Detecting HVAC cooling malfunctions in trains

PrimaVera consortium meeting

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February 1st, 2022

This presentation

- Challenges with Heating, Ventilation & Air Conditioning (HVAC) units at NS
- Real time monitoring
- Detecting malfunctions
  - Visual inspection
  - Based on diagnostic codes
- Future work

Summer challenges

rtlnieuws

Nieuws Economie Sport Entertainment Tech Lifestyle EditieNL Uitzendingen

Veel treinen zijn kapot door de hitte, dienstregeling beperkt

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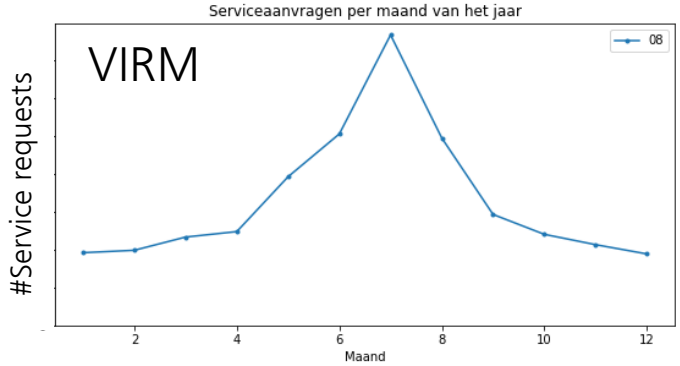
Feedback

Ook al is de ergste hitte het land uit, het treinverkeer vandaag is nog niet terug naar normaal. Veel treinen zijn door de hitte kapot gegaan, stelt de NS, die verwacht dat in de avond weer volgens het boekje

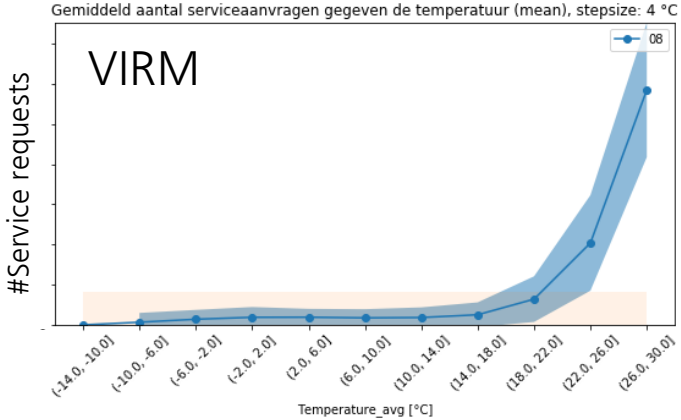
- Heatwaves are a challenge for rolling stock
- HVACs part of the challenge
  - Customer satisfaction
  - Rolling stock availability

HVAC cooling - summer challenges

(a)

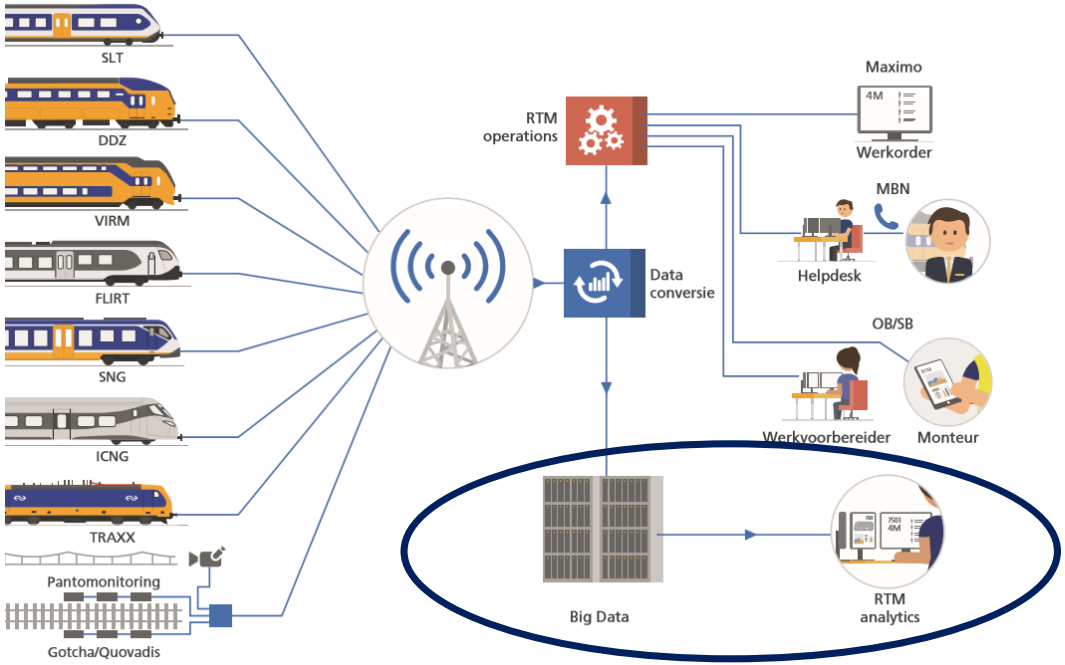


(b)



- How do we know about HVAC performance?
  - Train personnel can make a **service request** in case of suspected HVAC cooling malfunction.
- (a) HVAC service requests peak during summer months
- (b) Particularly during periods with high outside temperatures

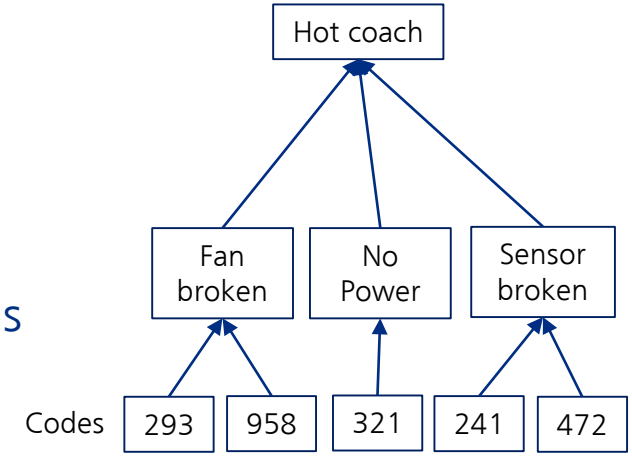
Real time monitoring (RTM)



- Train sets send diagnostic codes and sensor measurements in near real time
- Data is stored in data center for subsequent analysis
- Alternative information source for detecting malfunctioning HVACs

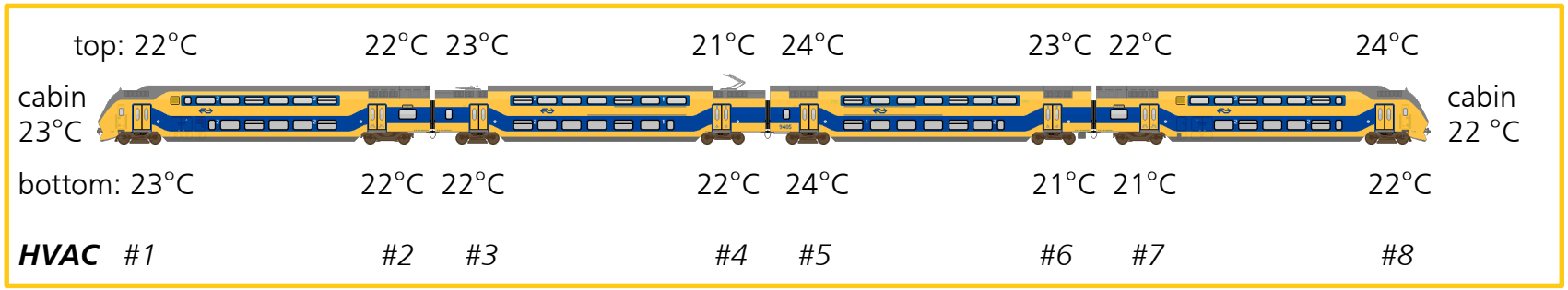
Potential benefits of real time monitoring

- Fault tree analysis
  - Based on expert knowledge about HVAC system
- Detecting failures, repairing HVAC systems
  - Temperature sensor readings: functional failure
    - ‘too hot in a coach’ – top event in fault tree
  - Diagnostic codes: could identify which (sub)system fails
    - Provided by HVAC manufacturer
    - Can help mechanic in repair process
    - Data can be used to estimate fault tree failure rates
- **Note: focus is to detect failure early (not prediction)**



* *Example data*
For illustration purposes

Strategy 1 : use temperature sensor readings



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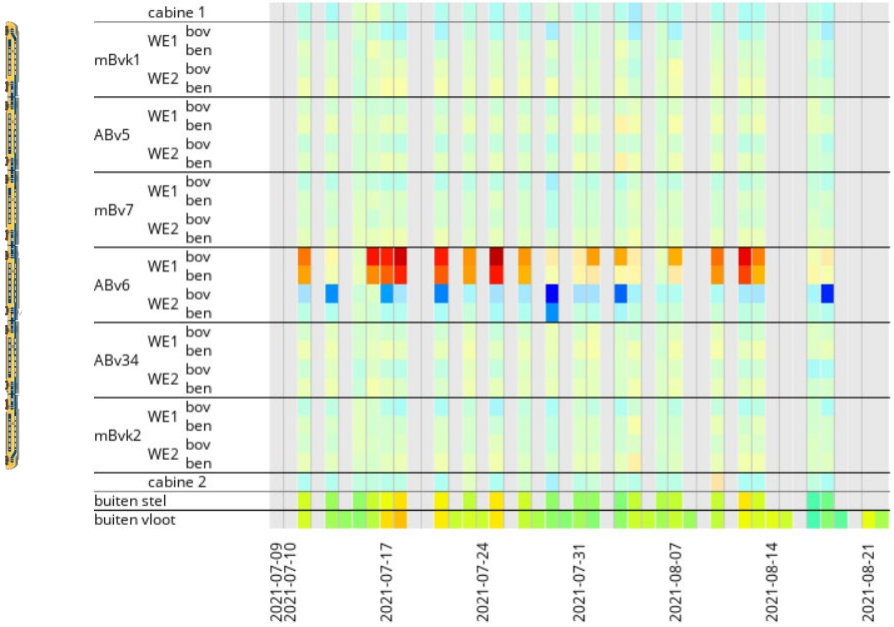
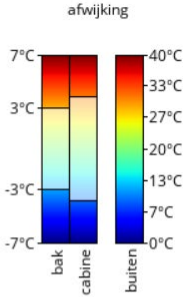
For illustration purposes

- Compute the median over all temperatures in a train set
- Compute deviation from median for each sensor
- High deviation indicates possible malfunction
  - Method is robust
  - Each train set is considered separately

Visualizing temperature deviations from median*

Coaches / HVACs





(grey: not enough data / not in service)

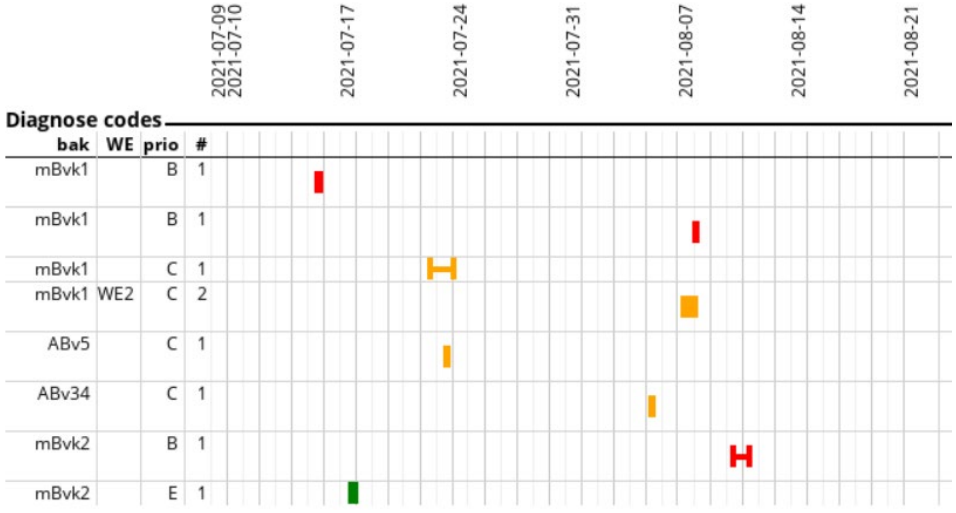
→ outside temperature

* *Example data*
For illustration purposes

- Visual inspection can be used to identify suspicious units
- Recent Bachelor project (Tom Veldman): machine learning can be used

Strategy 2: use diagnostic codes

- HVACs generates diagnostic codes (defined by manufacturer)
- These indicate potential failure / deviation in subsystems
- hundreds of codes for a 12 HVAC train set
- Potentially useful for Fault Tree analyses
- Unclear which codes are good indicators of functional failure



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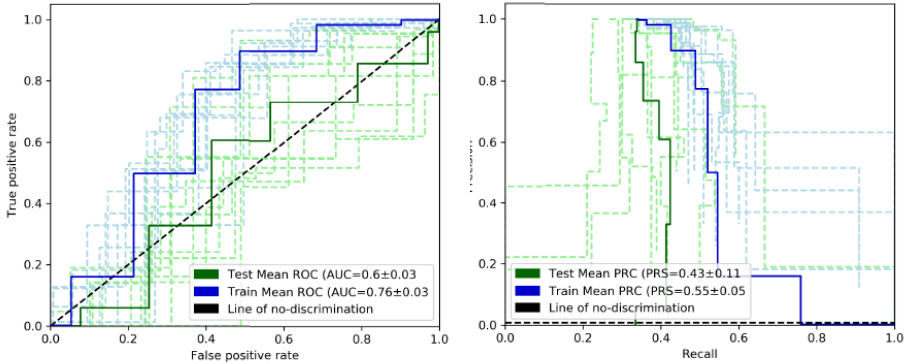
For illustration purposes

Strategy 2: use diagnostic codes

- Work by Duncan J. Jansen & Carlos E. Budde, University of Twente*
  - ‘Labelled dataset’: manual annotation of functional failures on subset of data; bootstrap to automatically label remaining data
  - Train and test a classifier** on diagnostic codes (using labelled dataset)



** *Similar results for:*
- *logistic regression and*
- *decision tree classifiers*

- ROC and precision recall curves show no evidence for good detection
- Challenge of overfitting: many codes & few defects

*Submitted to RSSRAIL'2022 (4th International Conference on Reliability, Safety and Security of Railway Systems)

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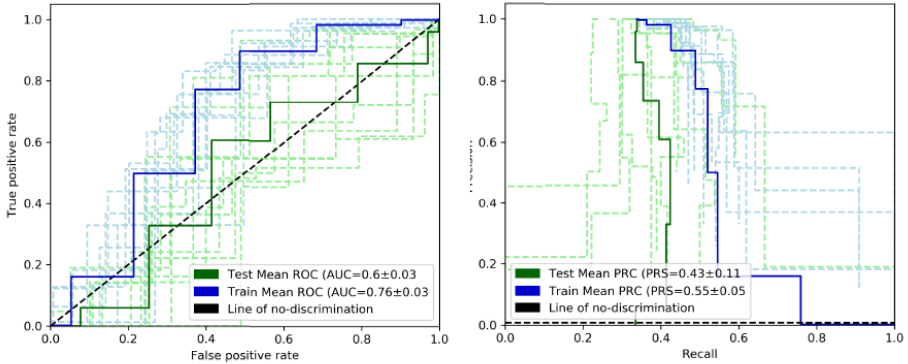

* *Similar re*
- *logistic*
- *decision*

Good: In 97% of the healthy periods, no diagnose codes are present
Bad: In 80% of the unhealthy periods, **no** diagnose codes are present
Bad: Only very few diagnose codes are quite related to functional failure

- ROC and precision recall curves show no evidence for good detection
- Challenge of overfitting: many codes & few defects

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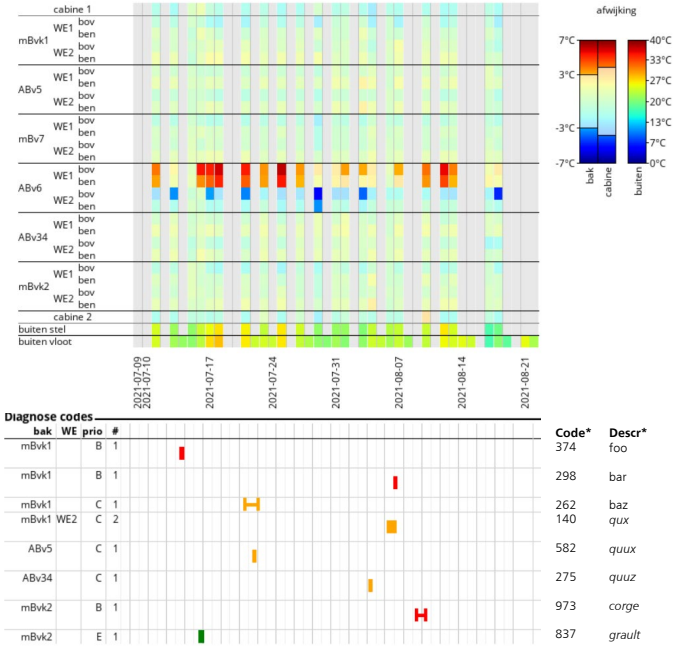
Current work flow at NS

- Weekly report with temperature heatmaps & diagnostic codes
  - Sent to maintenance engineers / maintenance shops
- Corrective maintenance:
  - Maintenance workers use heatmaps and diagnosis codes to identify problematic units
    - Extra attention during periodic (3-monthly) maintenance
    - If capacity allows for it
  - Have helped engineers identify recurring problematic HVAC units
- Preventive maintenance (yearly) more challenging (fluctuations in capacity demand)



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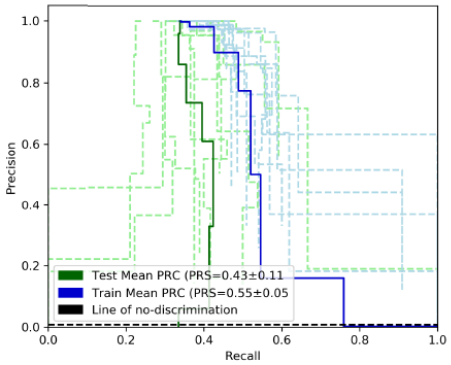
Challenges for NS

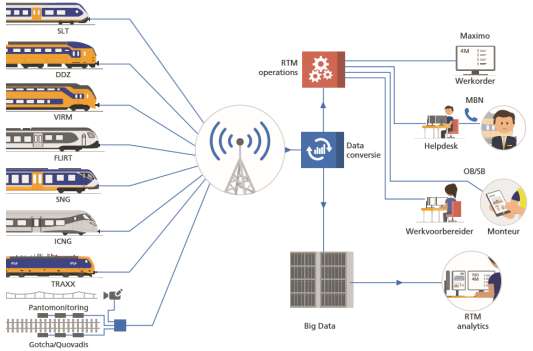
- Ground truth of failures / diagnosis based on maintenance data
  - Data quality / completeness in pipeline
  - Work order descriptions by mechanic may be incomplete / hard to interpret automatically
- Transition to more dynamic maintenance
  - Taking a train out of service un-planned / last minute is logistically challenging
  - Limited capacity in maintenance shops (tracks / people)
  - Maintenance culture: focus on planned work

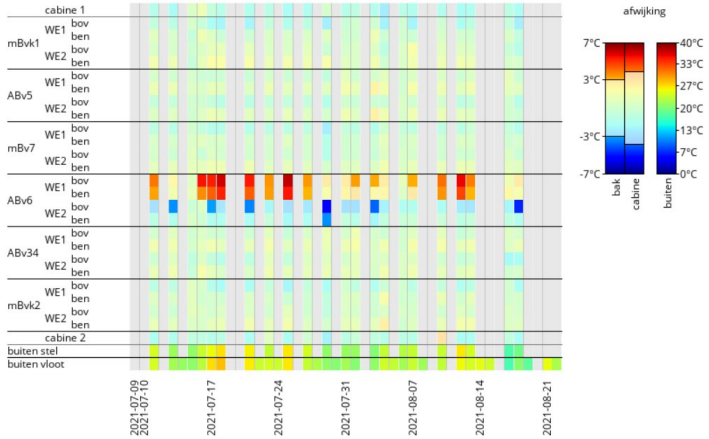
Future work

- Further develop automatic HVAC alarms for maintenance shops
- PrimaVera: investigate costs/benefits of more dynamic maintenance strategy. MSc student starting March 2022 (Rob Basten / TU/e)
  - When a heat wave is forecast, take suspicious train sets out of service early
    - So they will perform better during the heatwave
    - Early-ish warning may help planners in re-allocation of rolling stock
  - Deal with uncertainty of asset condition, future repair capacity, weather

Thank you!







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- Thanks to:
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