RailBeijing 2021

Real-time Parameter Estimation Using An Unscented Kalman Filter

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Outline of the presentation

- Introduction
  - EETC
  - Train motion model
- Framework
  - Unscented Kalman Filter
  - Driving Regime Identifier
  - Feature Extraction
- Case study
  - Data used
  - Results
- Conclusions

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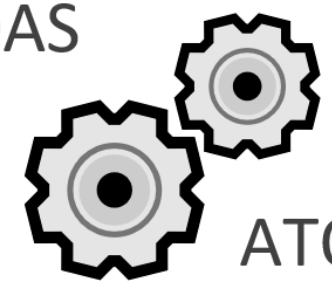
Introduction I - EETC

Energy-Efficient Train Control (EETC)

Key component



Energy-efficient timetabling

Ease of implementation

(Relative) low cost

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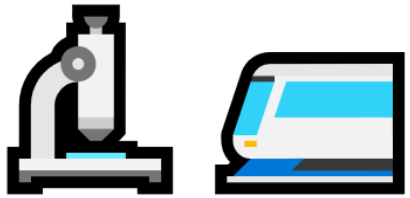
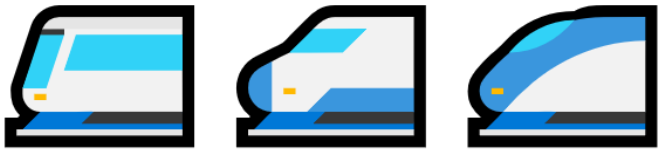
Introduction II - Impact of EETC

Energy consumption

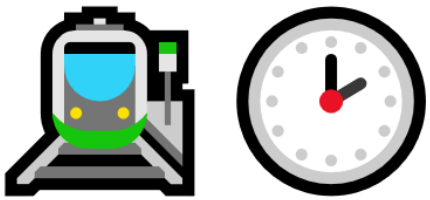
Train and track wear

Precise operation

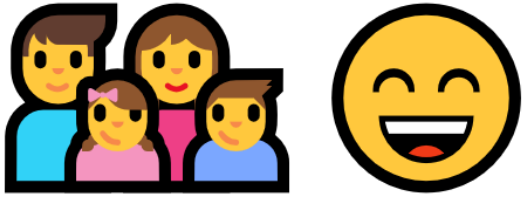




Capacity



Timetabling



Better service

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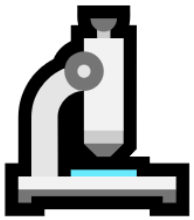
Introduction III - EETC calibration

Offline calibration
using historical data

Time
variations

Not accurate in the
long run or for all trains



Online calibration accurate
only when coasting

External
factors

Revolution:
Train-tailored solutions

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Introduction IV - Train motion model

$$\frac{dv}{dt} = f_t(v) - f_b(v) - r(v,s) - g(s)$$

It can reproduce train dynamics accurately if well calibrated

s Location
v Speed
f_t Tractive effort
f_b Brake effort
$r(v,s)$ Running resistance
$g(s)$ Track resistance

