BRU21

Better Resource Utilization in the 21st century

NTNU Strategy for oil and gas

NTNU

Lundin Norway

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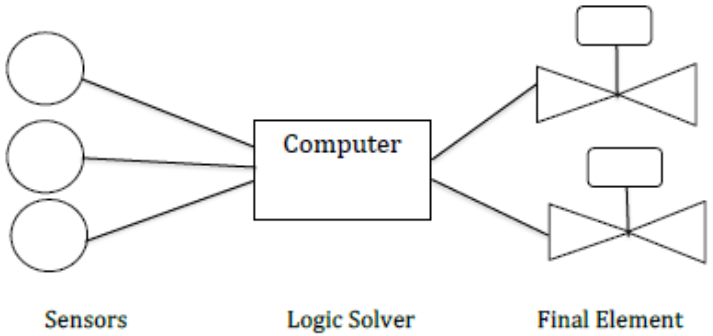
Predictive Maintenance

Agenda:

- Case of study
- Data
- Existing model
- System diagnosis (qualitative)
- Data analysis
- Possible health indicators
- Prognostics: ideas
- Anomaly detection: idea

Emergency Shutdown Valve (ESV) – SISs final element

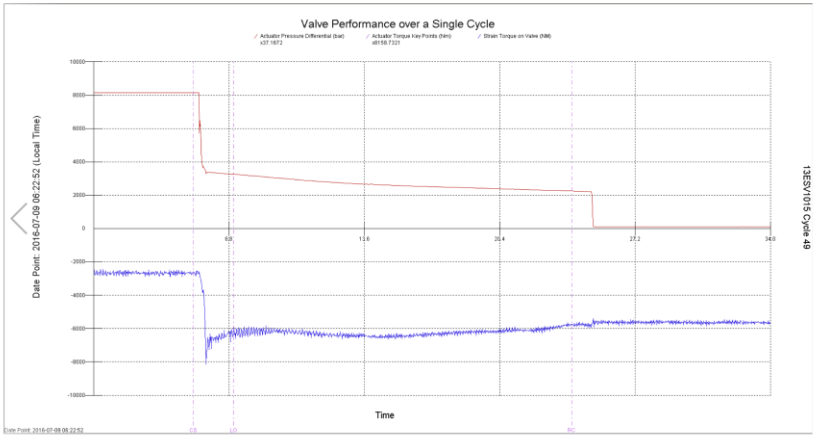
A Safety Instrumented System (SIS) is used for providing protection against failures of safety critical systems which is associated with potential harm of people, economy and/or environment (Rausand, 2014).



Final elements may be regarded as the most vital subsystems as they (upon events like process upsets) interact directly with the process, but due to the force and motion to be exerted when action is asked, these devices are rather vulnerable to creeping degradation processes (Wu et al. 2018)

The data regarding system condition monitoring:

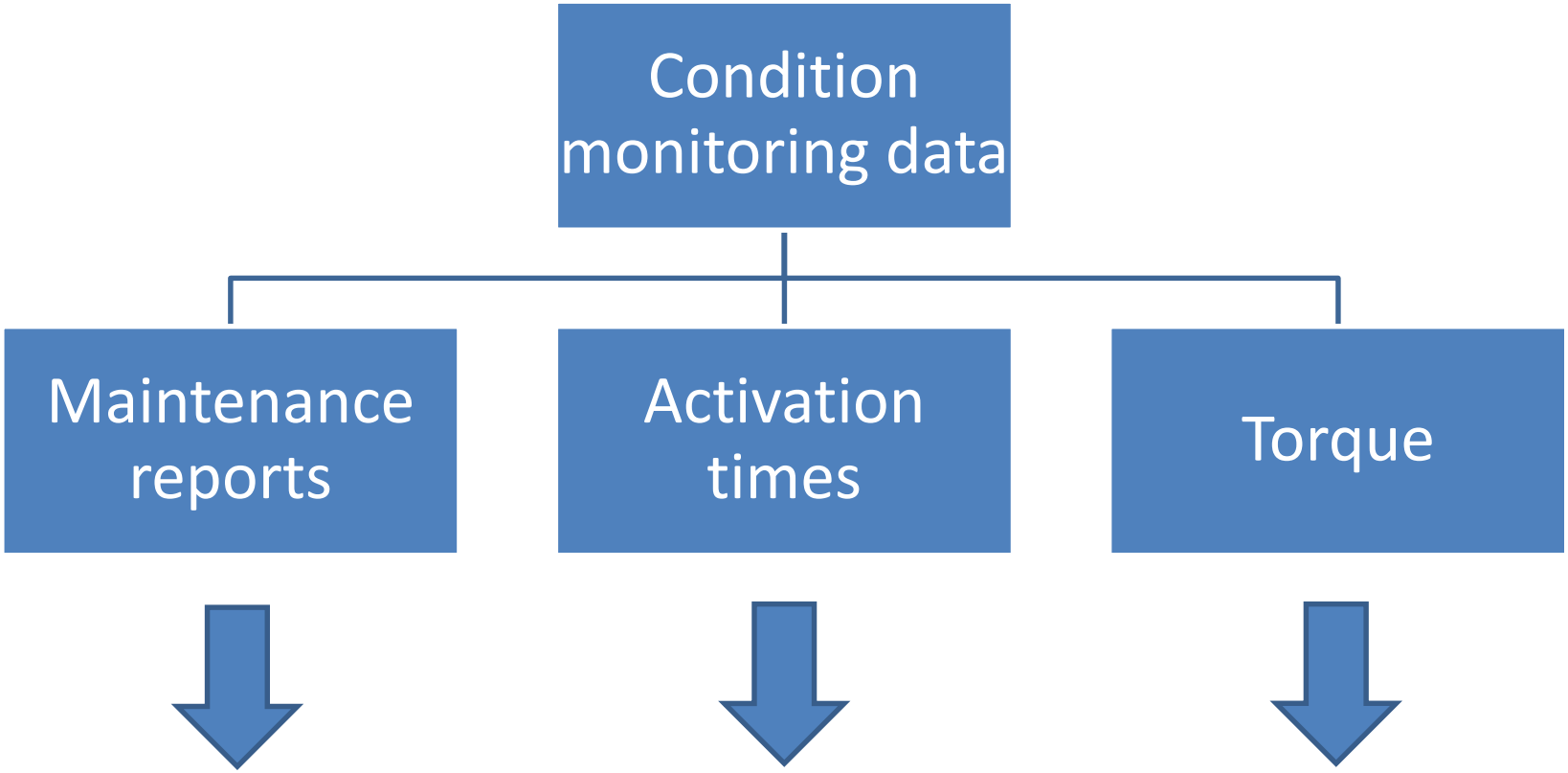
1) Reports from maintenance
2) Activation times of valves
3) Torque registered during valves activations



