH	BH-G11	Diesel	36	30/07/18	3p*	1.5p	2.1p	3.1p	72	36	0	29/07/21	
Bleo Holm	BH-340-PRV-61...	BH-CLH	BH-G11	Diesel	36	15/02/16	2.2p*	4.7p	2.1p	1.9p	72	36	0	14/02/19	
Bleo Holm	BH-340-PRV-61...	BH-CLH	BH-G11	Diesel	36	17/02/16		4.7p	2.1p	1.9p	72	36	0	16/02/19	
Bleo Holm	BH03-340-PRV-...	BH-CLL	BH-G10	Diesel	36	28/07/17	1.1p	2.2p	2.2p	2.2p	48	36	0	27/07/20	New Cert In G
Bleo Holm	BH03-340-PRV-...	BH-CLL	BH-G10	Diesel	36	29/05/18	1.1p	2.7p	1.6p	0.9p	48	36	0	28/05/21	New Cert
Bleo Holm	BH-340-PRV-45...	BH-CLL	BH-G76	Diesel	36	20/01/16	2f*	3.9p	1.1p	2p	48	36	0	19/01/19	
Bleo Holm	BH-340-PRV-45...	BH-CLL	BH-G76	Diesel	36	20/01/16	2f*	3.9p	1.1p	2.1p	48	36	0	19/01/19	

- PSV Manager gives
  - **Insights** on performance
  - Allows poor performance to be **rectified**
  - **Reduces** maintenance costs when appropriate

- Regarding the data
  - Some trends can be **identified**
  - Benefits can be **lost** if changes in maintenance intervals are implemented
  - Obvious, but small intervals can **dominate** changes in cost
  - ½ **billion** hours of data is a lot

RESULTS – Decrease interval to improve reliability Heating medium (3 assets)

- 37 tests, 8 fails
- Poor performance corrected through shorter maintenance intervals

- Opportune test can be undertaken for operational reasons (shutdown driven usually)

Maintenance Interval	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	-	-	-	-	-	-	-	-	-	-	-	0%	-	0%	-	0%	-	-
2	-	-	-	-	-	-	-	-	-	0%	-	0%	-	0%	-	-	-	-
3	-	-	-	0%	50%	0%	-	0%	-	-	0%	-	-	0%	-	0%	0%	-
4	-	67%	100%	-	-	100%	-	100%	-	0%	-	-	-	-	-	-	-	-
5	-	-	100%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	100%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average Intervals				3.9	3.7	3.4	3.1	3.3	3.4	3.3	3.2	2.0	2.0	1.8	1.6	1.8	1.9	1.8

- Poor performance at higher maintenance intervals

- Intervals reduced and no failures recorded recently

RESULTS – Overall no interval change but more targeted Production fluids (HP) (All assets)

- 498 tests, 16 fails
- Performance improved through more targeted maintenance and no overall change in interval

- Only represents two failures

Maintenance Interval	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	0%	-	-	0%	-	-	-	-	0%	-	0%	-	0%	0%	0%	0%	-	0%
2	0%	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	0%	0%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
4	0%	50%	0%	4%	17%	14%	0%	0%	33%	5%	0%	0%	0%	0%	0%	0%	0%	0%
5	-	0%	-	-	25%	0%	-	100%	13%	0%	-	0%	0%	0%	-	0%	17%	25%
6	-	-	-	33%	-	-	-	-	-	0%	-	-	-	0%	0%	0%	0%	-
All Intervals				2.6	2.9	2.9	3.2	3.3	3.2	3.4	3.2	3.1	3.0	2.6	2.5	2.5	2.7	2.8

- Performance variable with 13 failures in this period

- Maintenance optimised (no increase) and reduction to 2 failures in this period

RESULTS – Small increase in inspection interval
Produced water (6 assets)

- 170 tests, 9 fails
- Performance steady, though maintenance interval increased

Maintenance Interval	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	0%	0%	0%	-	-	-	-	-	-	0%	0%	-	0%	-	-	-	-	-
2	0%	-	0%	-	0%	0%	-	0%	0%	0%	0%	-	0%	-	0%	0%	0%	-
3	100%	0%	17%	0%	0%	0%	17%	0%	29%	0%	0%	0%	-	0%	0%	0%	33%	-
4	-	-	-	0%	0%	-	0%	0%	0%	-	0%	50%	0%	0%	0%	0%	0%	0%
5	-	-	-	-	-	-	-	-	0%	-	-	-	-	-	-	-	0%	-
6	-	-	-	-	-	-	-	-	-	0%	-	-	-	-	0%	0%	-	-
All Intervals				2.1	2.5	2.6	3.0	2.9	2.9	2.8	2.5	2.5	2.3	2.5	3.0	3.0	3.3	3.4

- Interval averaging 2.7 years
- Interval 3.2 years

Expansion of Method

- General process readily extendable to
  - Fire and Gas detection
  - Emergency shutdown valves
  - Blowdown valves
    - Issues can be more physical valve specific – low failure rates outside this
  - Instrumentation
  - EX equipment
  - Deluge (while the number of pumps is small, a large number of tests are carried out)
  - UPS batteries

Many thanks to Repsol-Sinopec for data

https://brandcentral.dnvgl.com/download/DownloadGateway.dll?h=BE1B38BB718539CC0AB58A5FF2EA7A83D7564C032139D3153C9F25D173630BA451AE1F4CEA84D93DC3D4B143887298B6

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