Parameter Uncertainties

Spatiotemporal variability

Contribution: Framework to calibrate EETC-based on-board tools in real time

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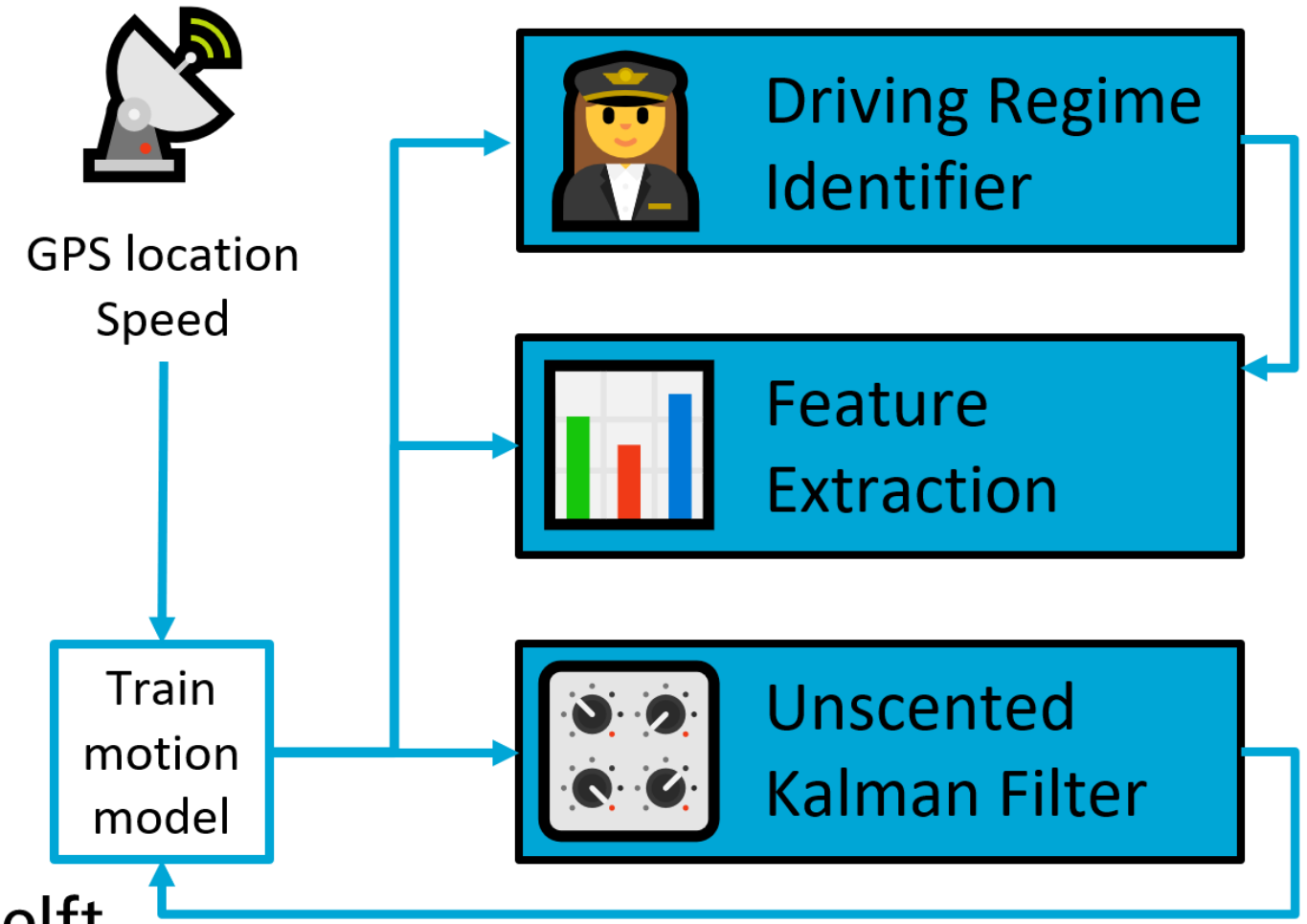
Framework


GPS location
Speed
Train motion model
Driving Regime Identifier
Feature Extraction
Unscented Kalman Filter

Framework: Unscented Kalman Filter

GPS location
Speed

Driving Regime Identifier

Feature Extraction

Train motion model

Unscented Kalman Filter

$$r(v,s) = r_0 + r_1 v + r_2 v^2$$

Running resistance parameters

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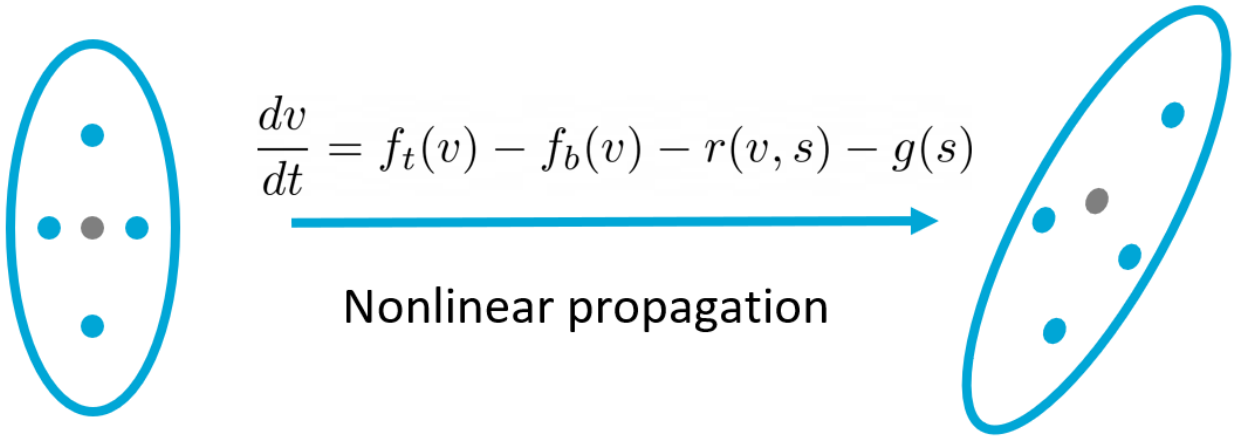
Framework: Unscented Kalman Filter

UKF: State observer to estimate parameters of nonlinear systems

State statistics sampled deterministically and propagated nonlinearly



Julier and Uhlmann (1997). New extension of the Kalman filter to nonlinear systems