Timestamp	Valve	Operation	IsToSafeState	OperationStatus	Travel	Max
2/19/2016 2:22:22.060 PM	'21ESV1061'	'PCS Close'	1	'OK'	18	60
2/19/2016 2:44:47.093 PM	'21ESV1061'	'PCS Open'	0	'OK'	49	150
2/20/2016 9:14:19.190 AM	'21ESV1061'	'ESD PS'	1	'OK'	2	3.5
2/20/2016 9:14:48.917 AM	'21ESV1061'	'ESD PS'	1	'OK'	1.3	3.5
2/20/2016 9:17:07.220 AM	'21ESV1061'	'ESD PS'	1	'OK'	2	3.5
2/20/2016 9:17:29.840 AM	'21ESV1061'	'ESD PS'	1	'OK'	1.4	3.5
2/21/2016 2:09:53.547 AM	'21ESV1061'	'ESD Close'	1	'OK'	17.8	60
2/21/2016 6:50:58.143 AM	'21ESV1061'	'PCS Open'	0	'OK'	48	150
4/12/2016 8:14:28.843 AM	'21ESV1061'	'ESD Close'	1	'OK'	17	60
4/13/2016 1:57:04.350 AM	'21ESV1061'	'PCS Open'	0	'OK'	46	150
4/21/2016 9:27:22.090 AM	'21ESV1061'	'ESD Close'	1	'OK'	18	60
4/21/2016 11:40:43.727 PM	'21ESV1061'	'PCS Open'	0	'OK'	48	150
4/22/2016 3:37:18.810 AM	'21ESV1061'	'ESD Close'	1	'OK'	17.7	60
4/22/2016 10:11:11.363 AM	'21ESV1061'	'PCS Open'	0	'OK'	49	150
6/22/2016 12:27:11.257 PM	'21ESV1061'	'ESD Close'	1	'OK'	17.1	60
6/22/2016 5:11:24.280 PM	'21ESV1061'	'PCS Open'	0	'OK'	43	150
7/2/2016 5:33:50.333 PM	'21ESV1061'	'ESD Close'	1	'OK'	17.9	60
7/3/2016 12:07:00.040 AM	'21ESV1061'	'PCS Open'	0	'OK'	47	150
8/18/2016 4:12:09.450 PM	'21ESV1061'	'PCS Open'	0	'OK'	44	150
8/18/2016 4:16:12.693 PM	'21ESV1061'	'PSD PS'	1	'OK'	1.3	3.5
9/20/2016 2:07:56.903 PM	'21ESV1061'	'ESD Close'	1	'OK'	17	60
9/20/2016 9:32:21.720 PM	'21ESV1061'	'PCS Open'	0	'OK'	43	150
10/30/2016 8:10:15.980 PM	'21ESV1061'	'ESD Close'	1	'OK'	17.6	60
10/31/2016 4:01:42.287 PM	'21ESV1061'	'Already in Safe State'	0	'OK'	0	150
10/31/2016 4:28:34.543 PM	'21ESV1061'	'Already in Safe State'	0	'OK'	0	150

dato	vedlikeholdsaktivitet	beskrivelse	tilstand_før	tilstand_etter
27.02.2016 00:00			God	God
06.07.2018 00:00		Inspisert utstyr i felt og smurt opp	God	God
05.07.2018 00:00		Verifisert i IMS og tilhørende exc	God	God
08.06.2018 00:00	Test - periodisk test av funksjon/ytelse	Verifisert OK i IMS.	God	God
31.08.2017 00:00	Test - periodisk test av funksjon/ytelse	Verifisert OK i IMS. Visuell inspe	God	God

Condition Monitoring Data:



Condition Monitoring Data:

What to look for?

Condition monitoring data

Maintenance reports

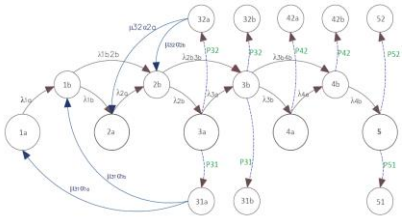
Activation times

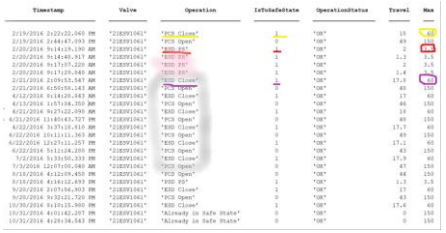
Torque

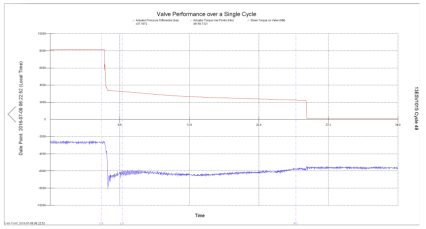
Existing model

In analysis

To be analyzed

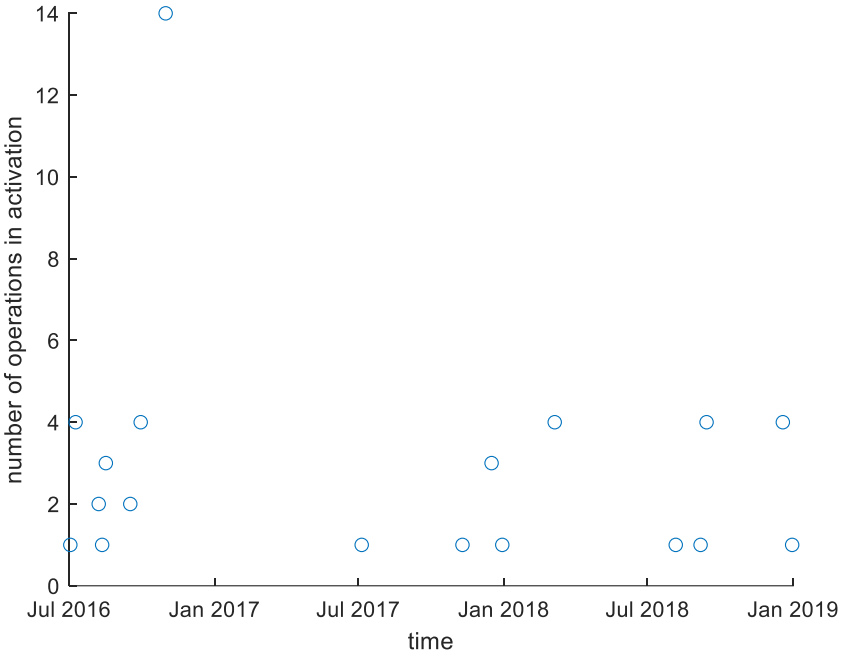


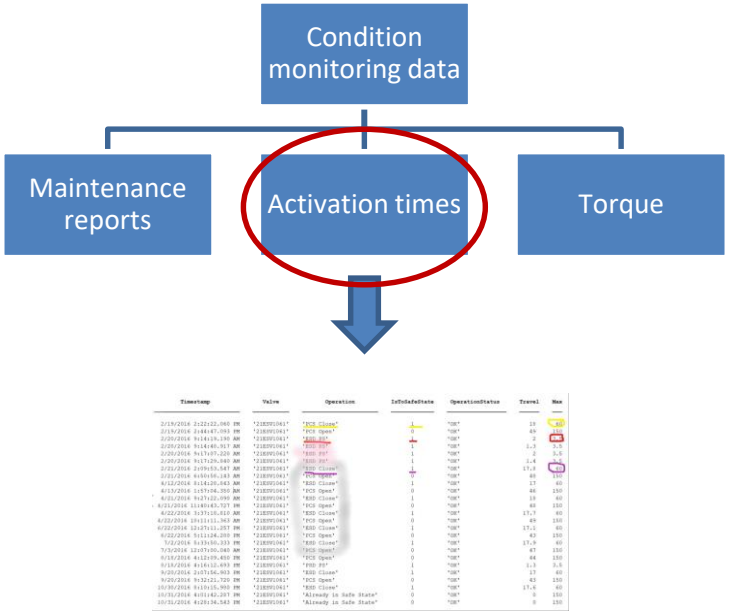




Activation times:

