Mobile Mining Machinery

Monitoring when fault modes are plentiful and sensors few.

Erik Jakobsson, 2022-09-07

Epiroc

Epiroc's journey towards condition monitoring

Outline

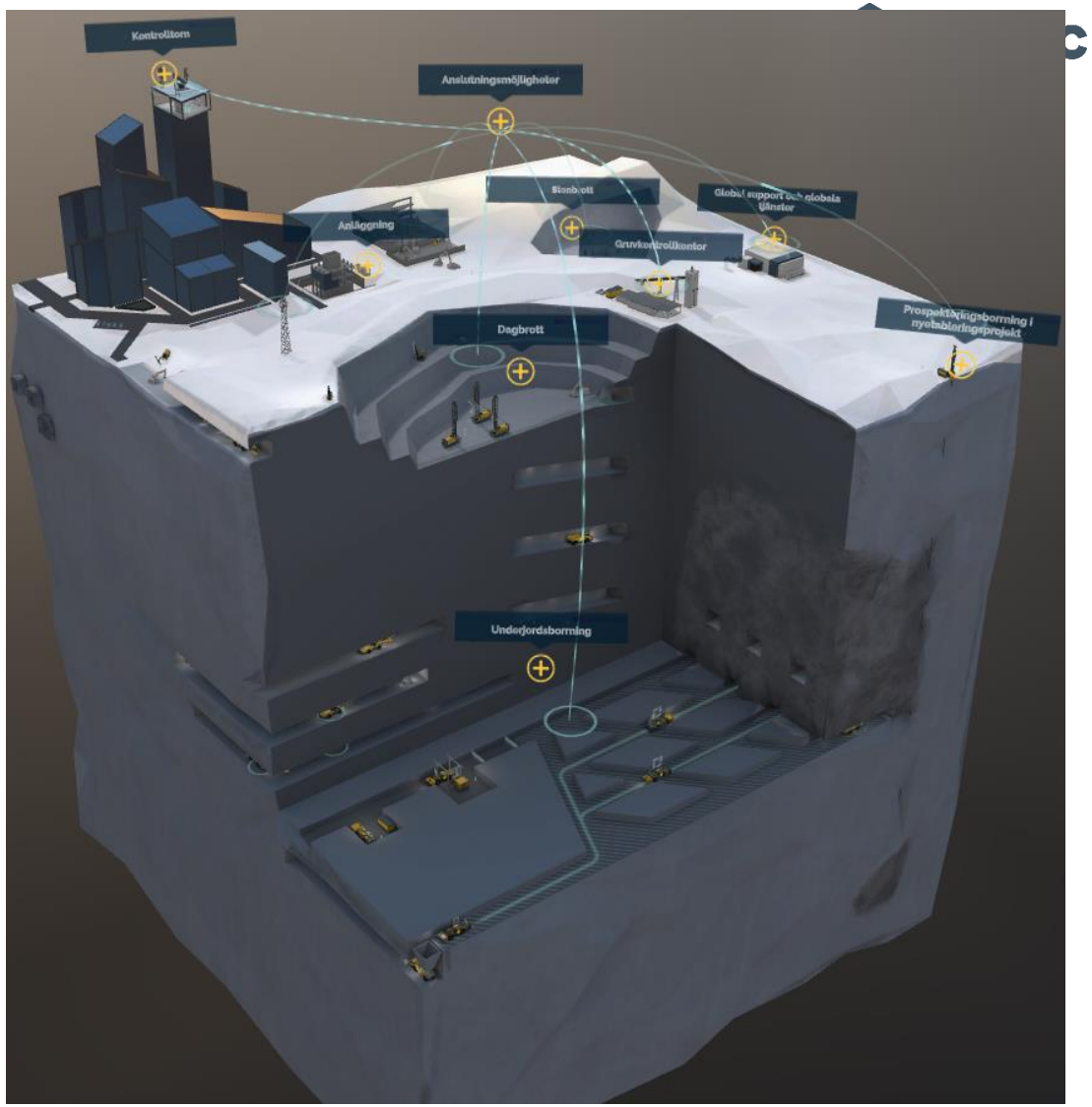
- General application. Why is this hard for us? (And many others?)
- Difficulties with accessing data
  - Ownership
  - Environment
- Value versus cost
- My particular work as a PhD-student
  - Maximize value from single sensor on hydraulic rock drills

Background

The type of equipment we make

Mining

- Mine operator owns infrastructure, machinery, and data.
- Many different machines
- Many different manufacturers of machines
- Limited connectivity



Data access

Difficult for OEMs

- No communication on site / low capacity
- Infrastructure owned by customer (mine operator)
- Production data is considered sensitive
- Customers want data for themselves
- Service data, rarely recorded and/or proprietary
- Etc…

- However, the situation is steadily improving!