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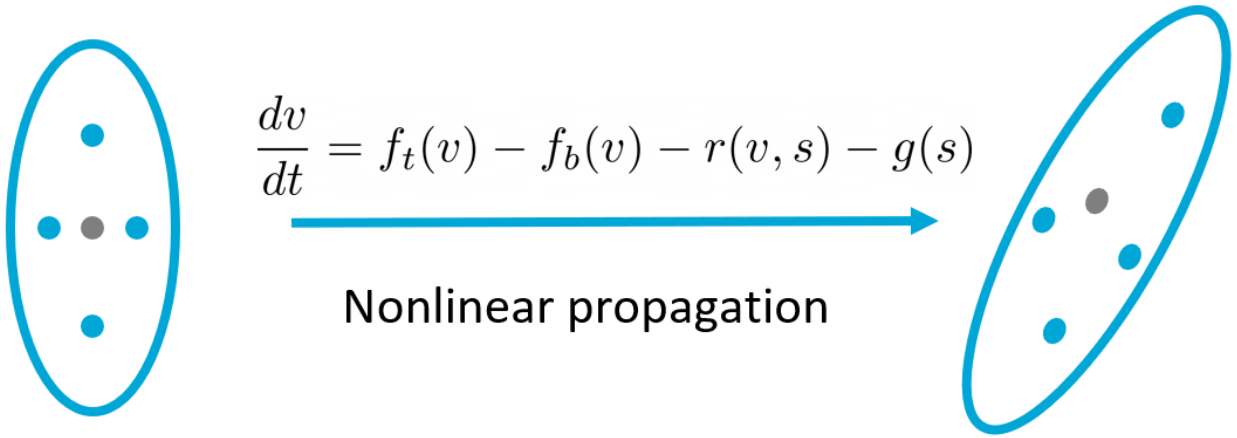
Framework: Unscented Kalman Filter

UKF: State observer to estimate parameters of nonlinear systems

State statistics sampled deterministically and propagated nonlinearly



Inputs:
Acceleration, Effort

Output: **Running resistance parameters**

Julier and Uhlmann (1997). New extension of the Kalman filter to nonlinear systems

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Framework: Driving Regime Identifier

GPS location
Speed

Driving Regime Identifier

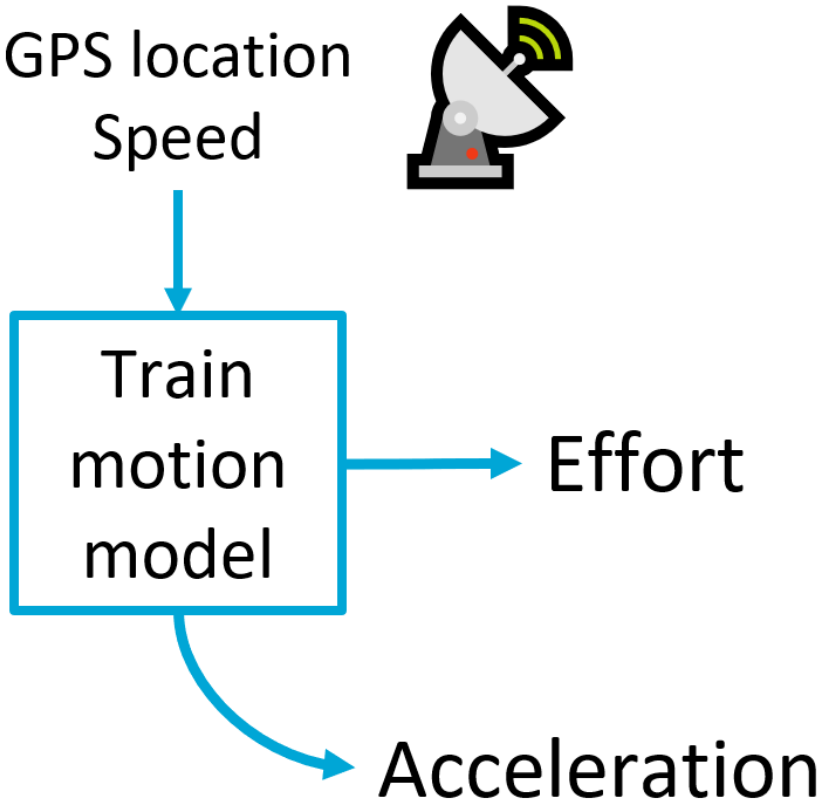
Current driving regime

Feature Extraction

Train motion model

Unscented Kalman Filter

Framework: Driving Regime Identifier



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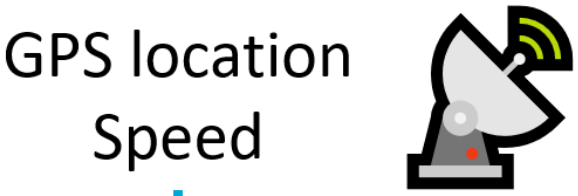
Framework: Driving Regime Identifier