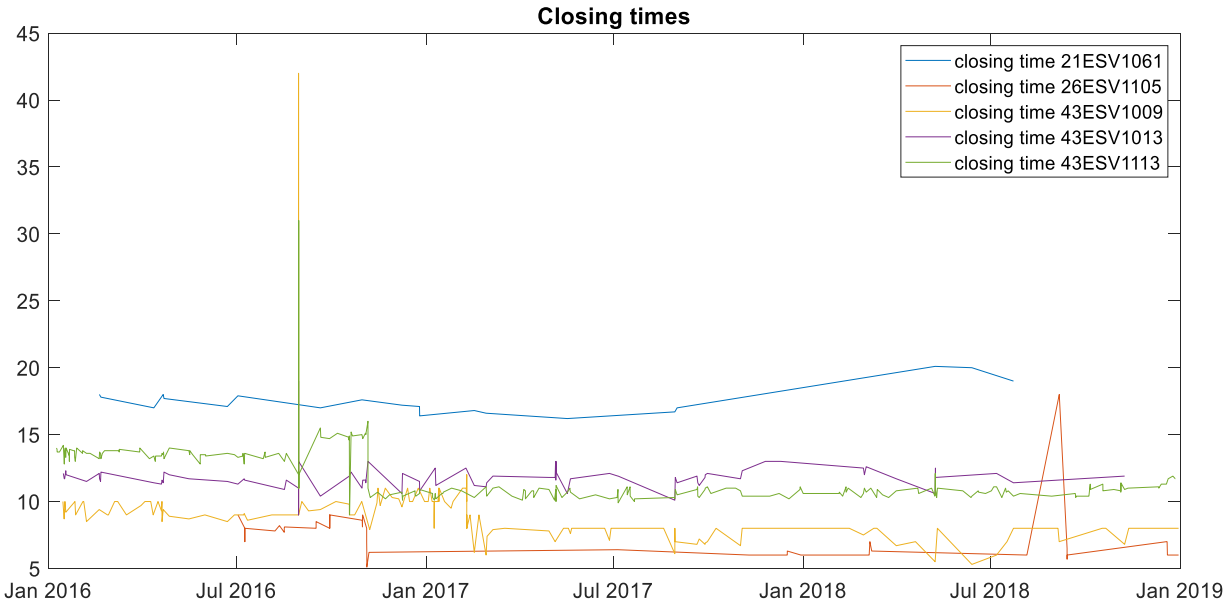
- The activations are random, they don't have a constant frequency
- Number of "operations" in each activations are also random and differ from case to case





Analysis of Activation times of ESVs

"In terms of the final elements of an ESD, they can suffer several failure mechanisms (…) For example, closing time on demand is an indicator of the performance of a shutdown valve." (Zhang, Zhang et al. 2020)



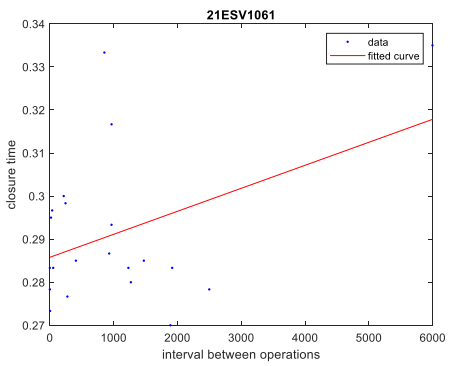
Contributors to Closure time:

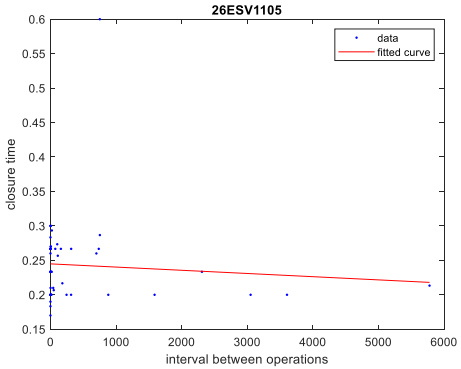
1) Time between activations
2) Number of actions within each "activation series"
3) Average closure time within each "activation"

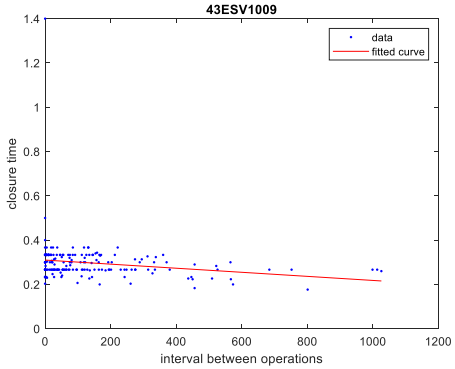
Analysis of Activation times of ESVs

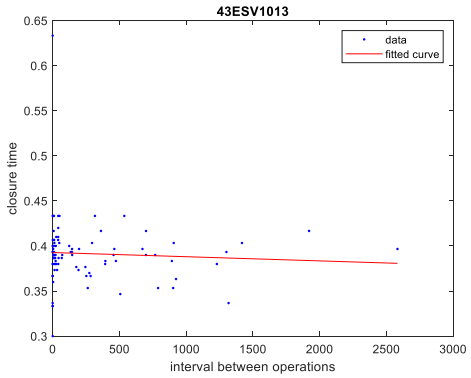
Assumed correlation (some of them):

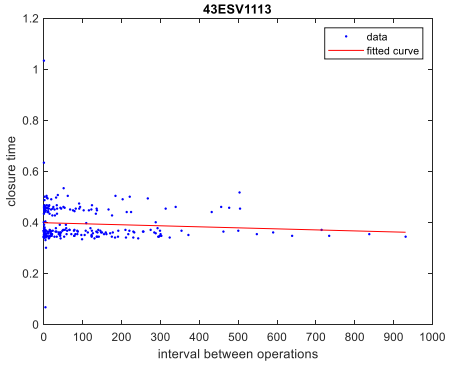
1) Closure time vs Time between activations
2) Number of “operations” within each “activation series” vs time
3) Average closure time within each “activation” vs time