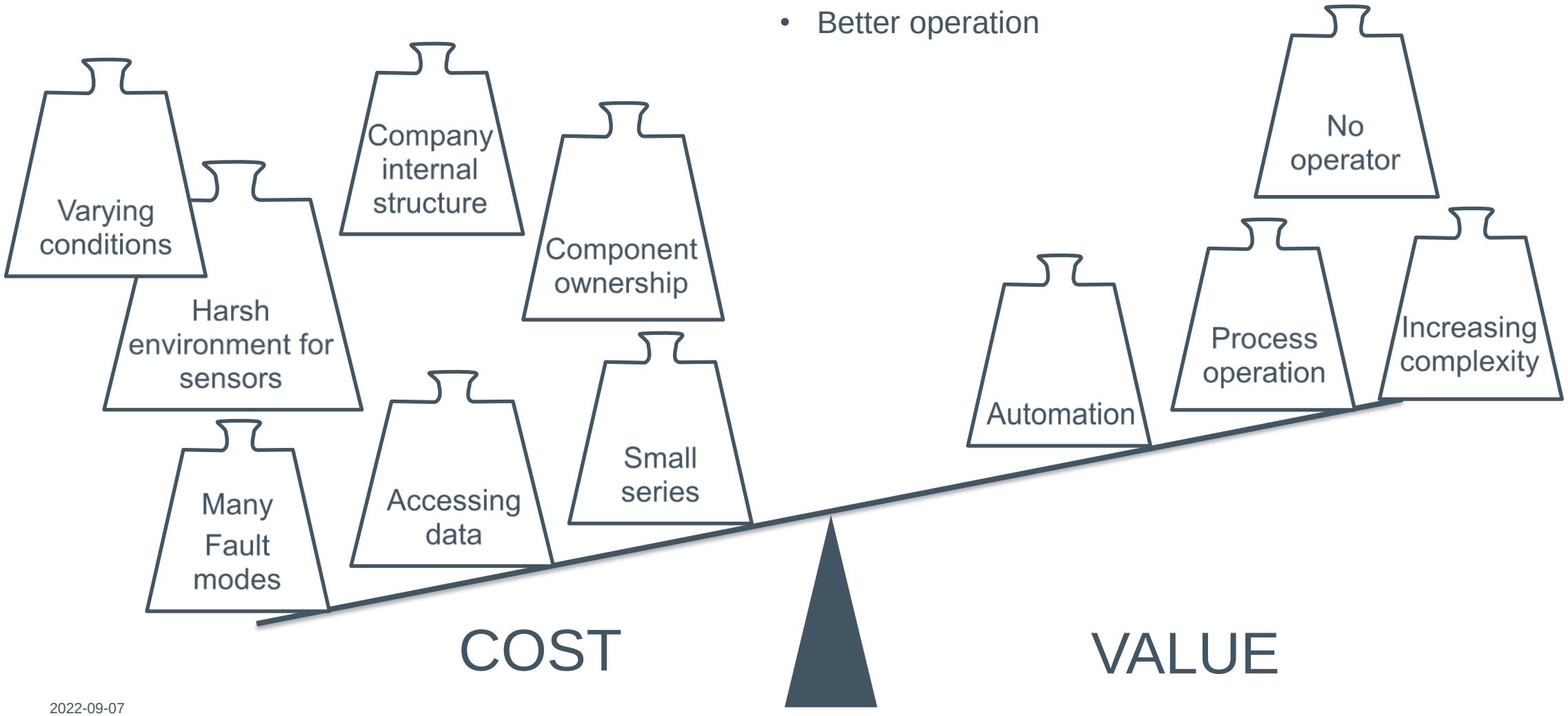
Data available here

Data needs to be here

Worth it?

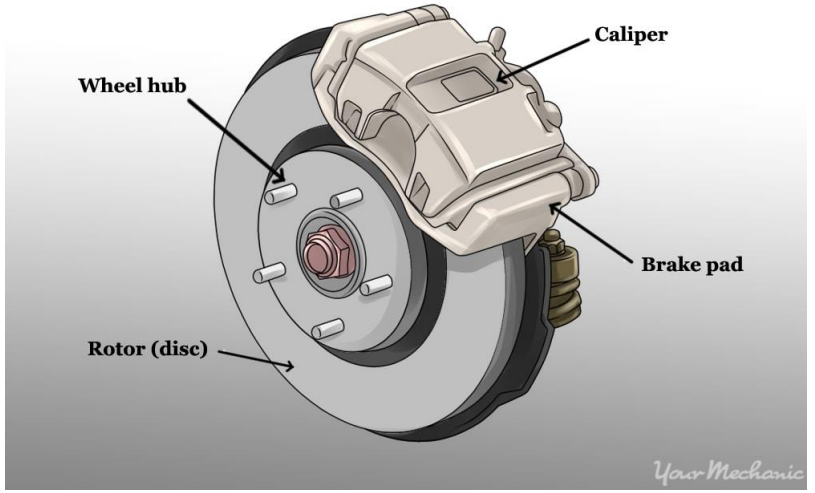
Reducing cost and adding value

- Less service cost
- No unexpected breakdown
- Better planning
- Better operation



Condition Monitoring

Different levels



Usage — *”Racing, 10%, commuting, 90%”*

Cause — *Revolutions and measured force*

Wear — *Pad thickness*

Result — *Lack of braking*

How to monitor when we cant wait for data?

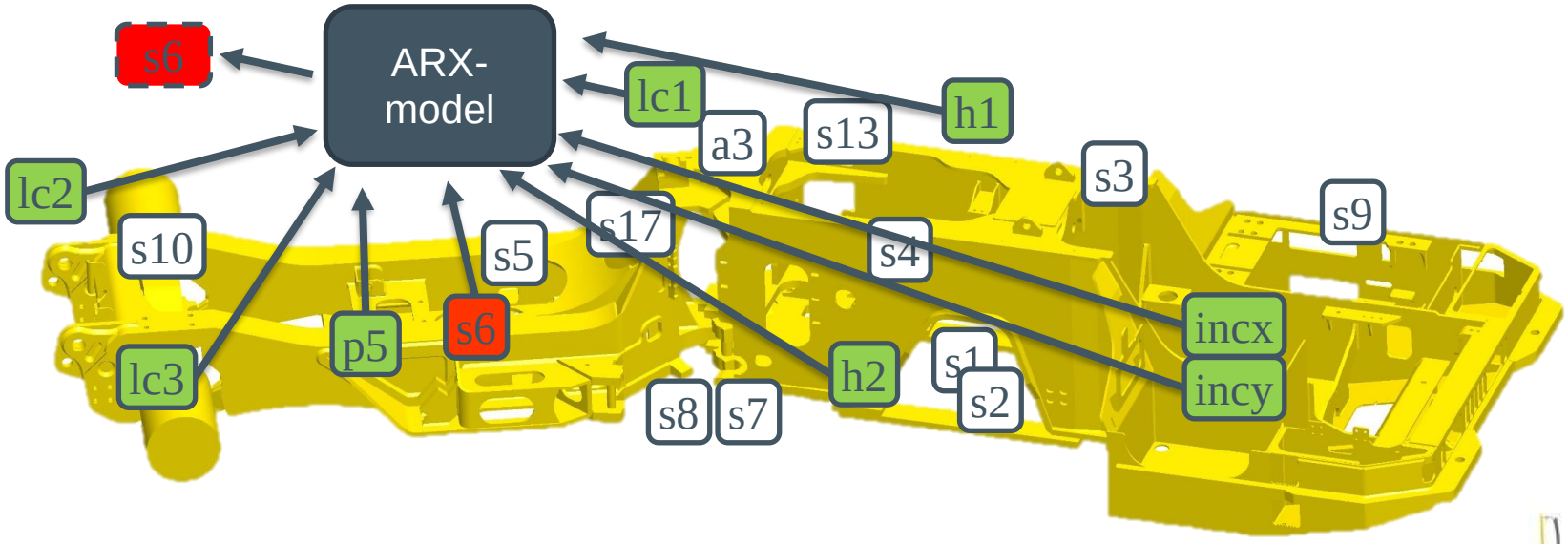
The only options for an OEM?

- Induced faults
  - Performed during development phase
  - Hard to cover all cases
- Data-driven approaches from previous products
  - Transfer learning
  - Domain adaptation
- Physics based approaches
  - Knowledge incorporated in (manual) modeling of system

The Mine Truck

Usage — Cause — Wear — Result

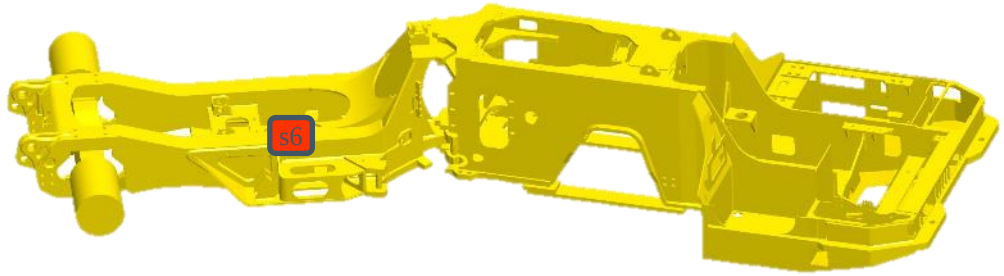
Driving modes — *Stress* — *Crack propagation* — -

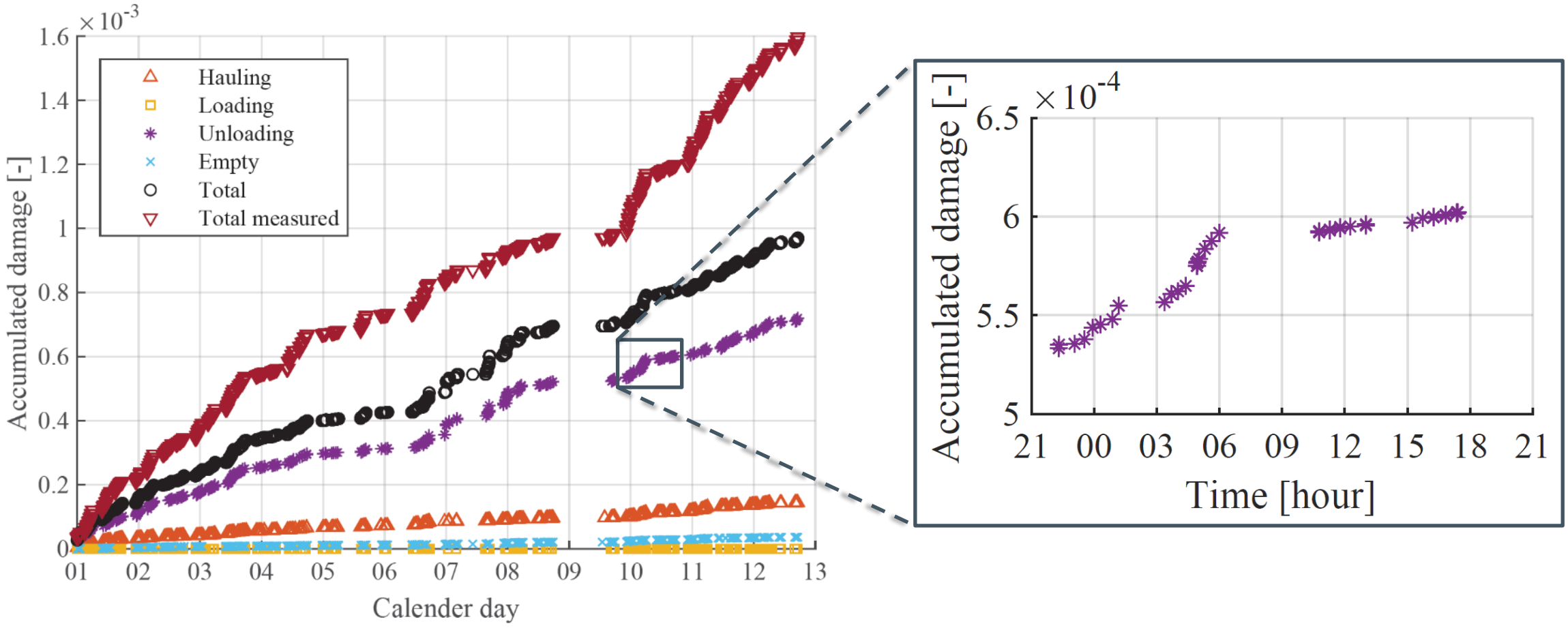


$$\begin{cases} \varphi(t) = (-y_{t-1}, \ldots, -y_{t-n_a}, u_t^1, \ldots, u_{t-n_b}^1, u_t^{n_b}, \ldots, u_{t-n_b}^{n_b})^T \\ \theta = (a_1, \ldots, a_{n_a}, b_0^1, \ldots, b_{n_b}^1, b_0^{n_u}, \ldots, b_{n_b}^{n_u}). \end{cases}$$

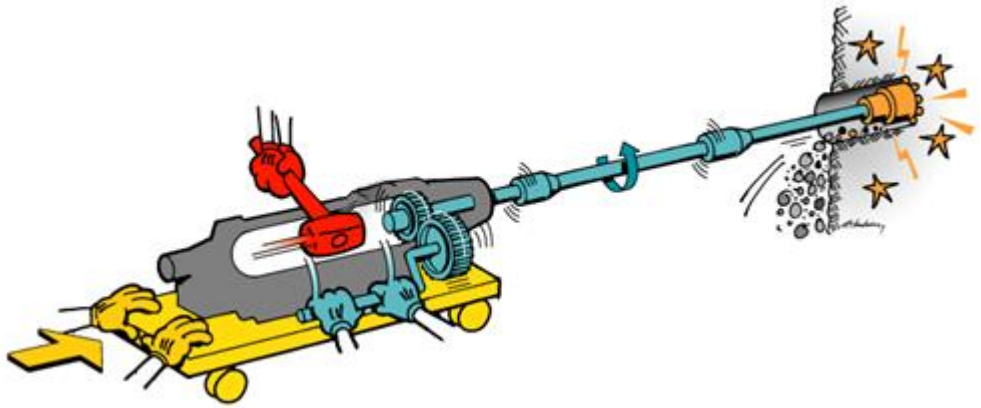
$$y(t) = \varphi_t^T \theta$$

Usage profiling





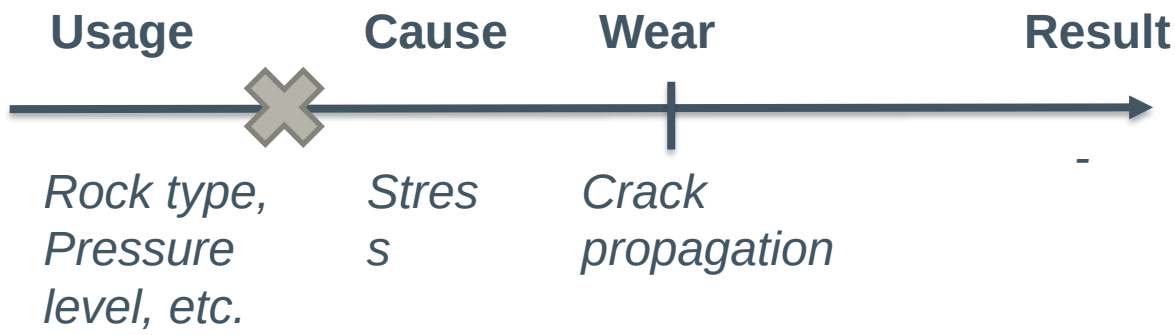
Hydraulic Rock Drills

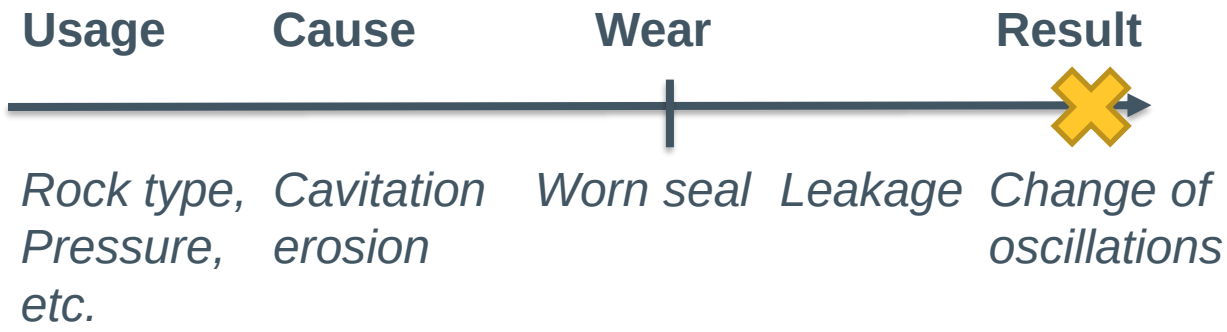


Rock drill fault modes

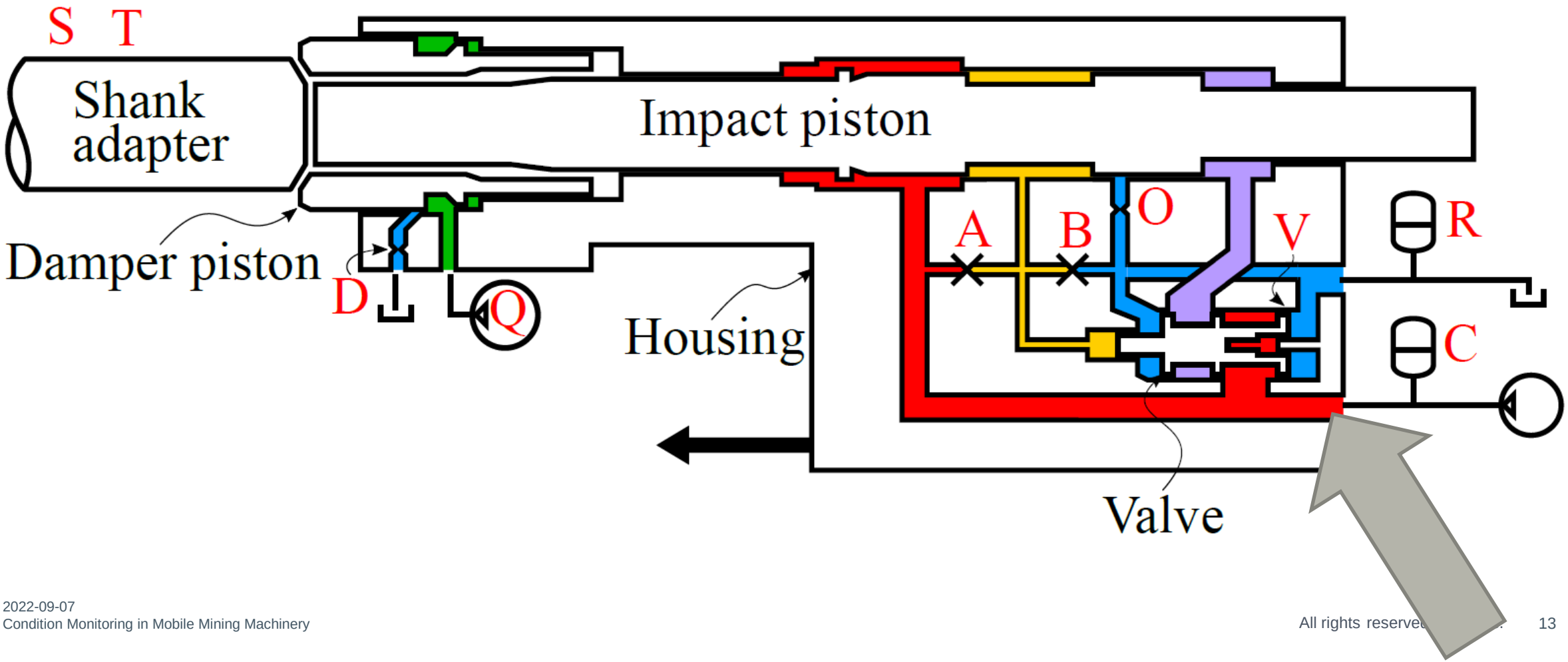
- Faults not affecting operation (before too late)
  - Fatigue
  - Cracks