Train motion model

Effort

- < 0 = Braking
- ≈ 0 = Coasting
- > 0 = Traction

Acceleration

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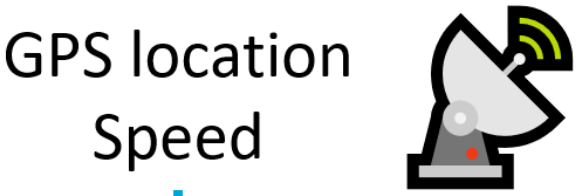
Framework: Driving Regime Identifier



Train motion model

Effort
- < 0 = Braking
- ≈ 0 = Coasting
- > 0 = Traction

Acceleration ≈ 0 = Cruising

Framework: Driving Regime Identifier

GPS location
Speed

Output: **Current driving regime**

Train motion model

Effort
- < 0 = Braking
- ≈ 0 = Coasting
- > 0 = Traction

Acceleration ≈ 0 = Cruising

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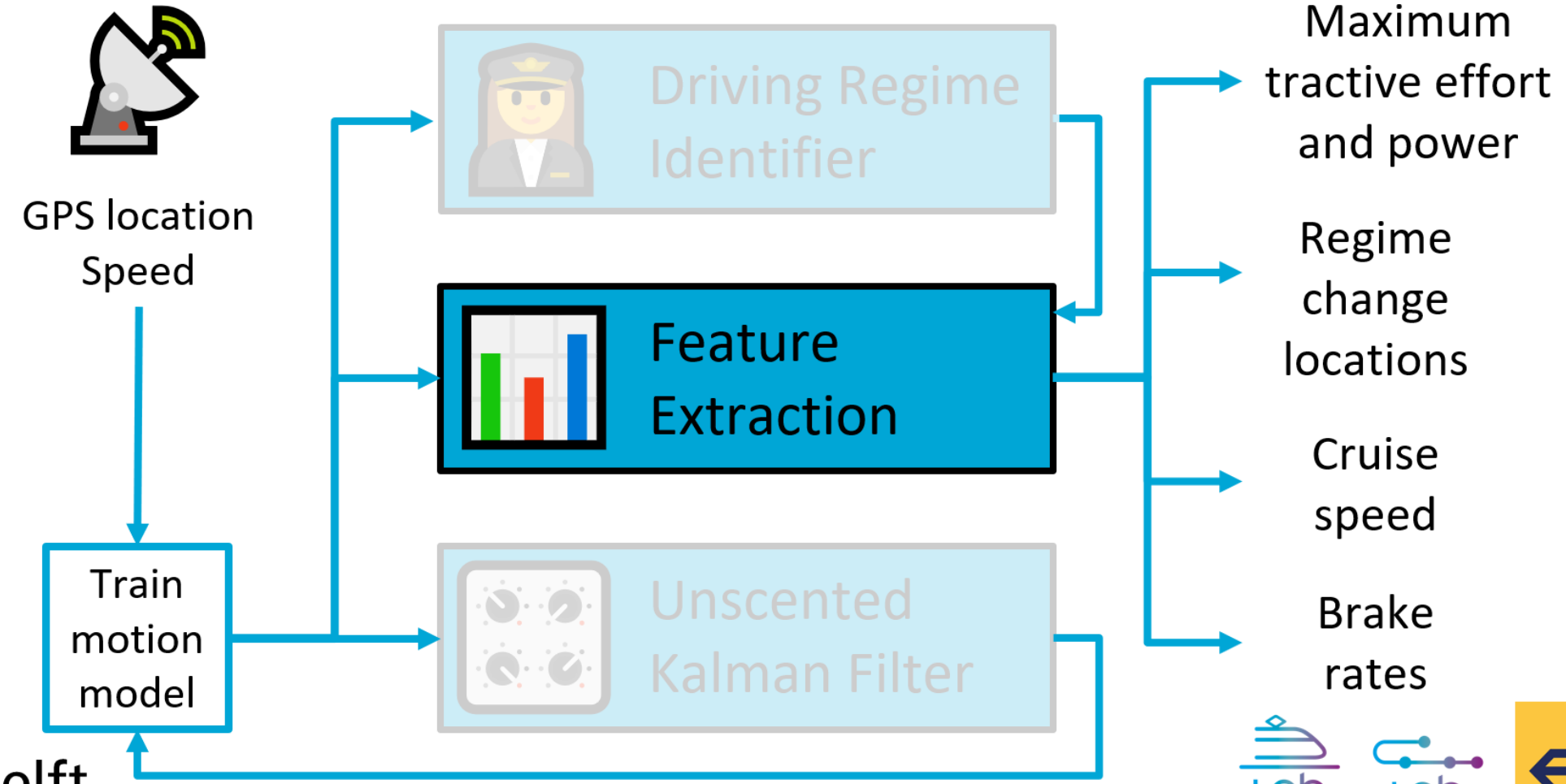
Framework: Feature Extraction



Case Study

- 67 train trajectories of the same rolling stock unit
- Line Eindhoven – Den Bosch
- Track mostly flat
- Input data: Speed and location measurements
- Sampling rate 10s

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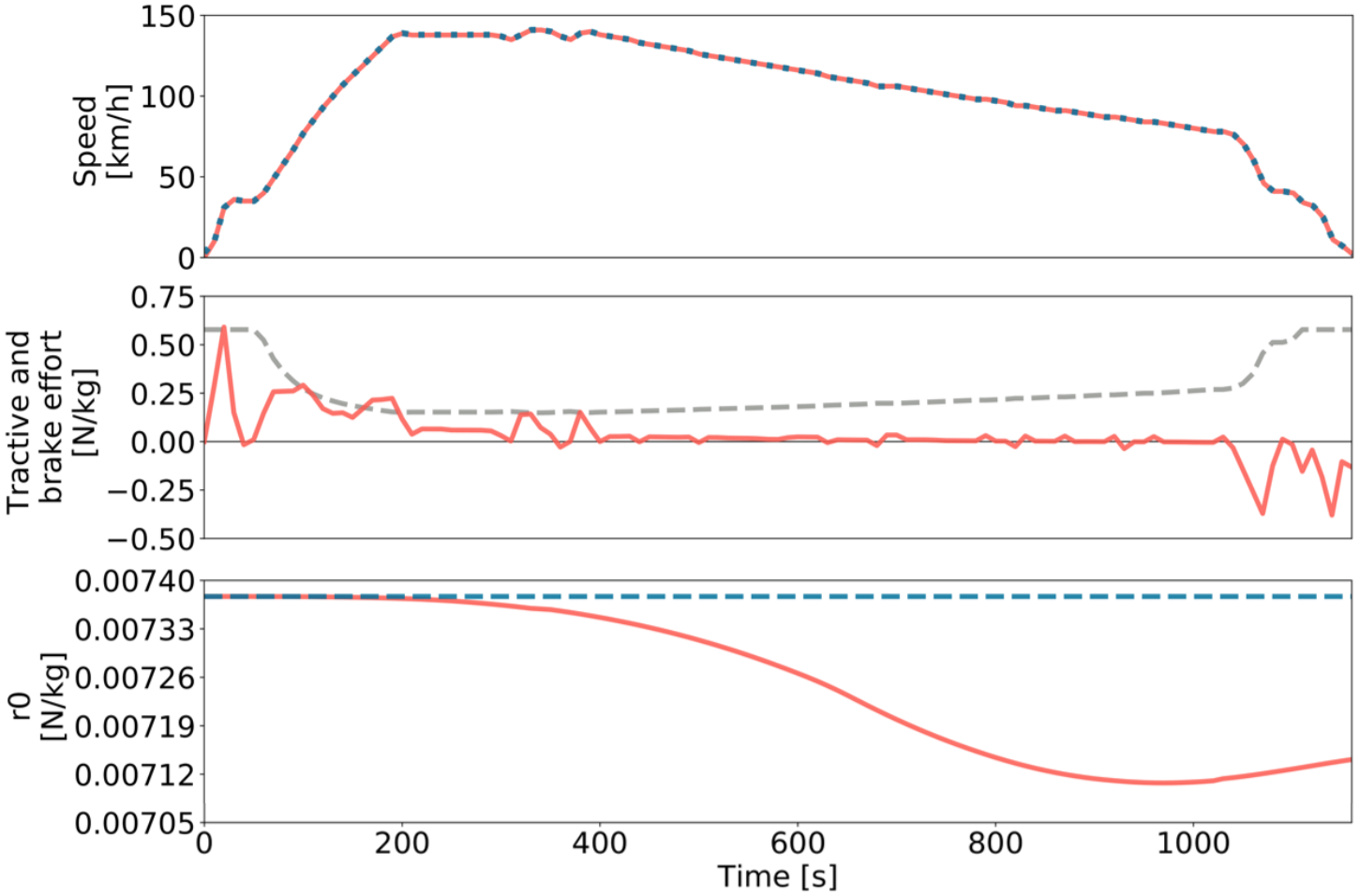
Results I: Parameter Estimation



UKF can track speed measurements and estimate the running resistance parameters

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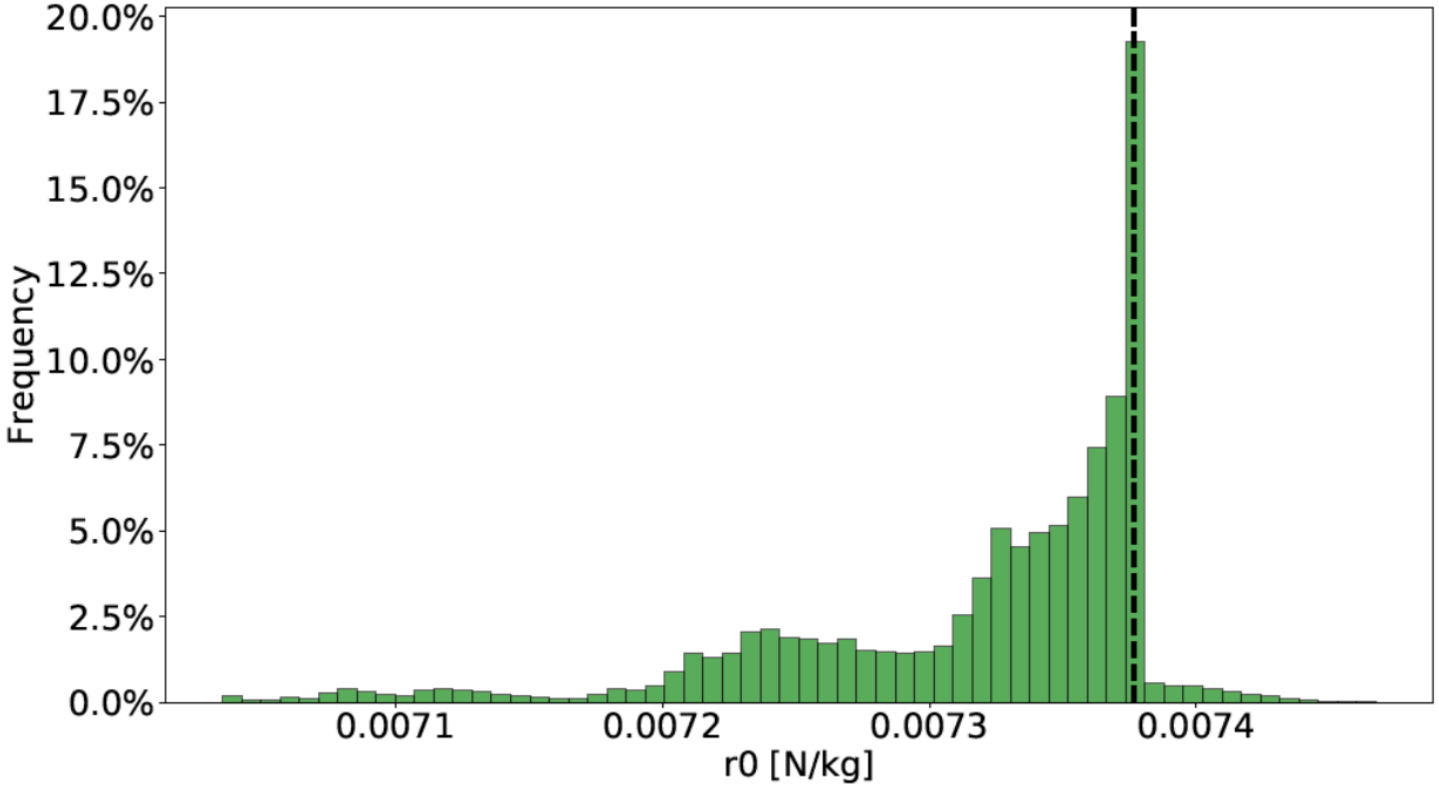
Results II: Running resistance parameters



Manufacturers tend to overestimate the value of the running resistance parameters

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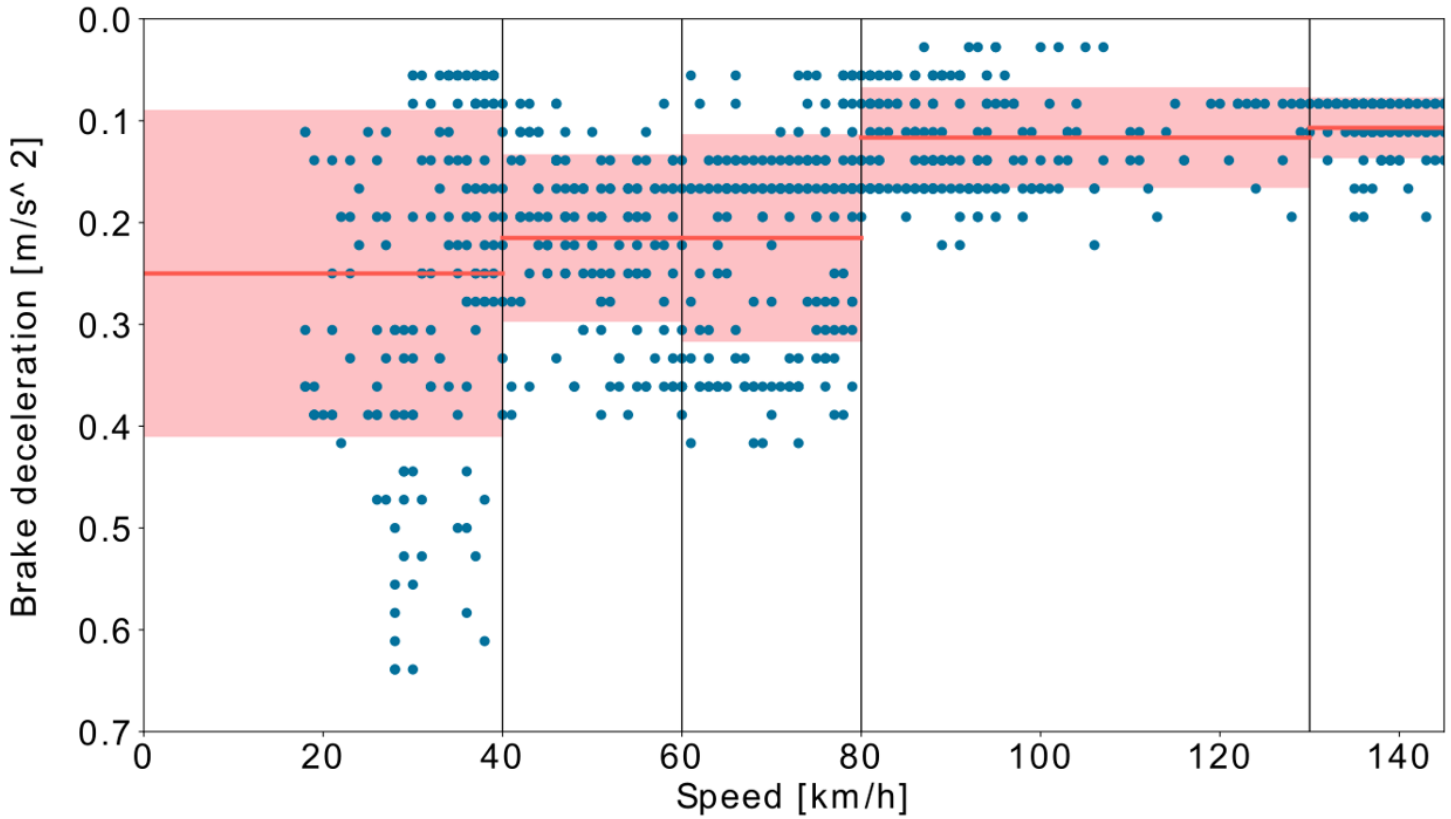
Results III: Brake rates



3 different brake rates along the 5 ATP braking speed steps

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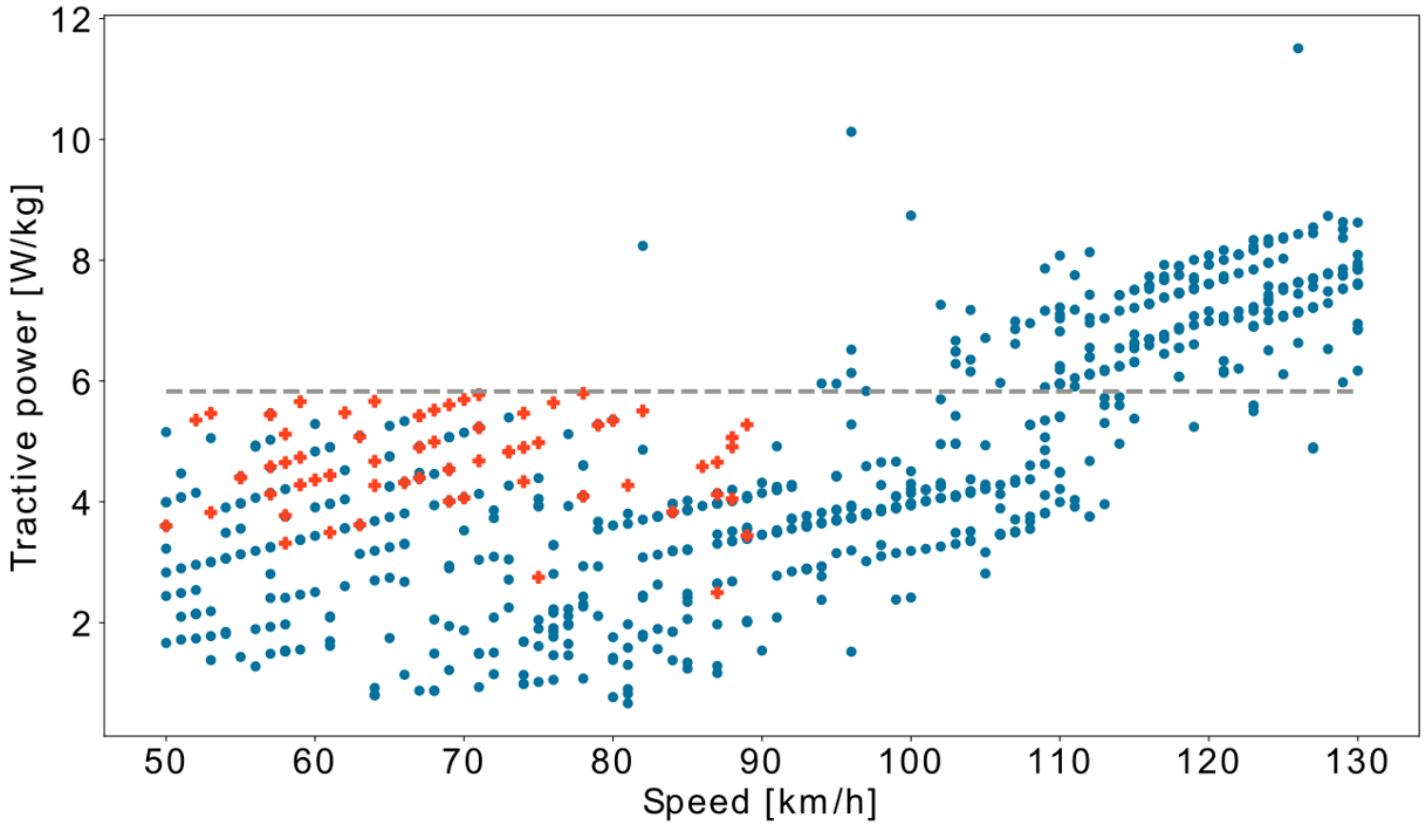
Results IV: Maximum tractive power



Manufacturer upper bound is accurate

We observe a change of power station after departure station

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Conclusions

- Parameter estimation framework for EETC applications
- Performance tested using real data in a case study
- Framework can determine
  - Running resistance parameters
  - Current driving regime
  - Bounds and statistics of input parameters of EETC applications
- Limitations:
  - No applied effort measurements lead to lower accuracy
  - UKF internal parameters difficult to tune
  - Low measurement sampling rate

Contact details + Download the paper

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Paper & Slides

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Variability sources I: Traction

$$\frac{dv}{dt} = f_t(v) - f_b(v) - r(v,s) - g(s)$$

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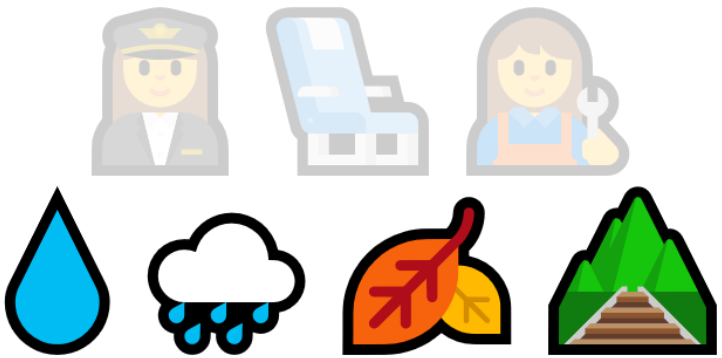
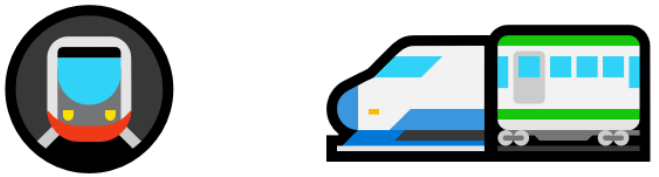
Variability sources II: Brake

$$\frac{dv}{dt} = f_t(v) - f_b(v) - r(v,s) - g(s)$$

Variability sources III: Resistance

$$\frac{dv}{dt} = f_t(v) - f_b(v) - r(v,s) - g(s)$$





$$r(v,s) = r_0 + r_1 v + r_2 v^2$$

Variability sources IV: Track

$$\frac{dv}{dt} = f_t(v) - f_b(v) - r(v,s) - g(s)$$