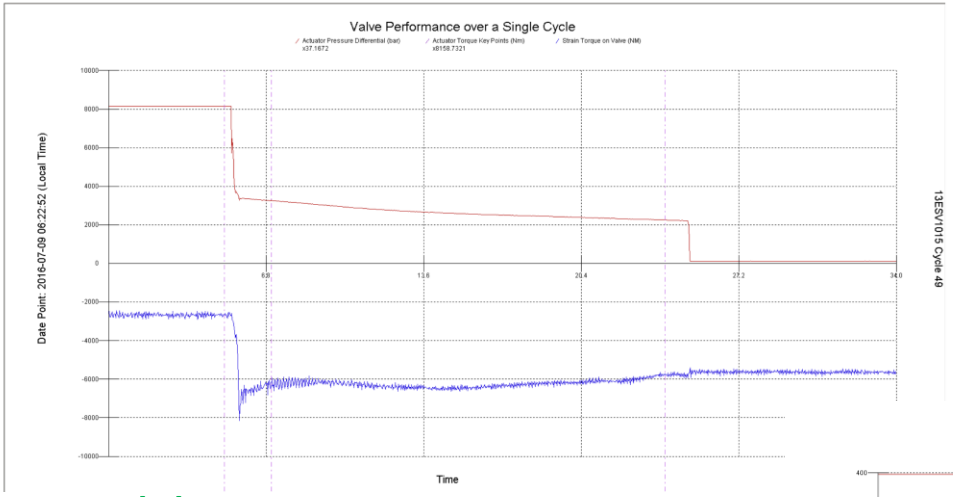




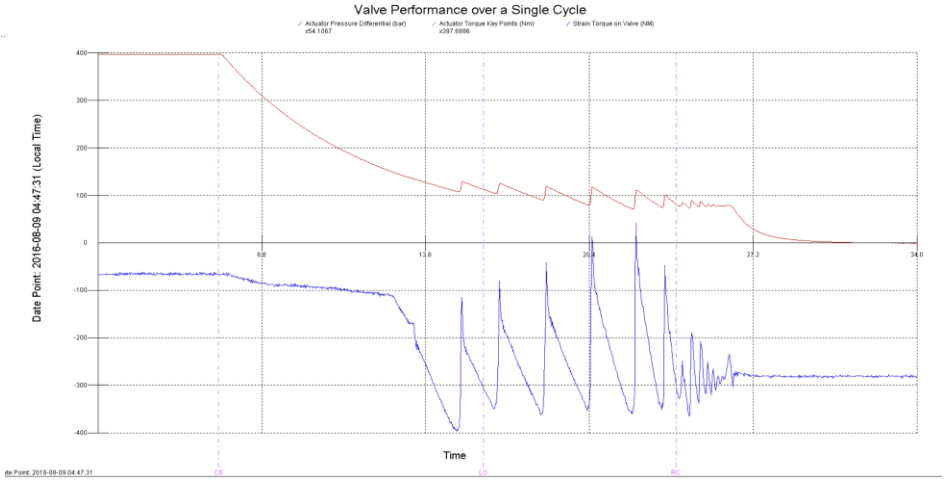




Analysis of torque



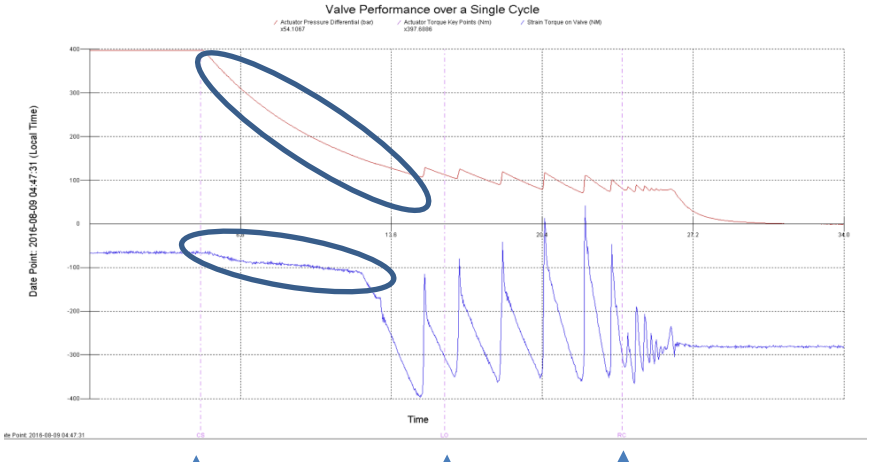
Healthy



Unhealthy

"The risk of spring fatigue depends on other factors too, such as the designed stress in the spring, **alongside the amplitude of the pulsation** and the material's maximum tensile strength."

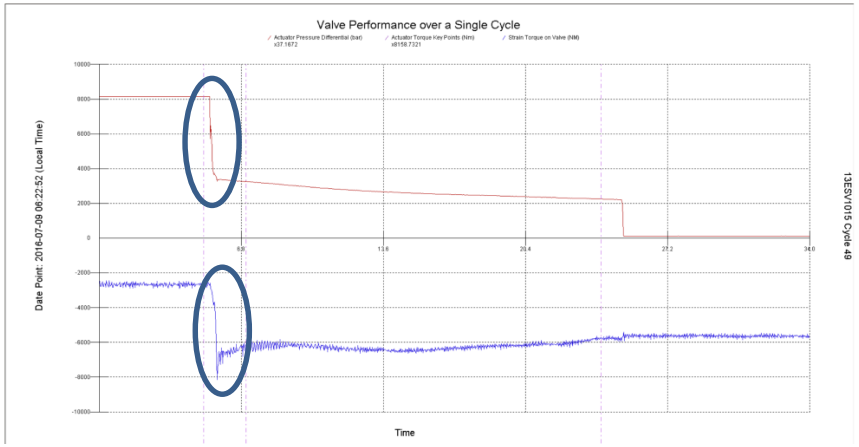
Analysis of torque



Close signal

Leave open

Reach close



Close signal

Leave open

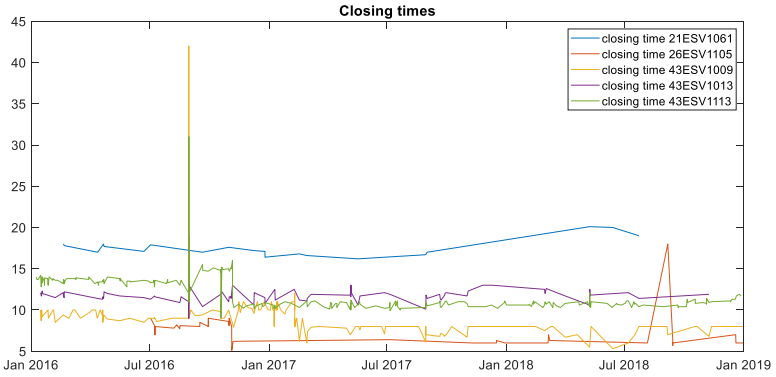
Reach close

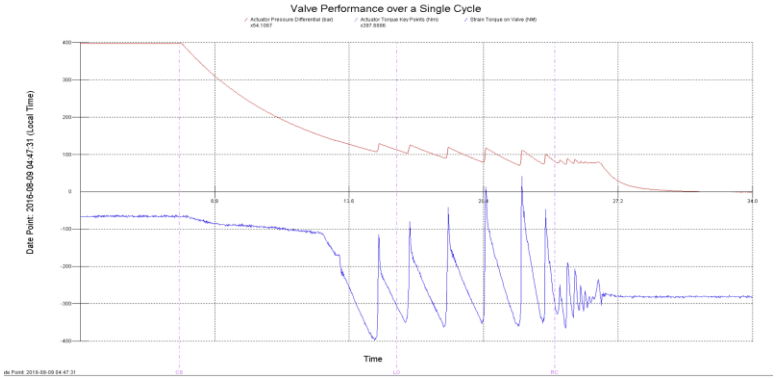
Health Indicators:

1) Breakaway force >> valve stuck in the position >> require more testing
2) Pattern in valve movement >> more friction leading to faster fatigue >> less tests

Challenges related to the data

- Lack of failure data for the analysis
- Unknown threshold of degradation: fatigue or others
- There can be some hidden behaviors making analysis difficult



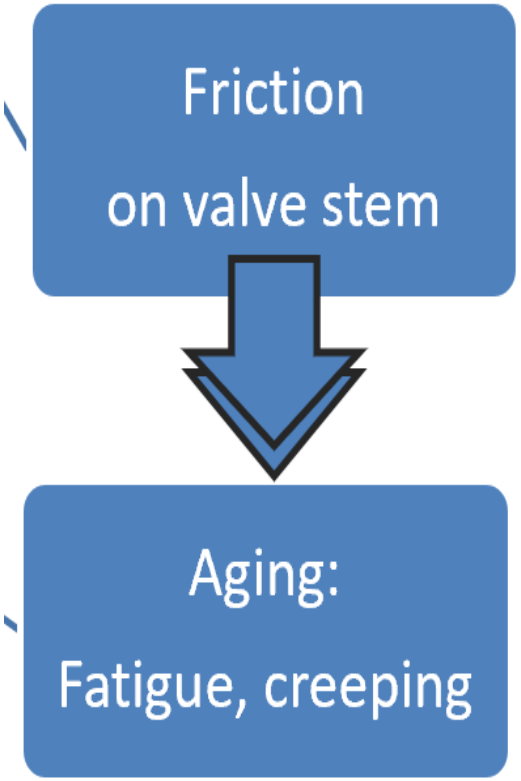


System knowledge & Data analysis: HI & contributors

DOP	Health Indicator	Contributors/explanatory variables
Sticky actuator	Time to close valve	• Time between activations ? • Time to LO • Gradient on LO • Differences in actuator pressure and torque • Time since last action
Valve stuck in the position		• Time between activations • Time between activations • Torque integral to LO
Friction on valve stem		• Time from LO to RC • Average amplitude in torque • Maximal amplitude • Total time spent in travel

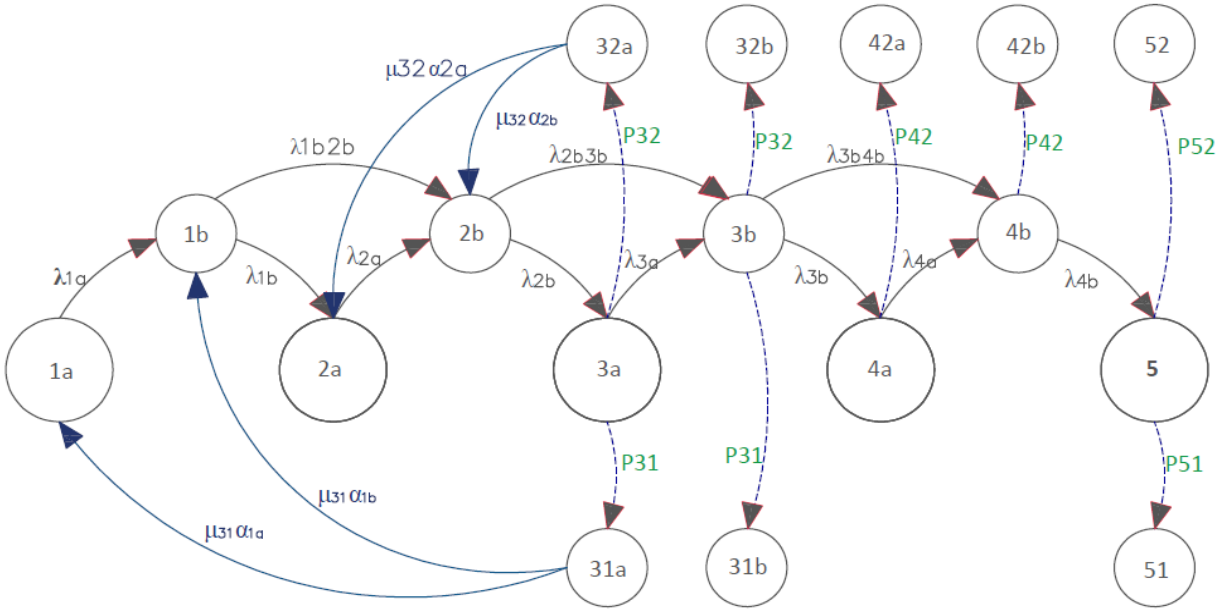
System knowledge & Data analysis: HI & contributors

FTC



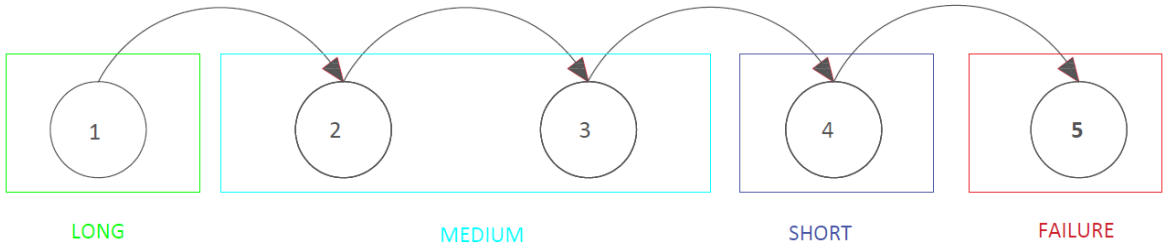
Health Indicator	Contributing factors
Torque integral	• Time from LO to RC • Average amplitude in torque • Maximal amplitude • Total time spent in travel
	• Total time spend in travel (cumsum of closure times from previous operations) • Total torque integral (cumsum from previous operations)