  - Faults affecting operation
    - Leakages / restrictions
    - Wrong flow levels
    - Pre charge levels

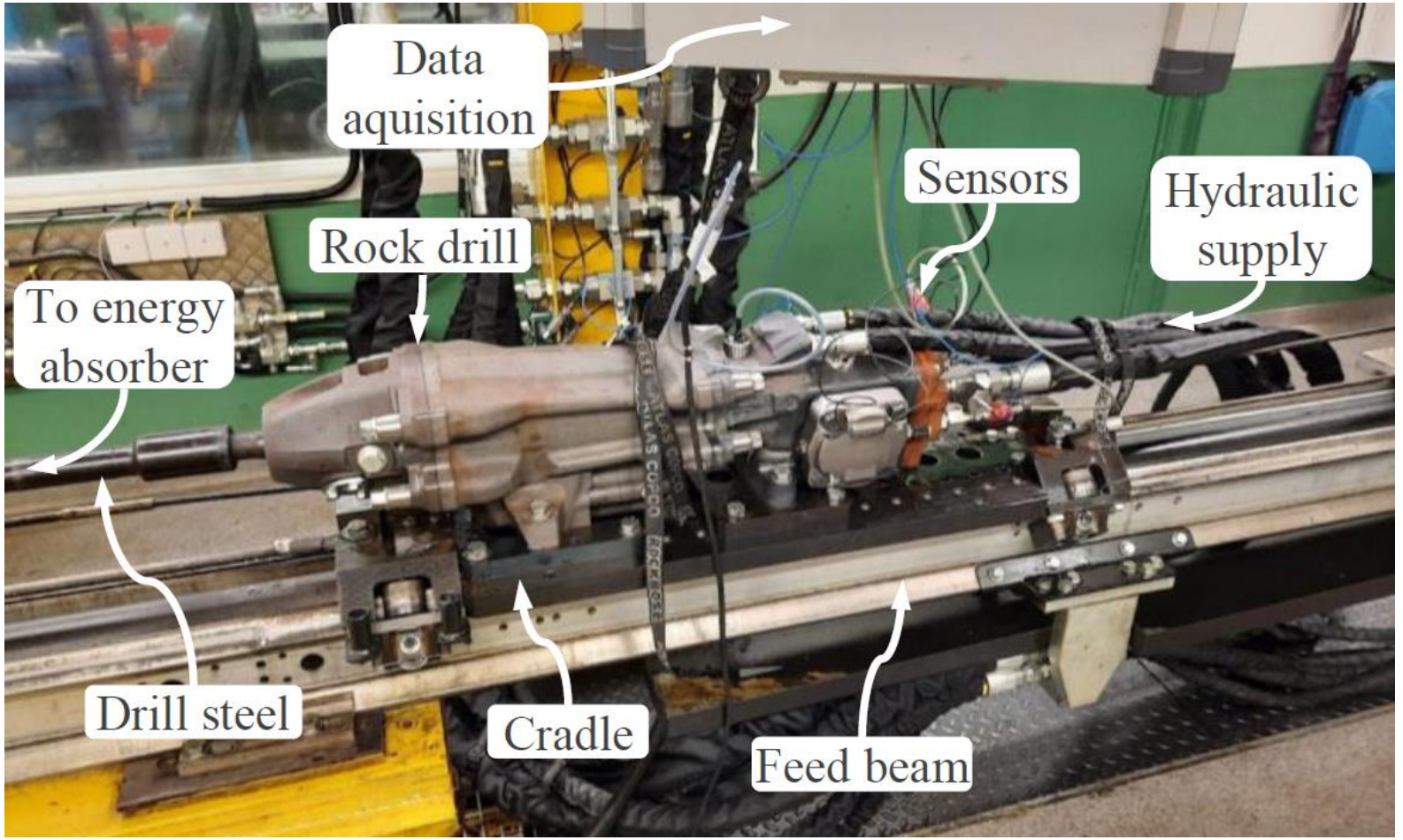




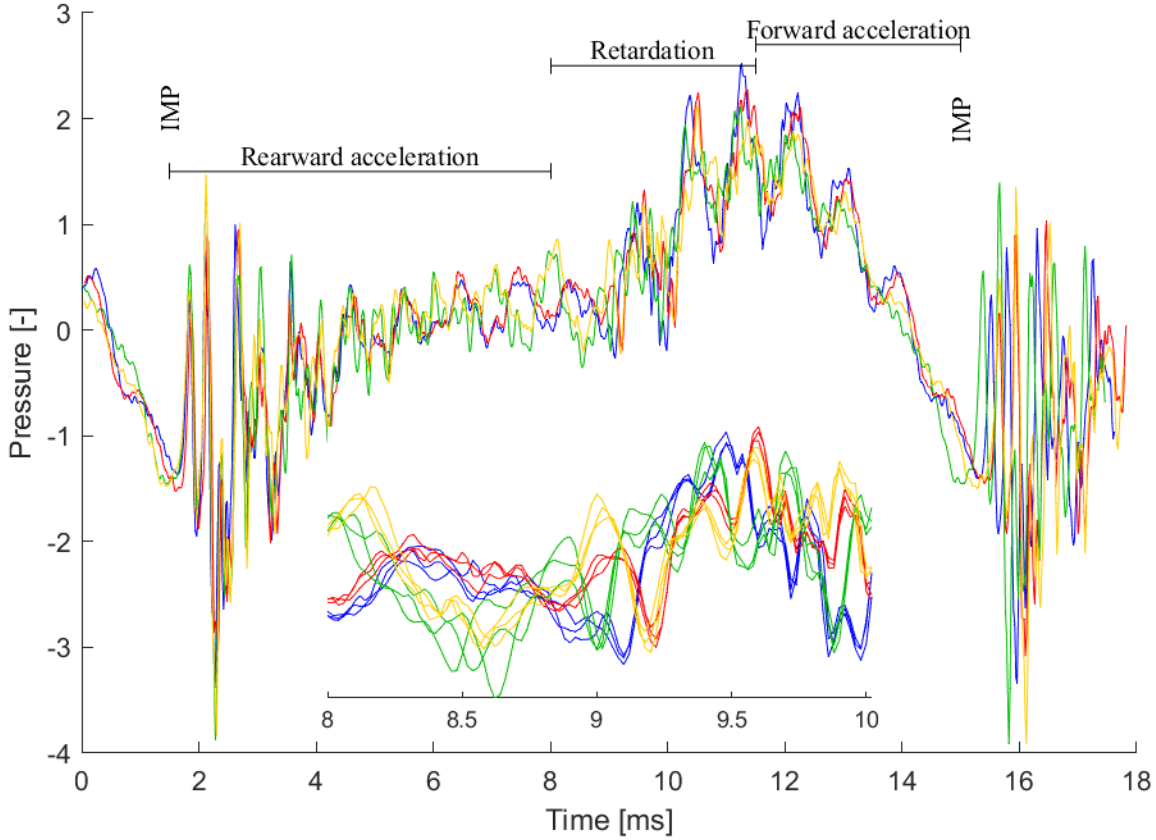
The Rock Drill



Data collection

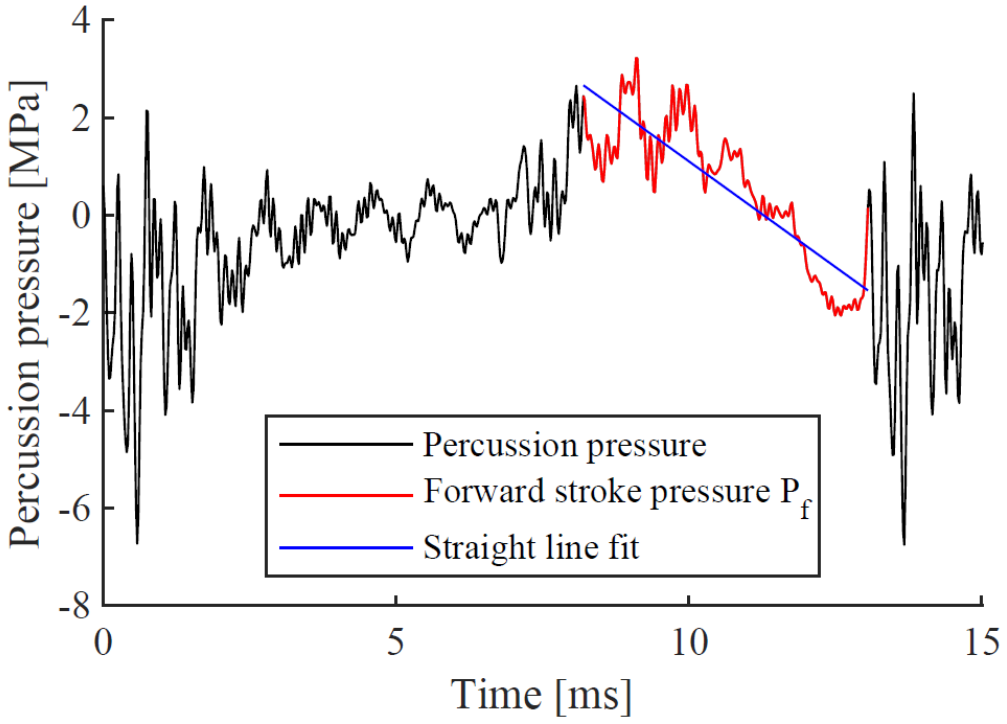


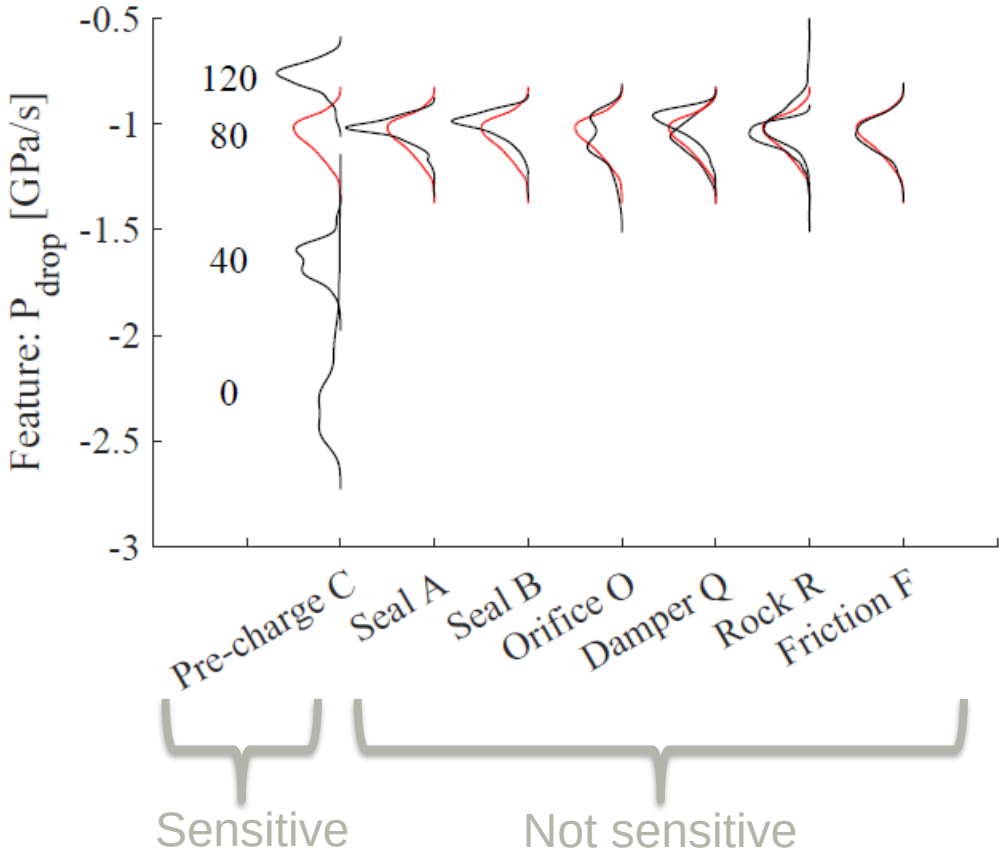
Measured pressure



- Subtle changes from faults
- Hard to predict wave propagation
- Variation from different configurations
- Timing changes

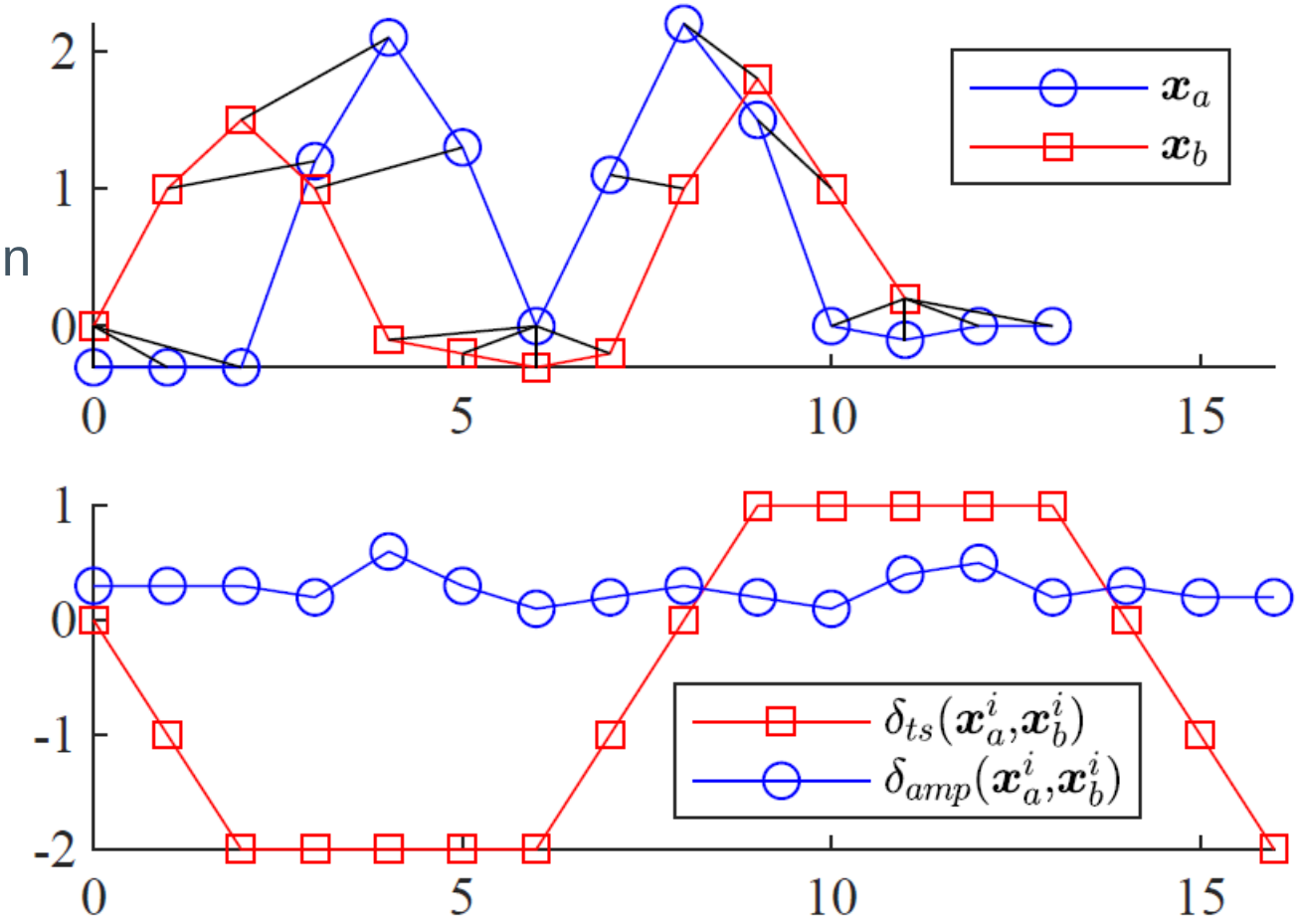
Handcrafted features





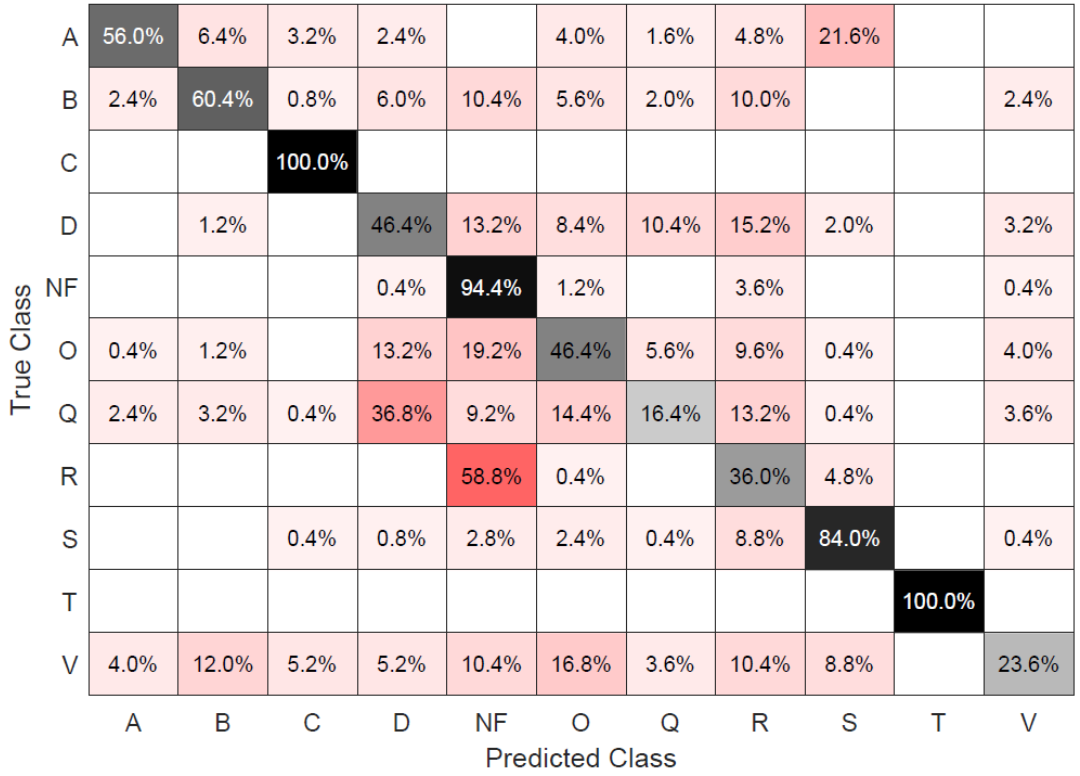
Dynamic-time-warping-converted-features

- Find DTW/synchronization
- Create new ”time series”
- Use the new time series for classification in



Results, relative features

Measured quantity	Same	Different
1NN-DTW, time series	92%	35%
SVM, time series	93%	35%
InceptionTime, time series	99%	34%
1NN-DTW, δ_{amp}	73%	40%
SVM, δ_{amp}	56%	40%
InceptionTime, δ_{amp}	79%	53%
1NN-DTW, δ_{ts}	71%	52%
SVM, δ_{ts}	26%	27%
InceptionTime, δ_{ts}	89%	62%
SVM, δ_{amp} and δ_{ts}	63%	43%
SVM, δ_{amp} and δ_{ts} + f	65%	50%

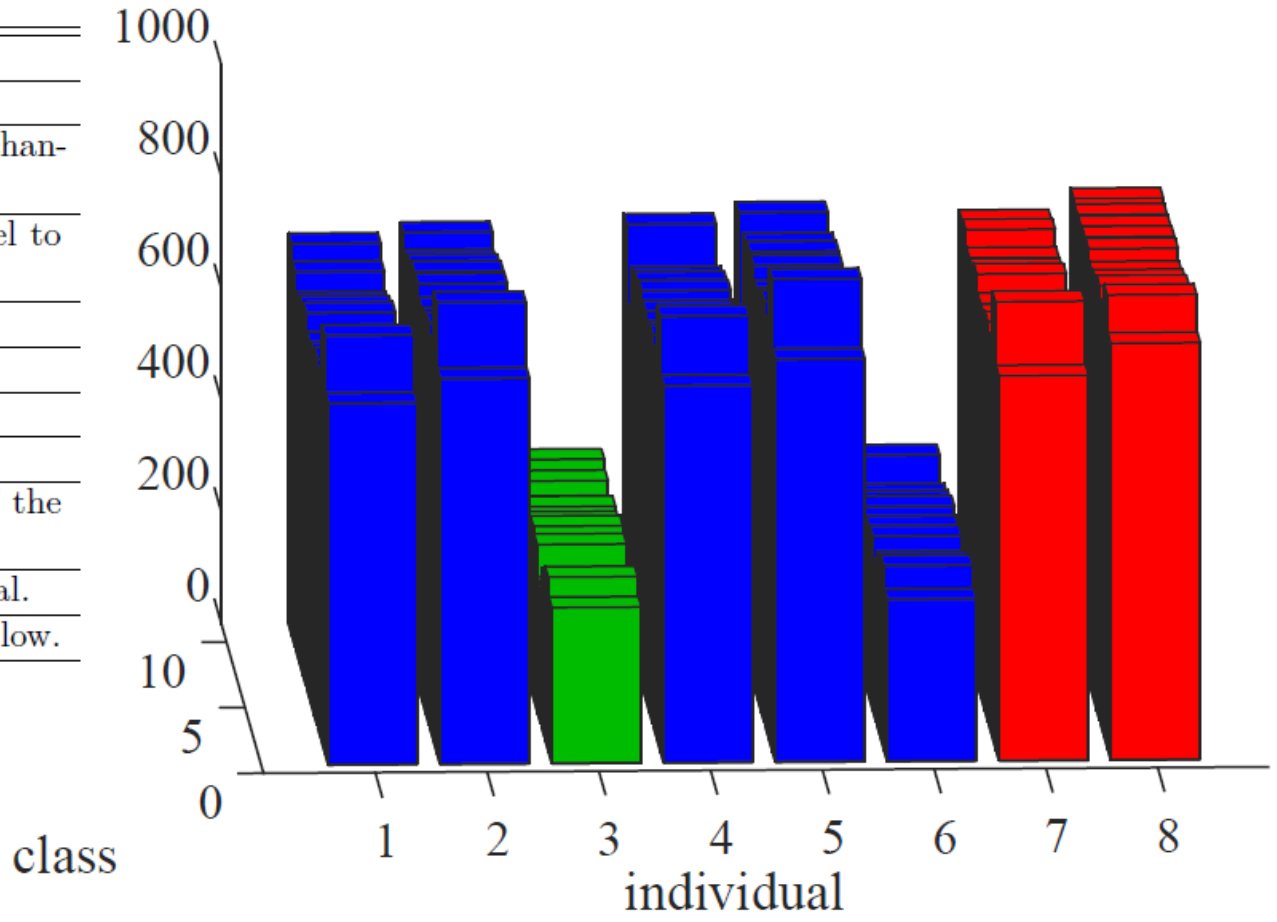


Slightly less

A lot better

The Rock Drill Dataset

Label	Letter	Description
1	NF	No-fault
2	T	Thicker drill steel.
3	A	A-seal missing. Leakage from high pressure channel to the control channel.
4	B	B-seal missing. Leakage from control channel to the return channel.
5	R	Return accumulator, damaged.
6	S	Longer drill steel.
7	D	Damper orifice is larger than usual.
8	Q	Low flow to the damper circuit.
9	V	Valve damage. A small wear-flat on one of the valve lands.
10	O	Orifice on control line outlet larger than usual.
11	C	Charge level in high pressure accumulator is low.



Remaining challenges

- Implementation of rock drill monitoring
  - Sensor placement/durability
- Transfer learning and domain adaptation *between*:
  - Configurations
  - Models
  - Or even from simulation model to real world data
- The gap between the research front and the industry
  - More focus on catching the last 0.1% on some test set, than to generalize model to be useful on more domains