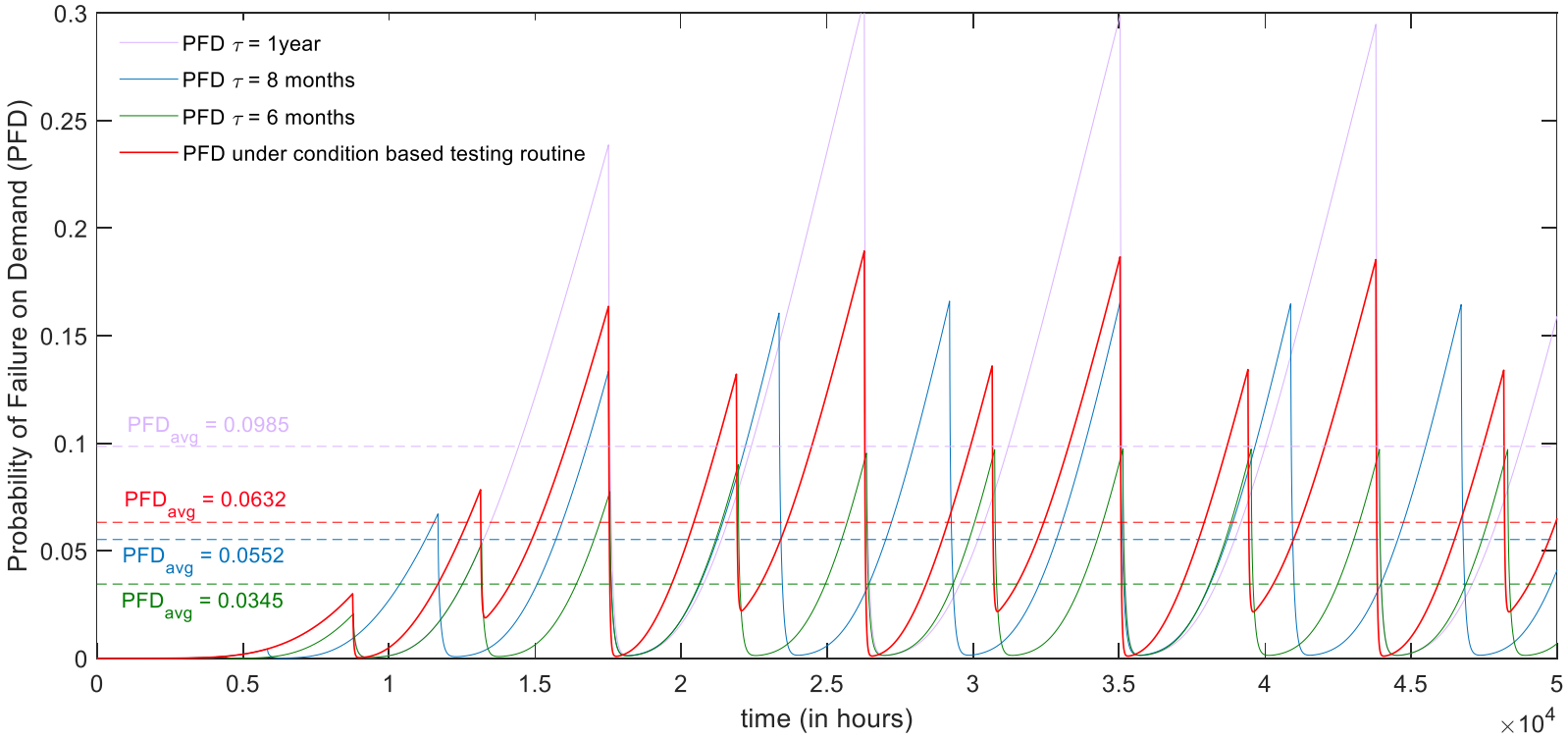
PHD Multiphase Markov model for degradation, testing and maintenance of ESVs



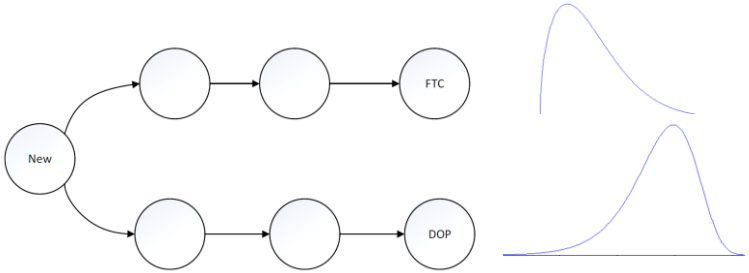
- Laskowska, Ewa Maria; Vatn, Jørn. (2019) State Modelling and Prognostics of Safety Valves used in the Oil and Gas Industry. *Proceedings of the 29th European Safety and Reliability Conference(ESREL). 22 – 26 September 2019 Hannover, Germany.*
- Laskowska, Ewa Maria; Vatn, Jørn. (2020) **Degradation modelling using a Phase Type Distribution (PHD).** *Proceedings of the ESREL and PSAM Conference on Safety and Reliability. 1 – 6 November 2020 Lido, Italy.*

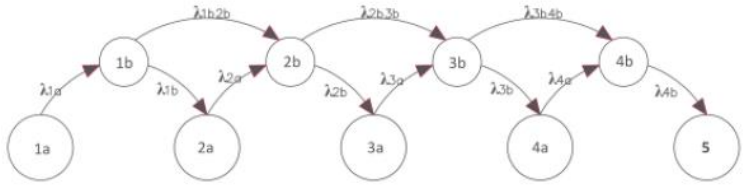
Model extension: Condition based inspection policy





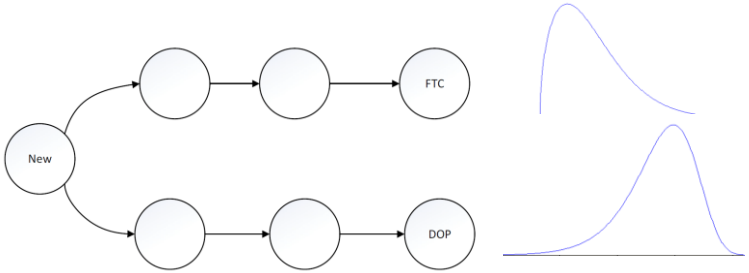
System prognostics : Phasetype Markov model

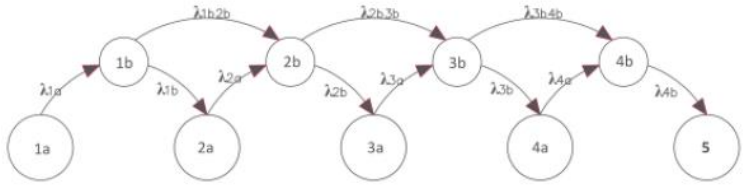




Competing risk Markov model	Existing phase-type Markov model
1. Consider two competing failure modes DOP and FTC 2. Based on the historic data (OREDA) and expert judgment set up "theoretical" distribution of each failure mode 3. Find the phase-type structure for each failure mode 4. Set up health indicators and covariates (from previous slide) 5. Estimate coefficients for variables	1. The structure already exist 2. The condition described by 5 states would a HI and closure time or torque integral could be used as covariates 3. Data doesn't match (dates and number of maintenance inspections vs ESV activations

System prognostics : Phasetype Markov model





$$\lambda = e^{\beta_0+\beta_1 z_1+\beta_2 z_2 \ldots}$$

Since they modeled the expected value of T, they suggested to multiply the intensity matrix by a factor expf□ 0xg.

(Bo Lindquist, Phase-Type Distributions for Competing Ris[illegible]

$$\exp\{-\boldsymbol{\beta}'\mathbf{x}\}$$

A least square approach to estimate $\boldsymbol{\beta} = [\beta_0, \beta_1, \beta_2, \ldots]$ is now given by minimizing Equation (12):

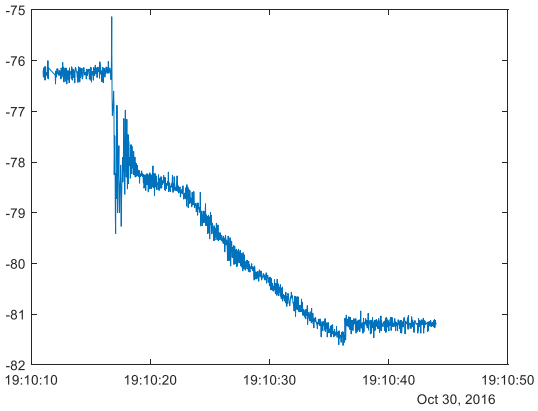
$$Q(\boldsymbol{\beta}) = \sum_{j=1}^{J} \left(s_{j,2} - \mathrm{E}(Y_j(t_2)|Y_j(t_1) = s_{j,1})\right)^2 \qquad (12)$$

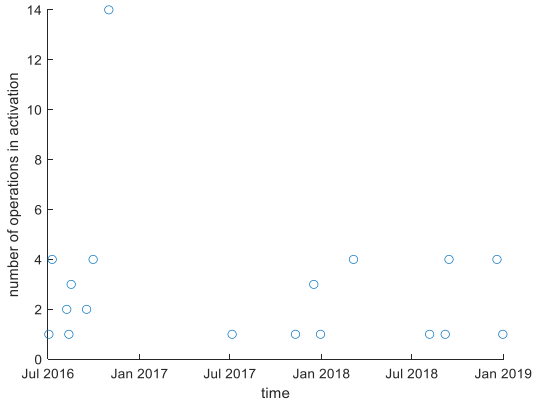
(Jørn Vatn, Maintenance Optimization Course compedium)

Anomaly detection: Machine Learning

Particularity of my data:

- Activations of ESVs are data are times series on its own – just due to having measurements at different points of time
- Each activation of ESV is a time-dependent variable with some pattern.
- The activations frequency is not constant – it's random variable which by itself could be an indication of some problems
- Because of the above point the data are not cyclic data and the times between activations can differ a lot
- Time needed to perform an activation of valve is way smaller than intervals between activations what makes a presentation of the data on the timeline unreadable





Anomaly detection: Machine Learning

PCA: correlation in the data	Time series Analysis: search for trend
Correlations	Trend
1. Is PCA feasible on the «my» data 2. How to set up covariates?	1. How the data should be formated/presented 2. Do exist suitable methods to analyze the data I have? 3. What are popular time series models?

To investigate: Cazes et al. [8] and Lauro and Palumbo [21] have introduced principal component analysis methods that are suitable for interval-valued data.

Current idea: Interval-valued time series

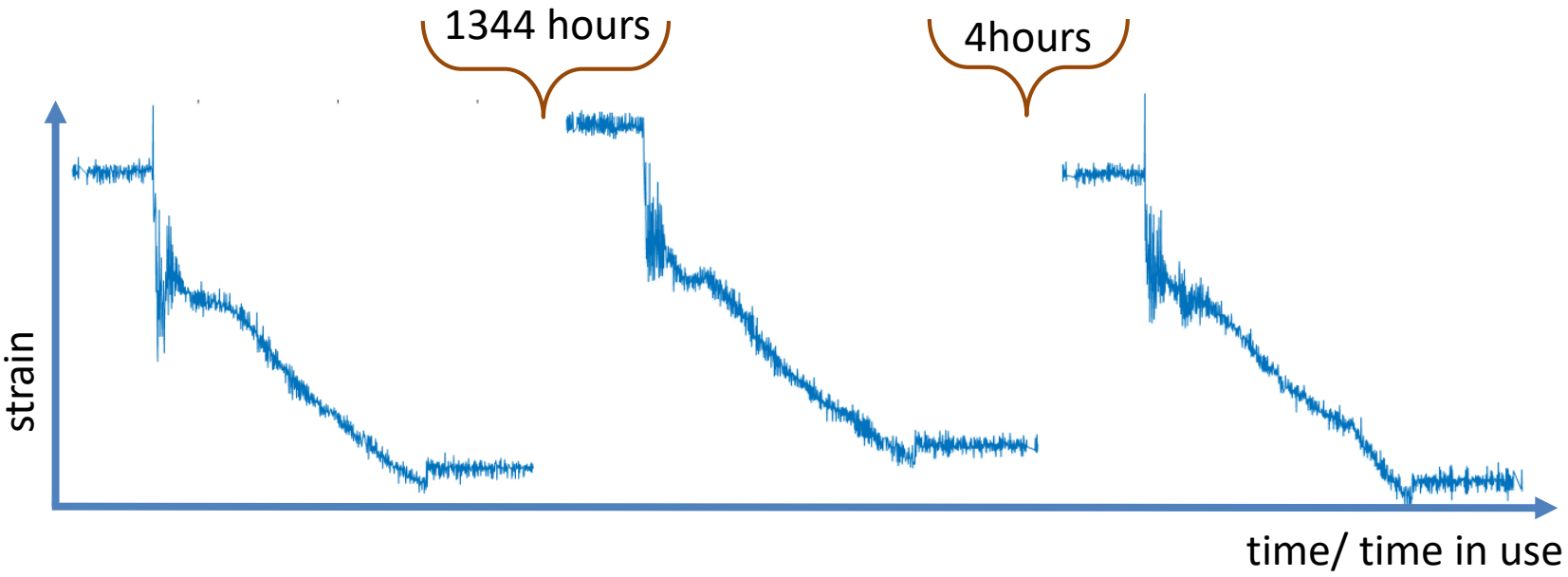
Interval-valued time series are interval-valued data collected in a chronological sequence. Interval-valued data arise quite naturally in many situations in which such data represent uncertainty (for instance, confidence intervals), variability (minimum and maximum of daily temperature), etc.

Anomaly detection: Machine Learning

Models proposed for interval-valued time series:

- autoregressive (AR) model
- autoregressive integrated moving average (ARIMA) model
- ANN
- on a hybrid methodology that combines both ARIMA and ANN models

Time series where the time axis is actually "time in use"



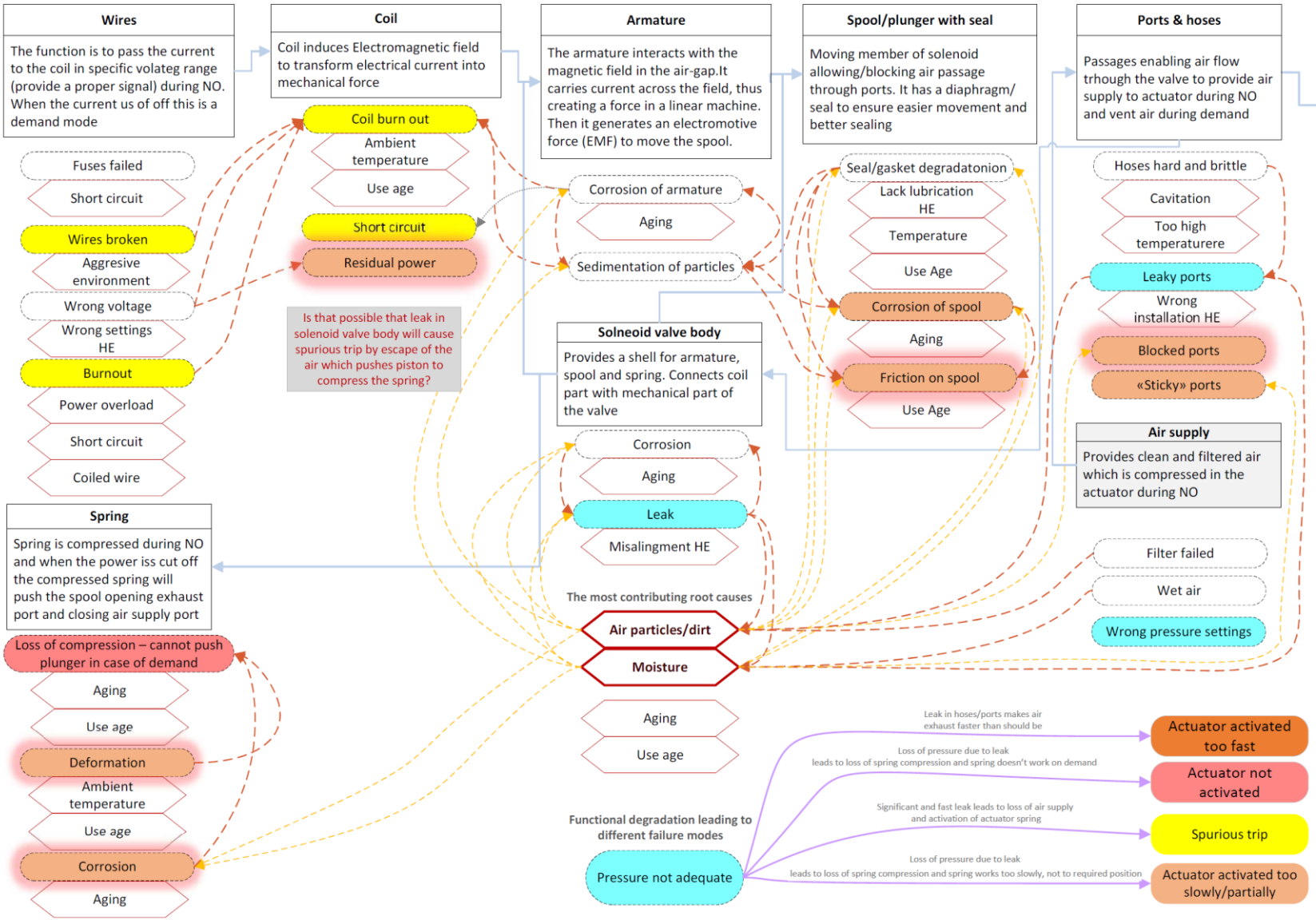
Thank you

System diagnosis - motivation

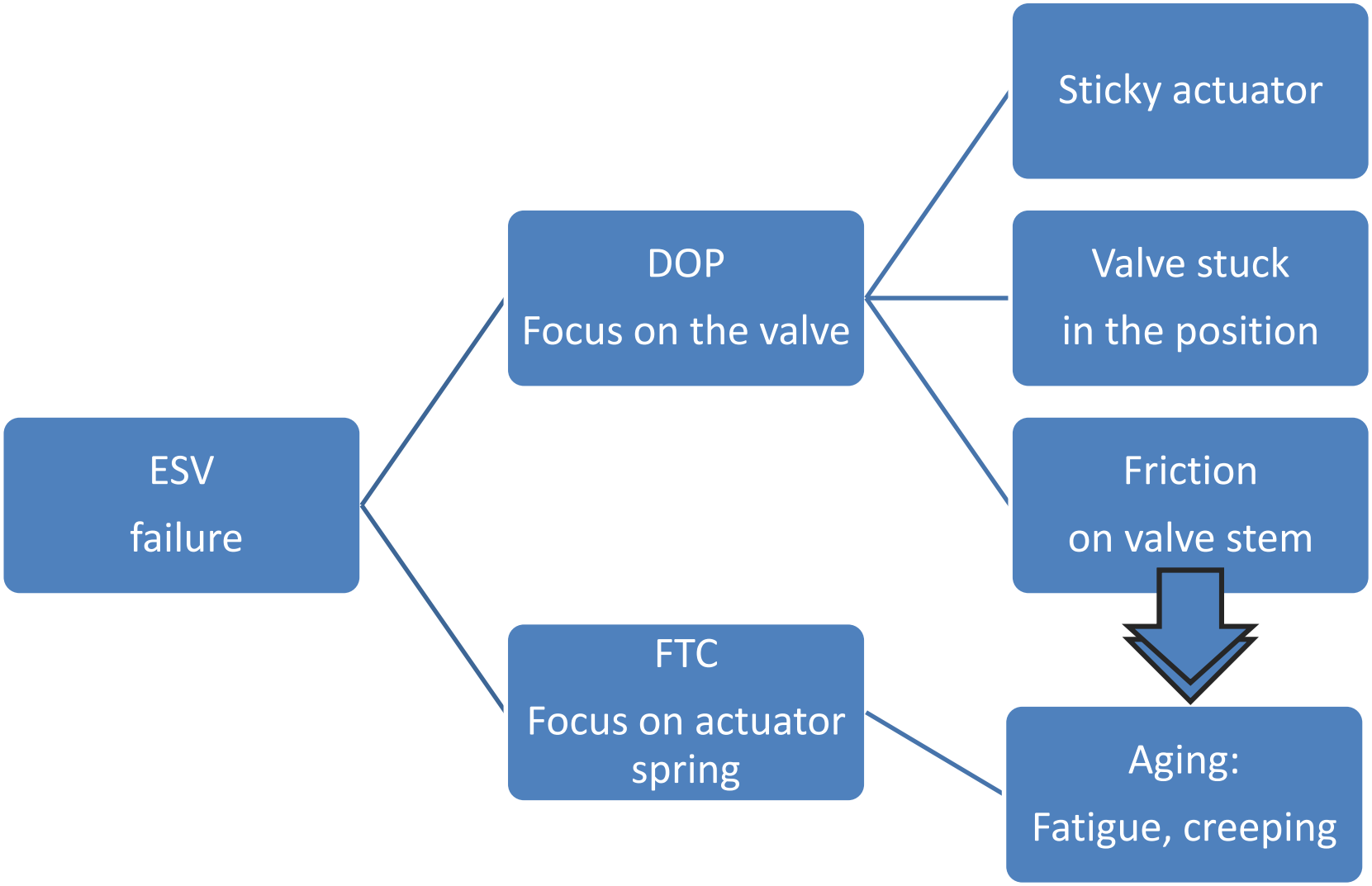
Motivation	Application
• Investigation of dependencies between failure modes to improve testing optimization • System knowledge as the input for torque data analysis	• Recognize leading failure mechanisms for optimization of inspection strategy under assumption of testing negative impact • Setting up health indicators based on the understanding of the system degradation

"… having a good understanding on the stress mechanisms related to the tests becomes paramount in deciding on the test interval duration in the equipartitioned case" (Hafver, Oliveira et al. 2019)

System diagnosis:



Safety critical failure modes and degradation mechanisms:



Safety critical failure modes and degradation mechanisms: