Tecnun
Universidad
de Navarra

ceit

Avances en el diagnóstico de la calidad de vía ferroviaria mediante técnicas de Machine Learning

Adrián Sansiñena Rodríguez

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Ceit - Grupo DAIM

Co-funded by the European Union

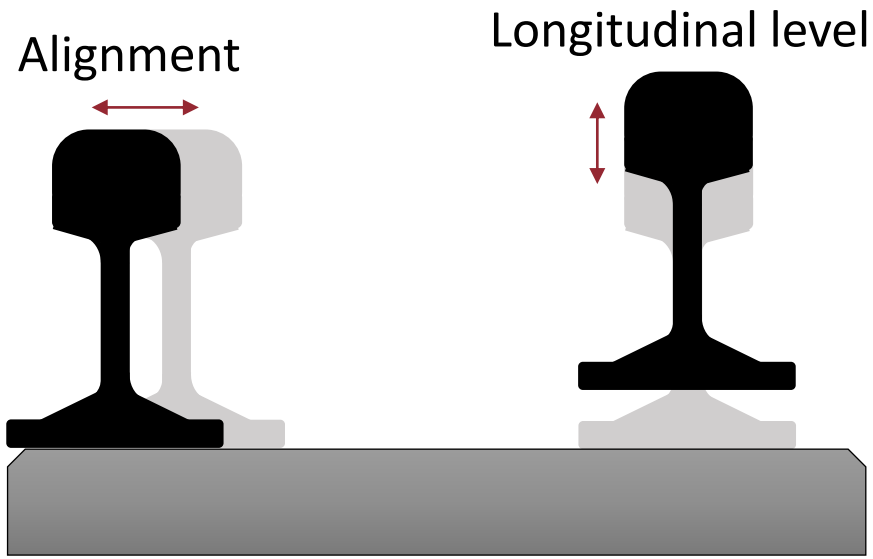
Europe's Rail

FP1 MOTIONAL
European Rail Network and Mobility Management

FP3 iam4Rail

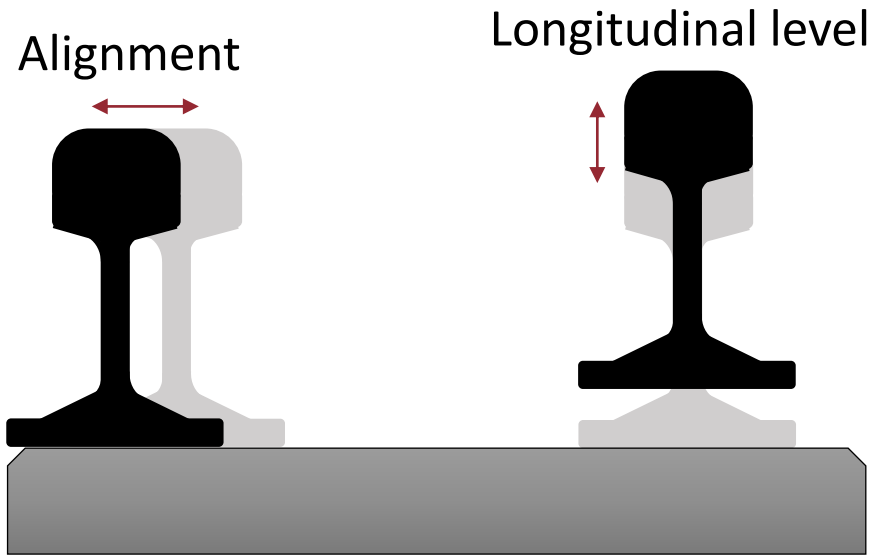
Introduction

Track Irregularities



Introduction

Track Irregularities ⟷ Track Quality Degradation



- Safety risk
- Comfort worsen (vibrations, noise)
- Maintenance costs

Introduction

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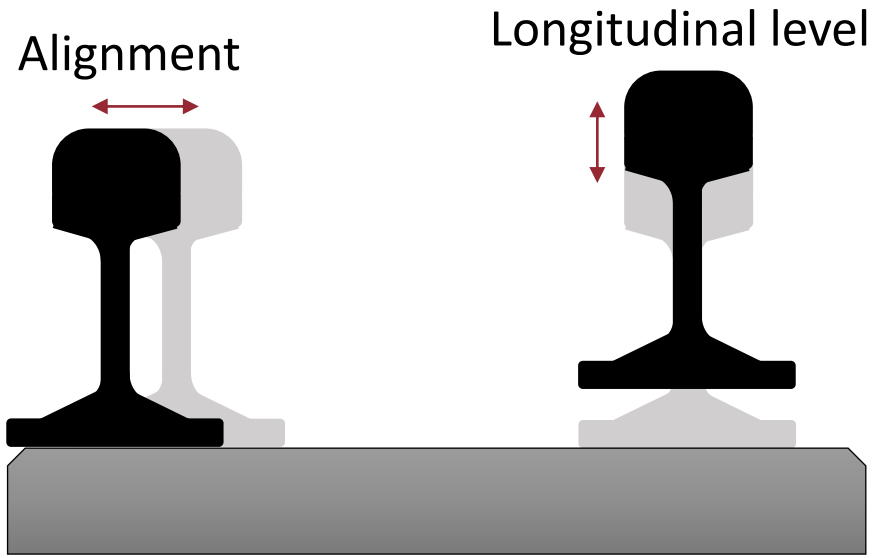


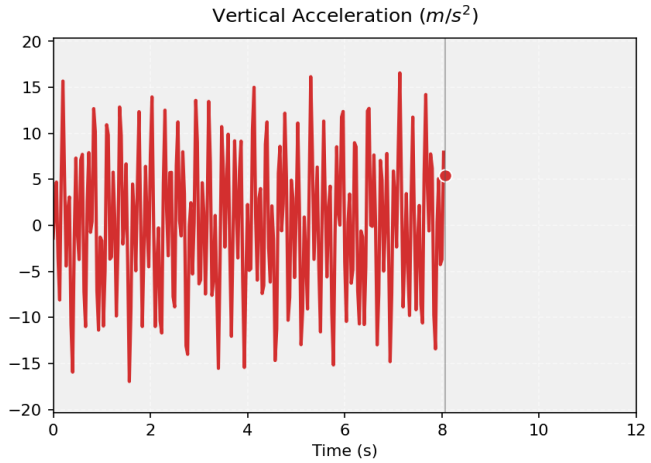
- Safety risk
- Comfort worsen (vibrations, noise)
- Maintenance costs

Traditional diagnostic methods

https://www.pandrol.com/product/track-geometry-trolley/

https://www.spoorpro.nl/materieel/2021/12/20/nut-van-dynamisch-meten-besproken-tijdens-harmotrack-project-uic/

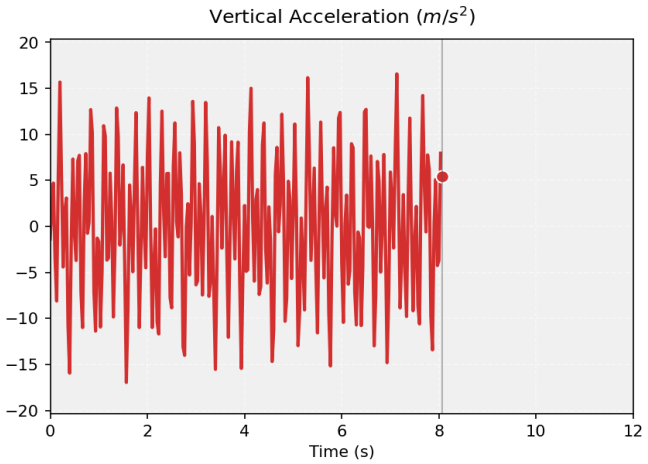
Introduction

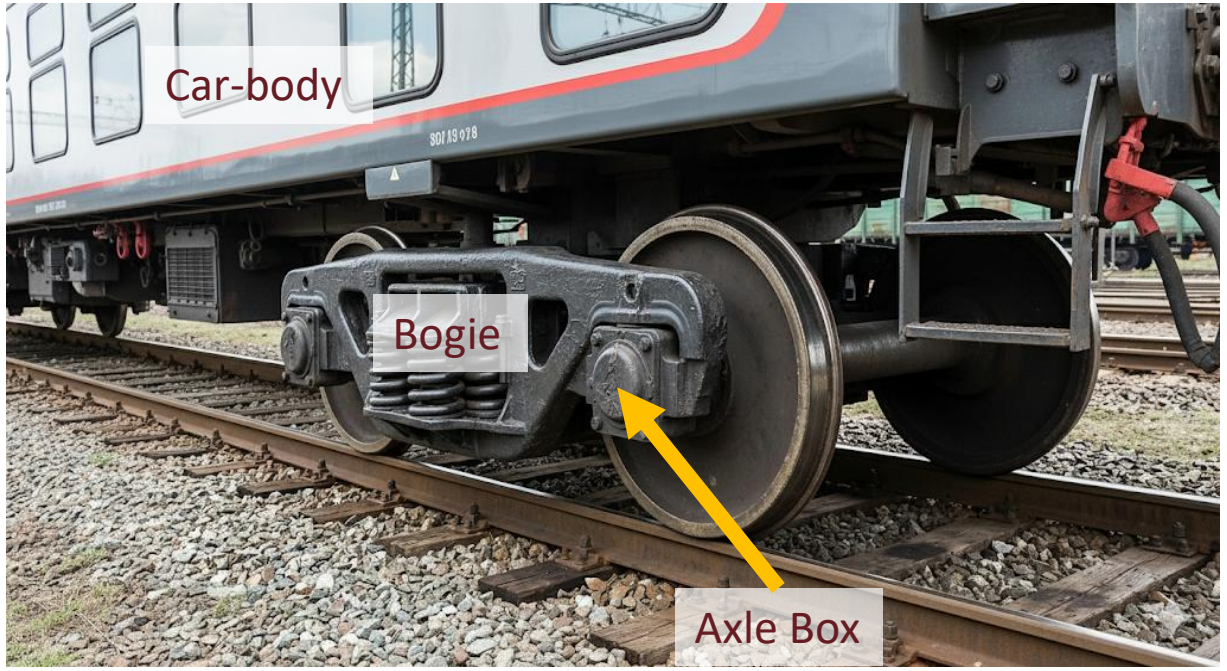


Track quality assessment

Track Diagnostic System

Introduction



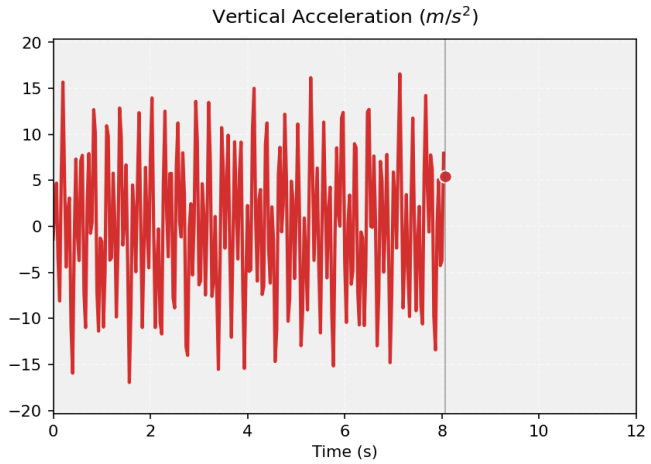


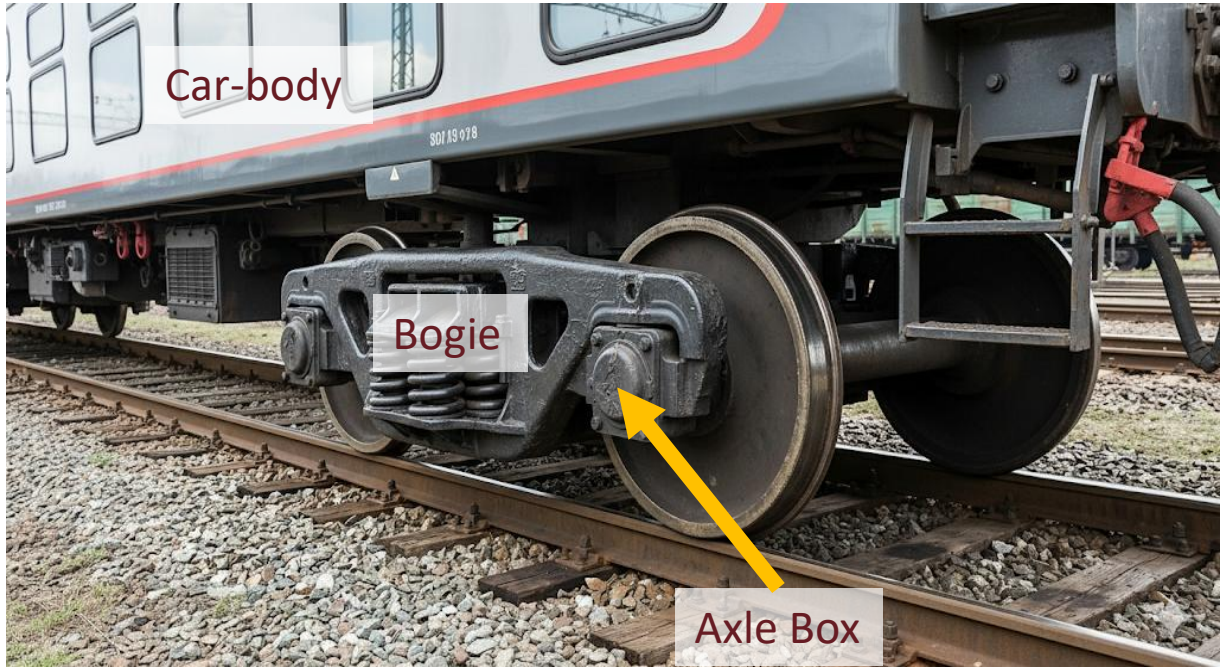
Track quality assessment

Track Diagnostic System

- ✓ In-service vehicles
- ✓ Cheap system
- ✓ Continuous monitoring (at least 1 measure per day)

Introduction





Track quality assessment

Track Diagnostic System

VEHICLE SYSTEM DYNAMICS
https://doi.org/10.1080/00423114.2025.2483972

IAVSD

Taylor & Francis
Taylor & Francis Group

Check for updates

A systematic review of acceleration-based estimation of railway track quality

Adrián Sansiñena[a,b], Borja Rodríguez-Arana [a,b] and Saioa Arrizabalaga[a,b,c]

Objectives

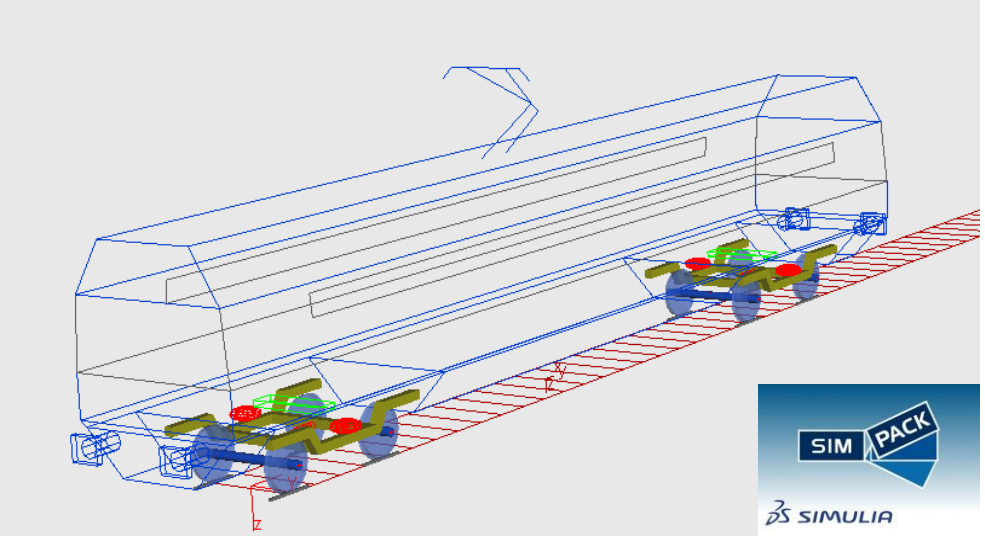
From accelerations measured on board in-service vehicles:

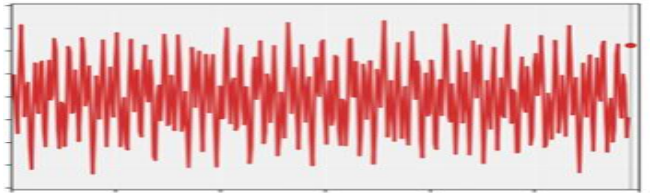
- Propose a modular and flexible ML methodology for track quality diagnosis
- Integrate:
  - Data generation
  - Feature learning
  - Sensor selection
- Application to the estimation of two track-quality indices.

Data

Generation of synthetic data

SIMPACK Multibody simulations software → Raw acceleration time series





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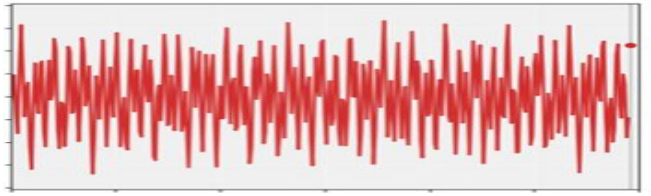

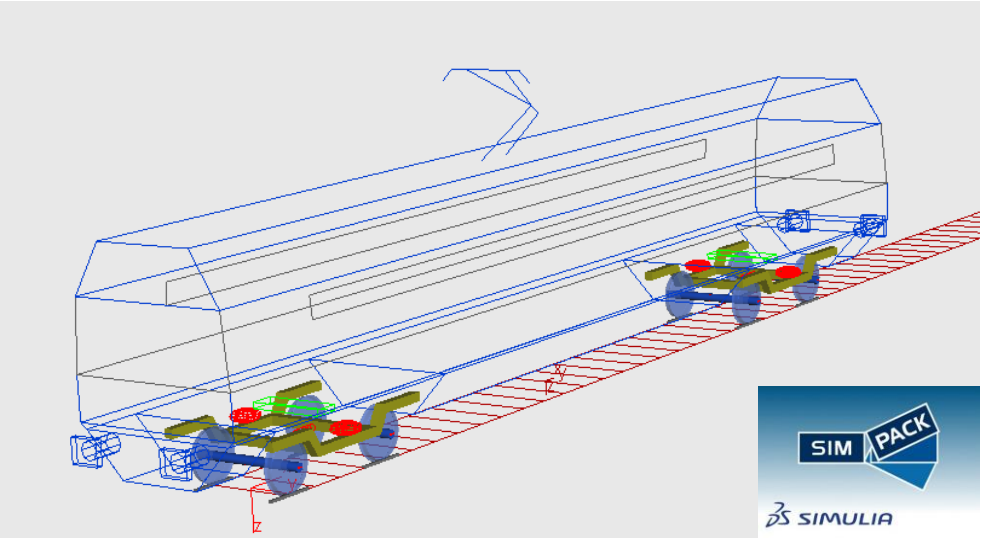

Several simulation parameters:

- Speed
- Load
- Track layout
- ...

Data

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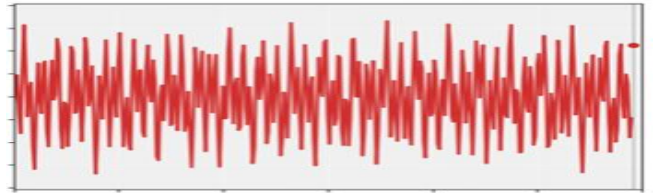
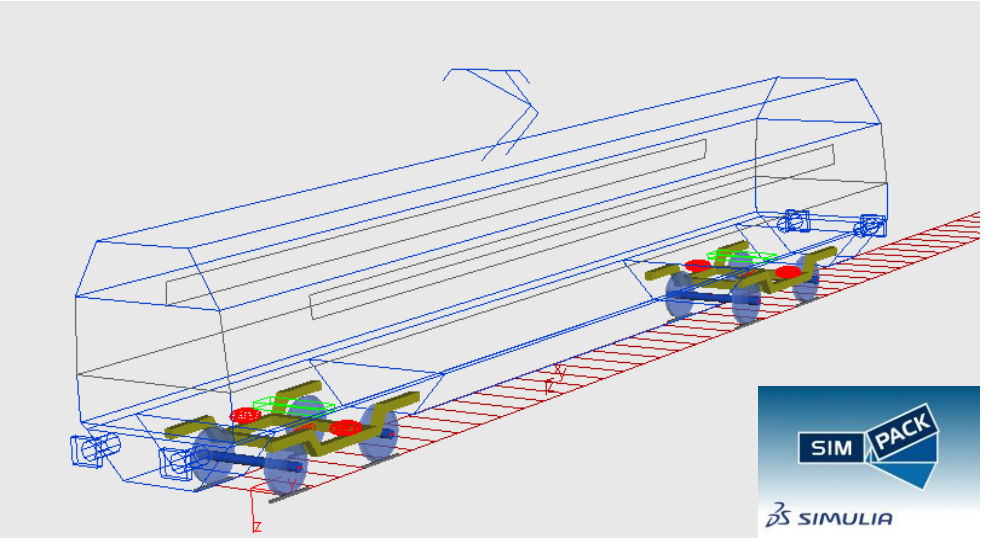




Several simulation parameters:

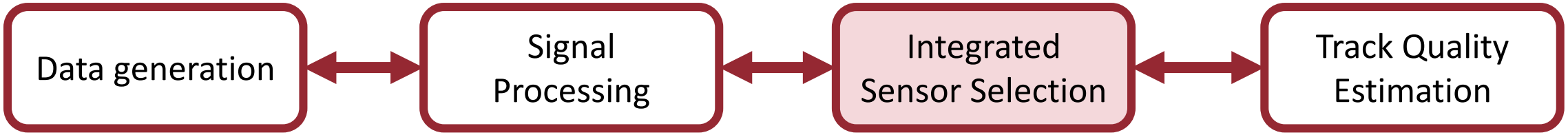
- Speed
- Load
- Track layout
- ...

Simulations represent a regional train with a maximum speed of 80 km/h under a wide range of scenarios.

→ Representative and general for this type of vehicle.

Methodology

General methodology for track assessment



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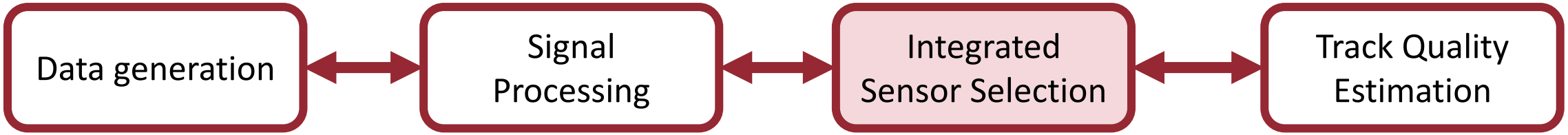
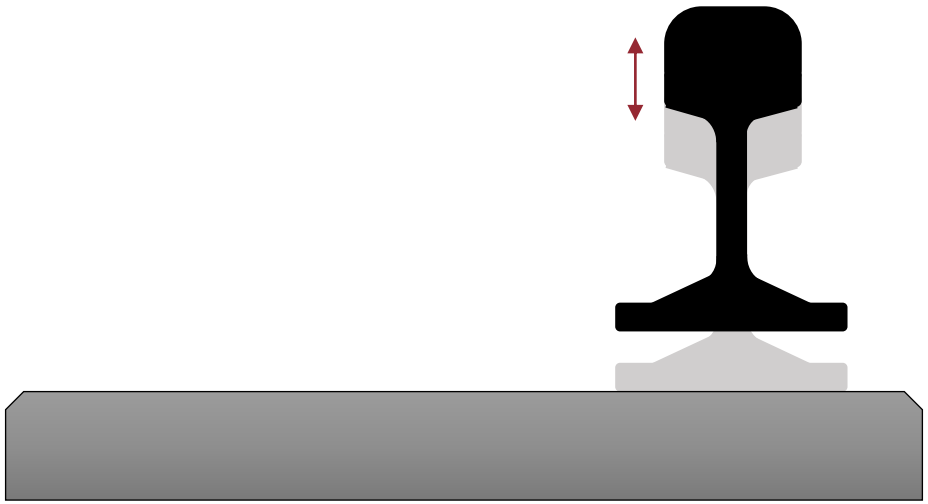


Two application cases studied:

Longitudinal level



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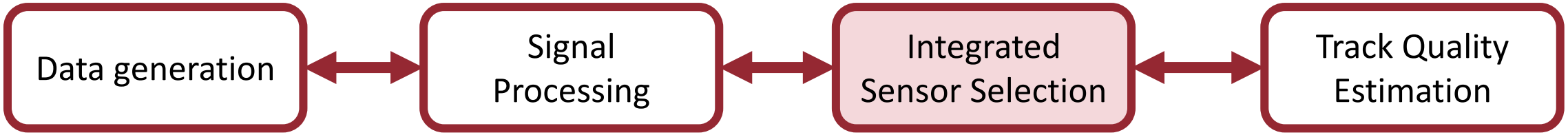
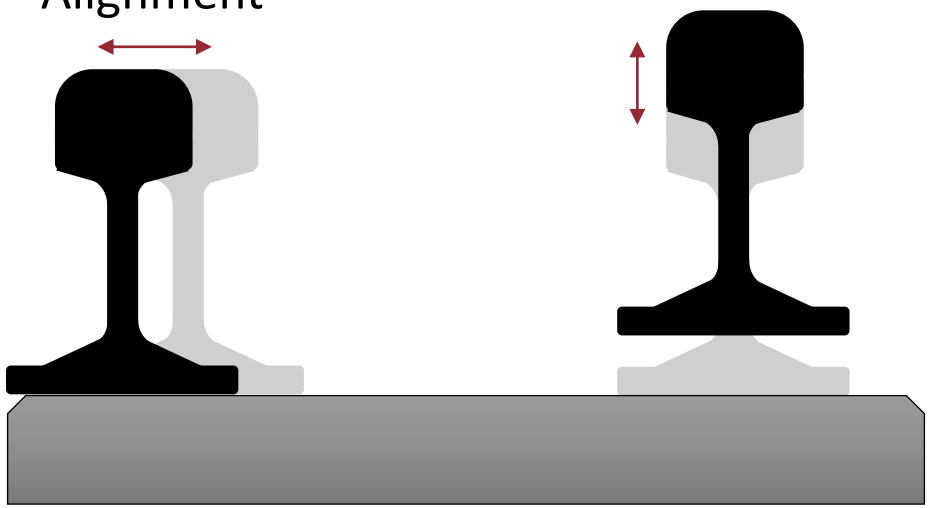


Two application cases studied:

Alignment

Longitudinal level



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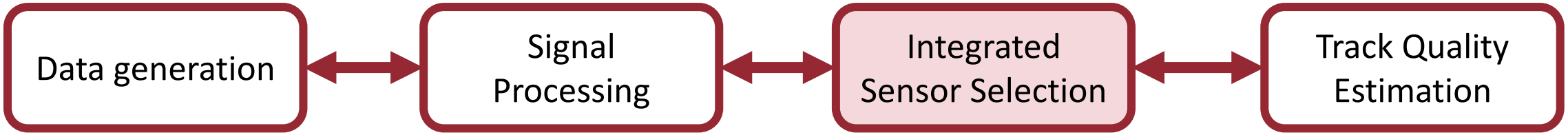

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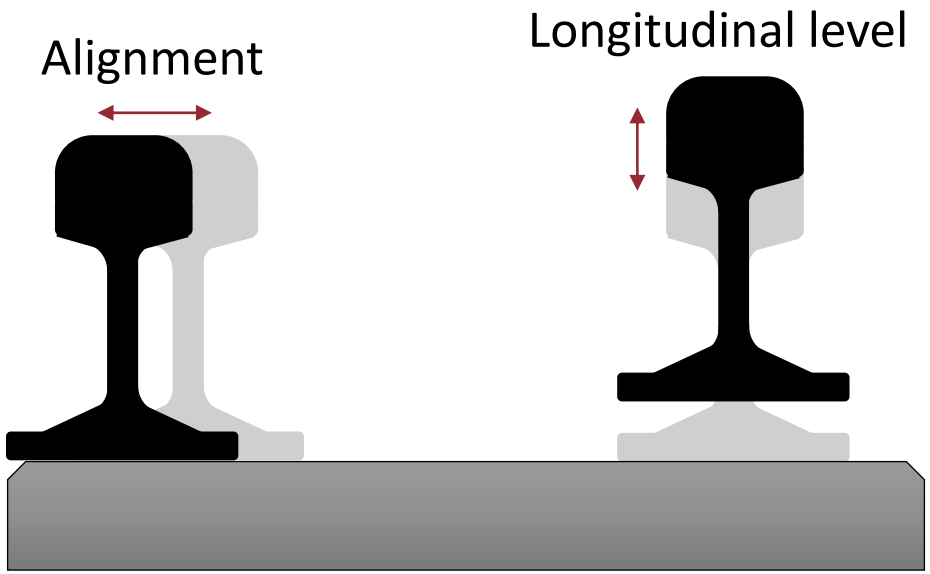

We use the **EN-13848** track quality definition:

Standard deviation of irregularities in a **200 m section**.

Regression of a single value from acceleration time series

Longitudinal Level Quality Estimation

“Easy” case. Vehicle-track interaction is simpler → We prioritize compact models and tabular data

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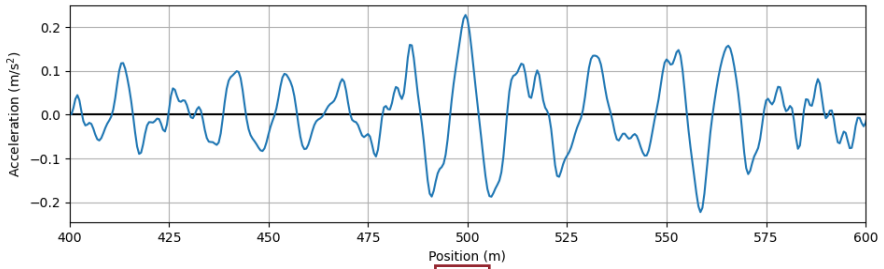
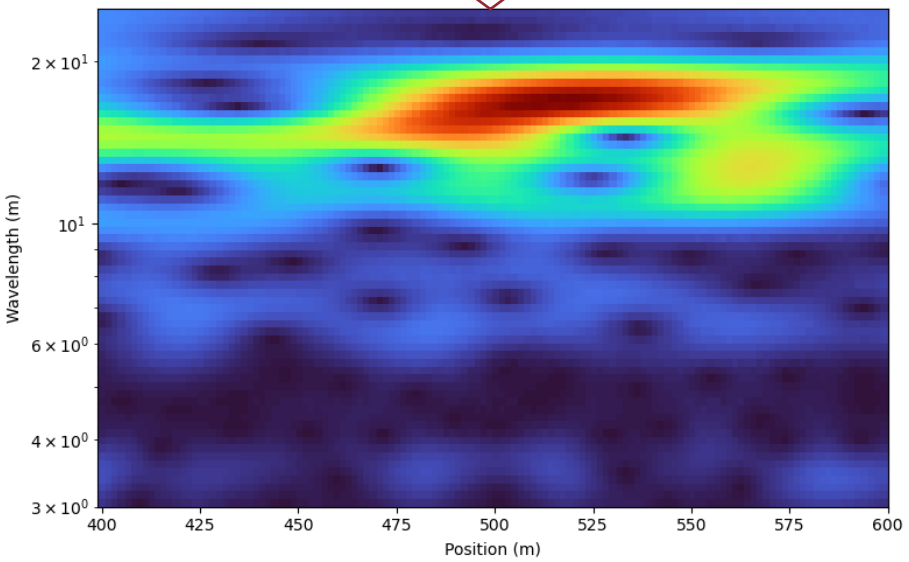
Signal Processing:



Ad-hoc features

- RMS
- peak-to-peak value
- Dominant frequency
- …



PCA → First 10 principal components

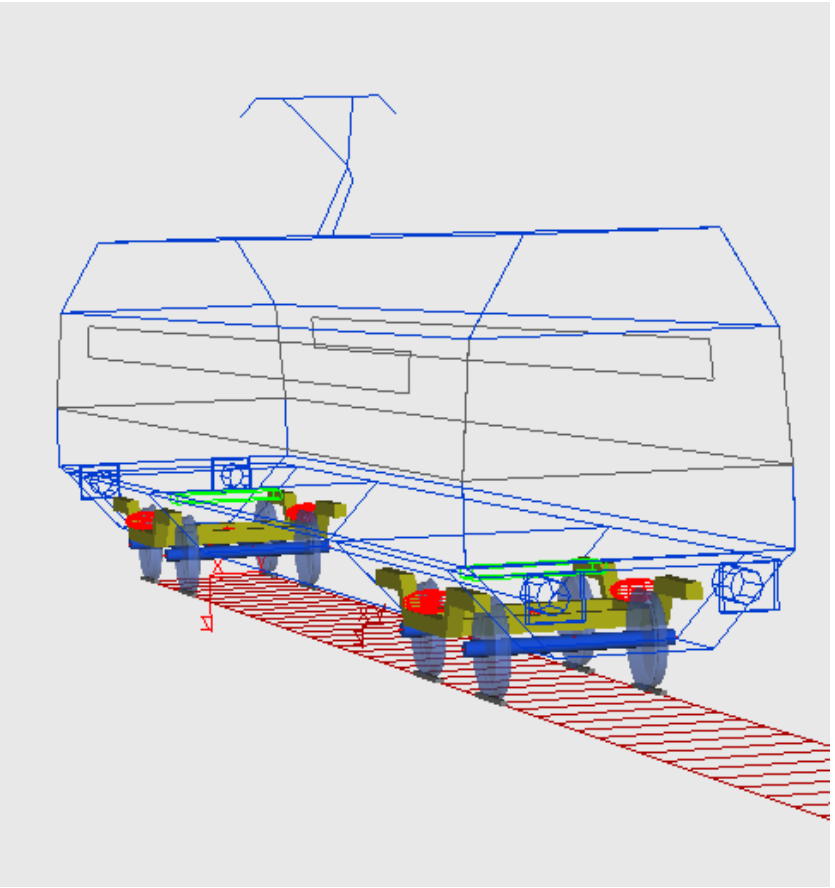
Input Dataset

Longitudinal Level Quality Estimation

Sensor selection:

NSGA-II for multi-objective optimization:

- Estimation RMSE
- Number of sensors



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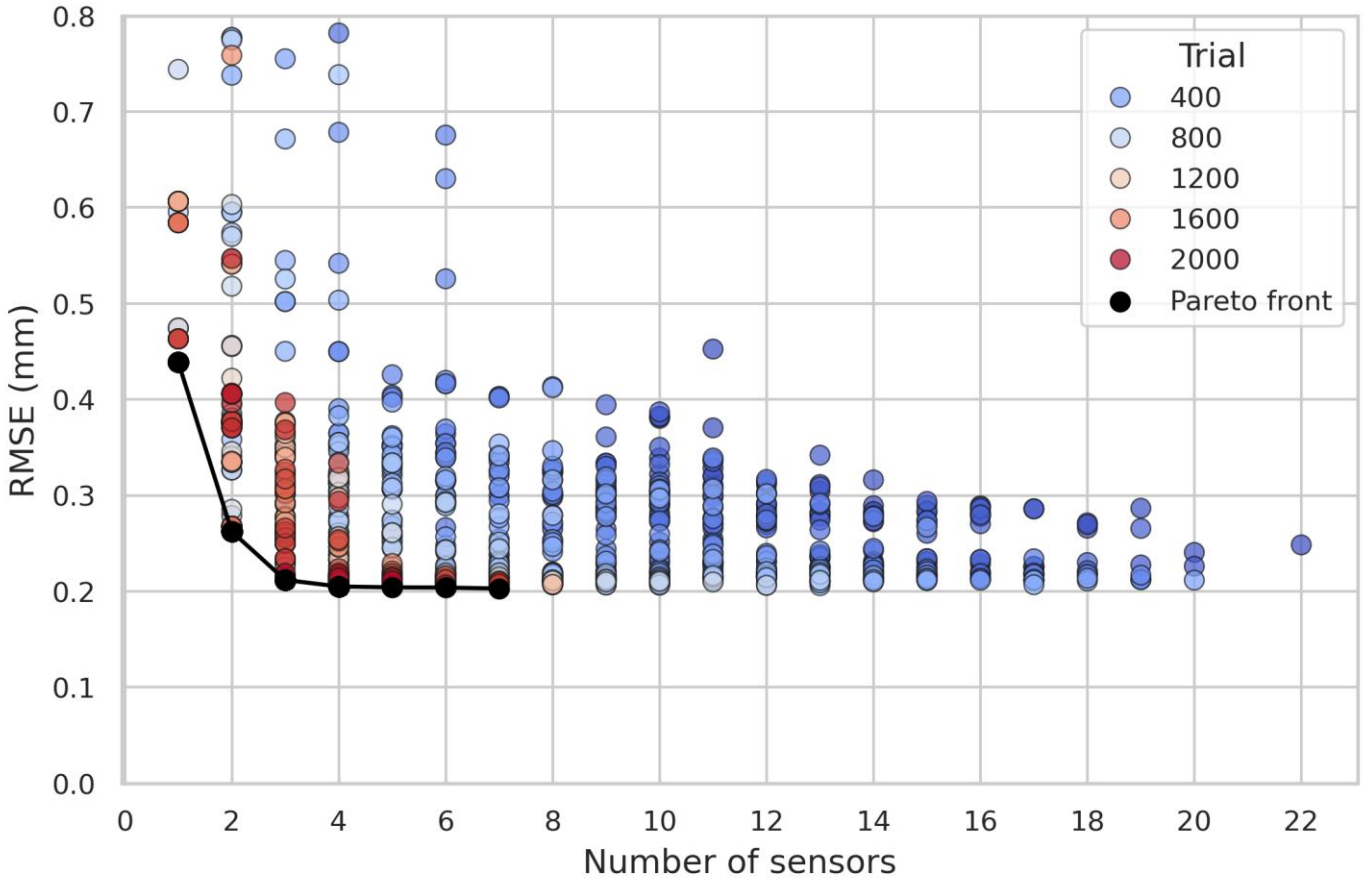

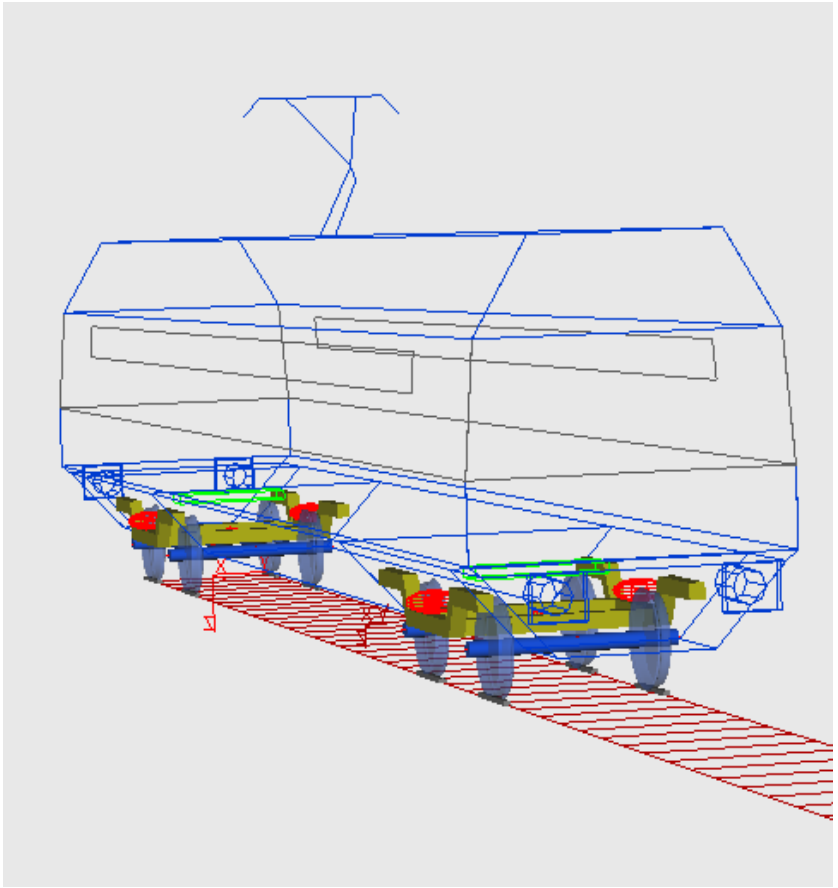

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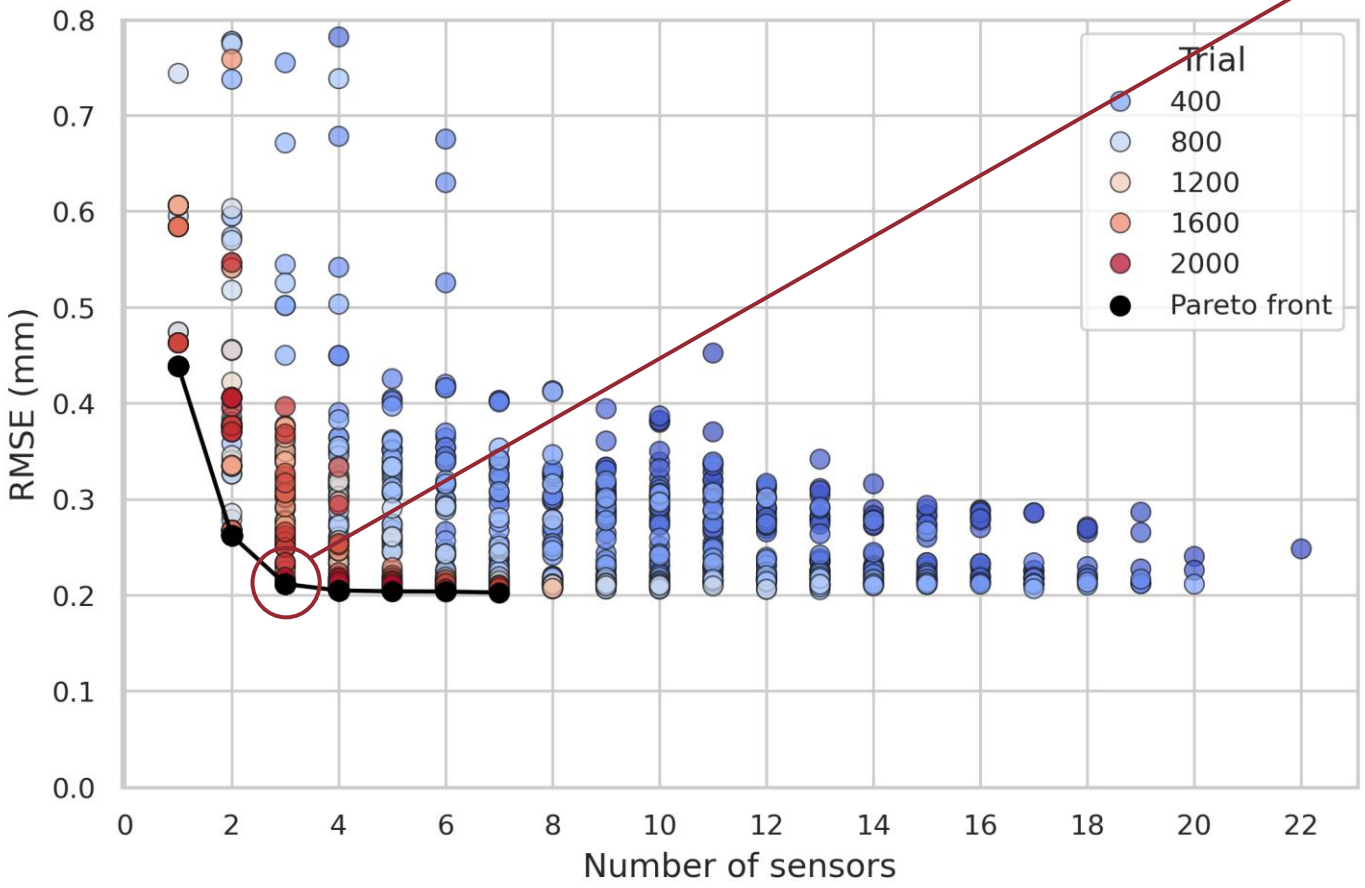
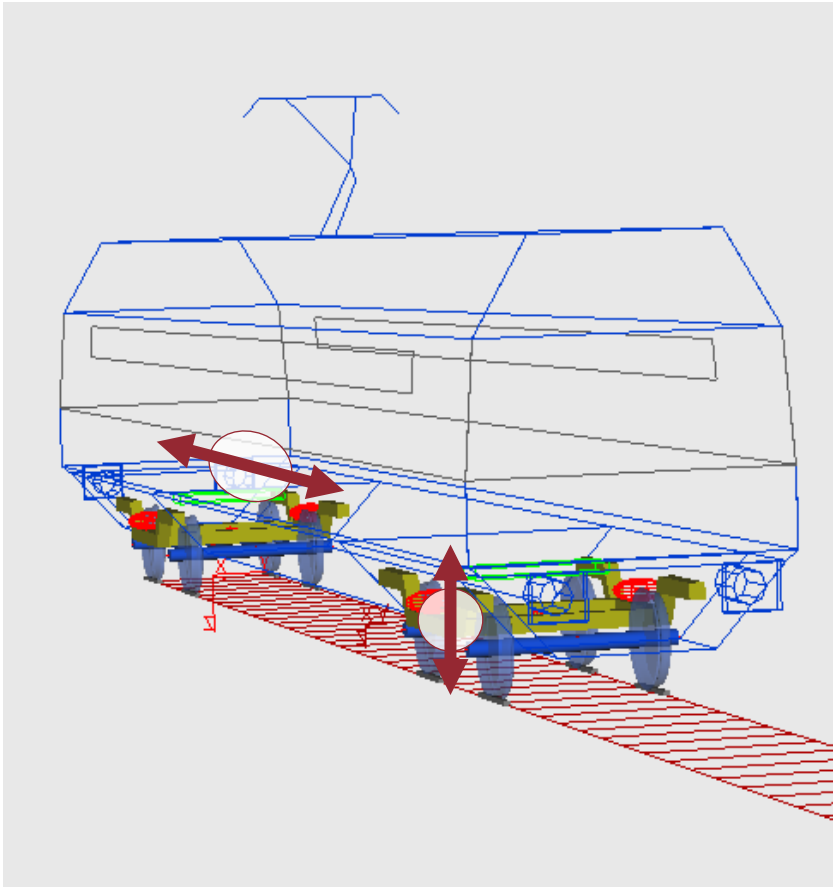


Train speed
Acc. Vertical Front Bogie
Acc. Long. Back of the Car-Body



Longitudinal Level Quality Estimation

Track Quality Estimation:

With data coming from the selected sensor configuration:

Longitudinal Level Quality Estimation

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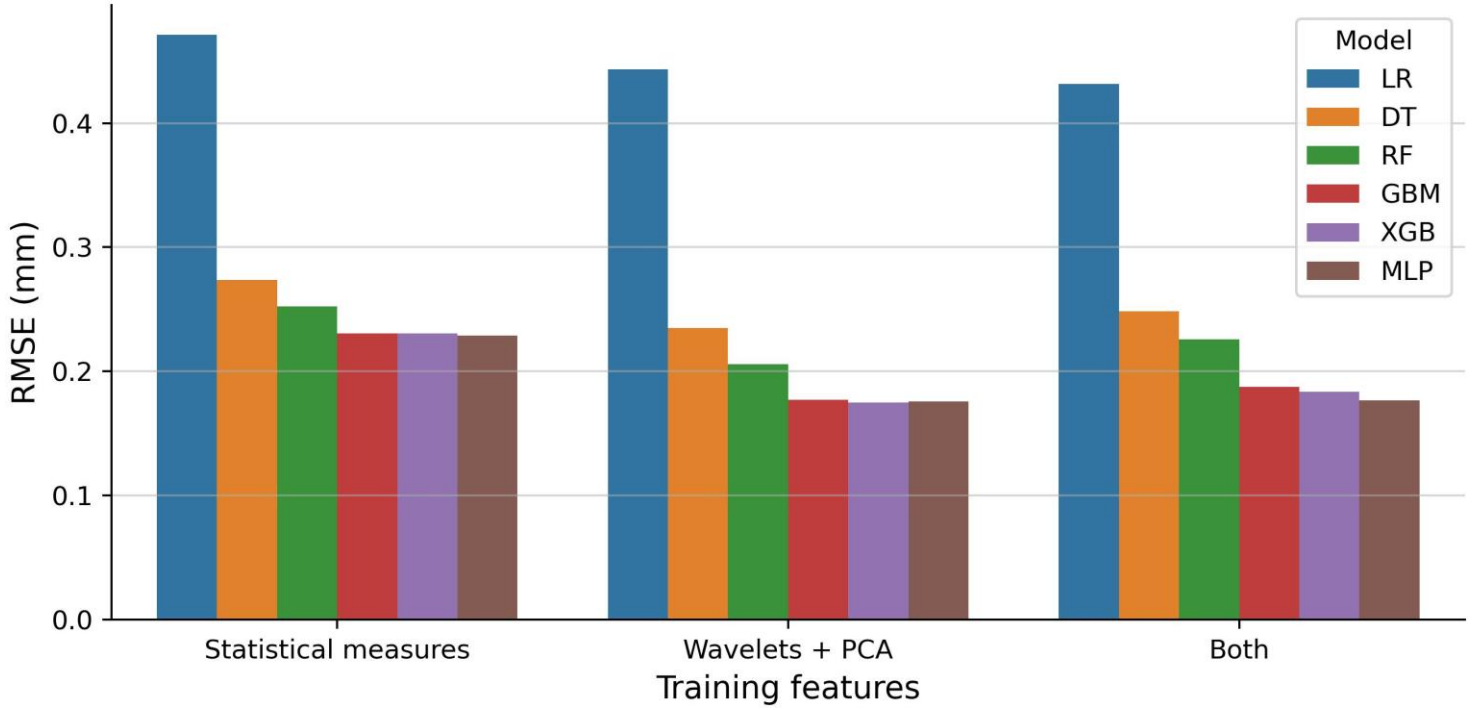
With data coming from the selected sensor configuration:

Train several baseline models: linear regression, Decision Tree, Random Forest, GBM, XGBoot and MLP

→ Use XGBoost because of its training speed



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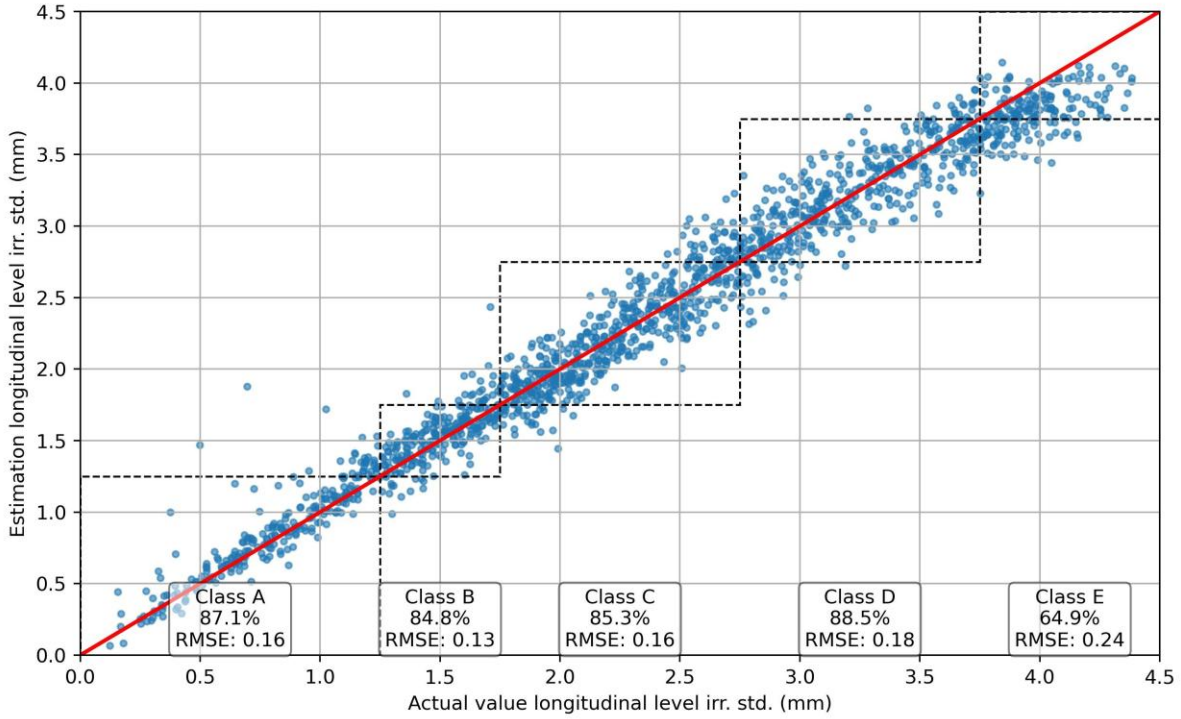
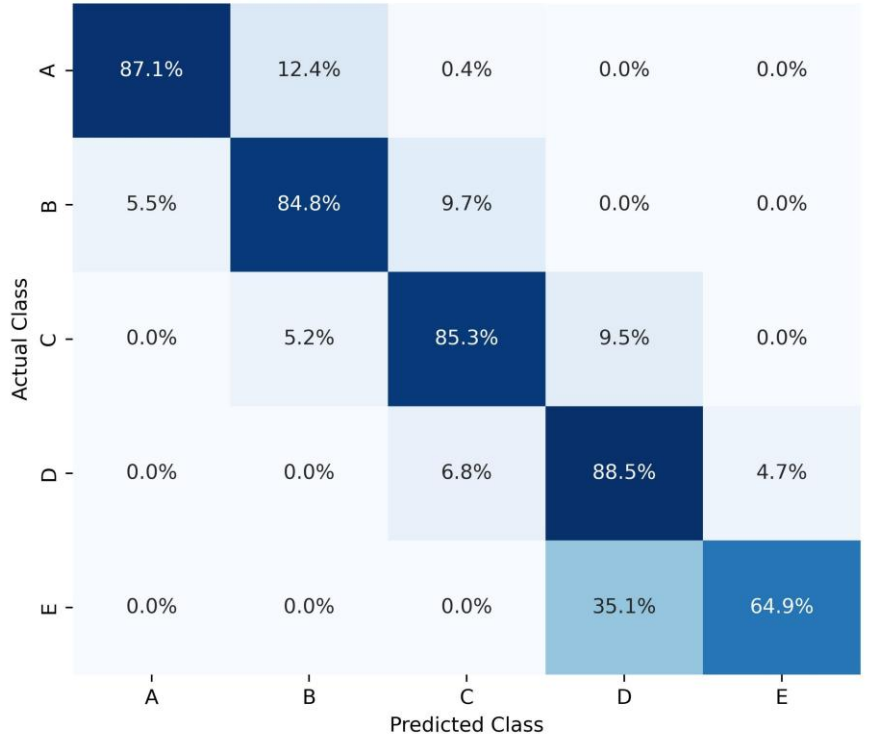
RMSE:
0,175 mm





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applied sciences

MDPI

Article

An Integrated Machine Learning and Optimization Framework for Railway Track Quality Assessment: Application to Longitudinal Level

Adrián Sansiñena [1,2,*], Borja Rodríguez-Arana [1,2] and Saioa Arrizabalaga [1,2,3]

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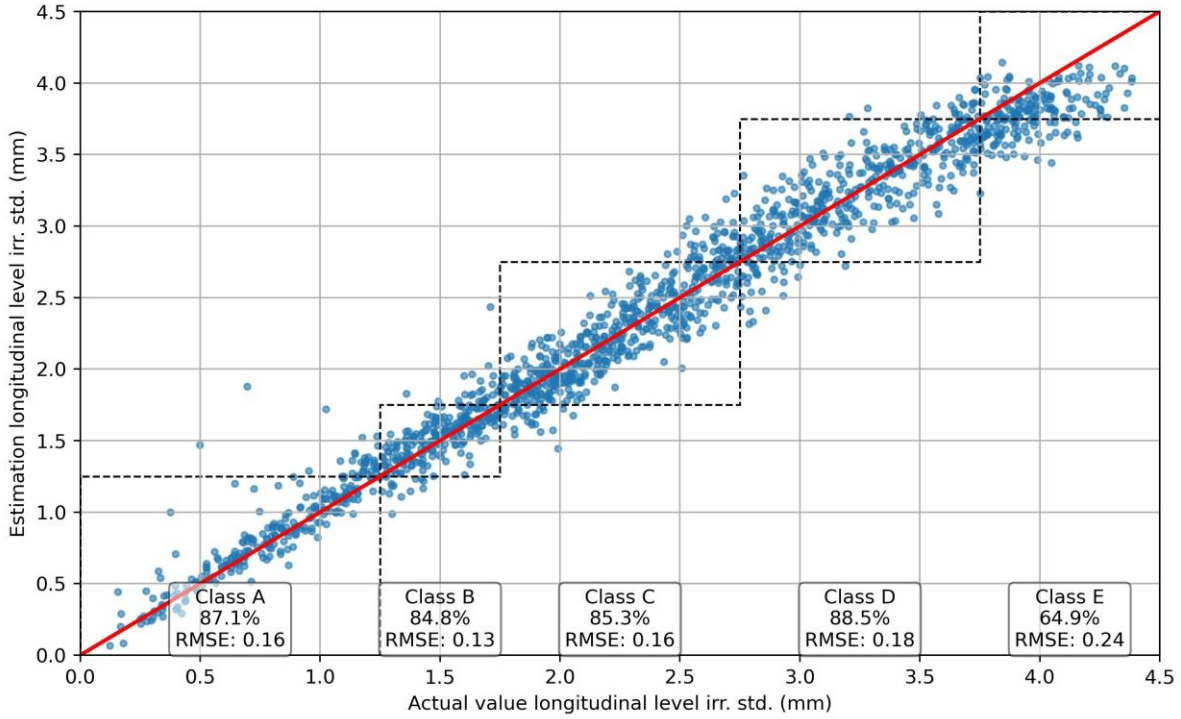
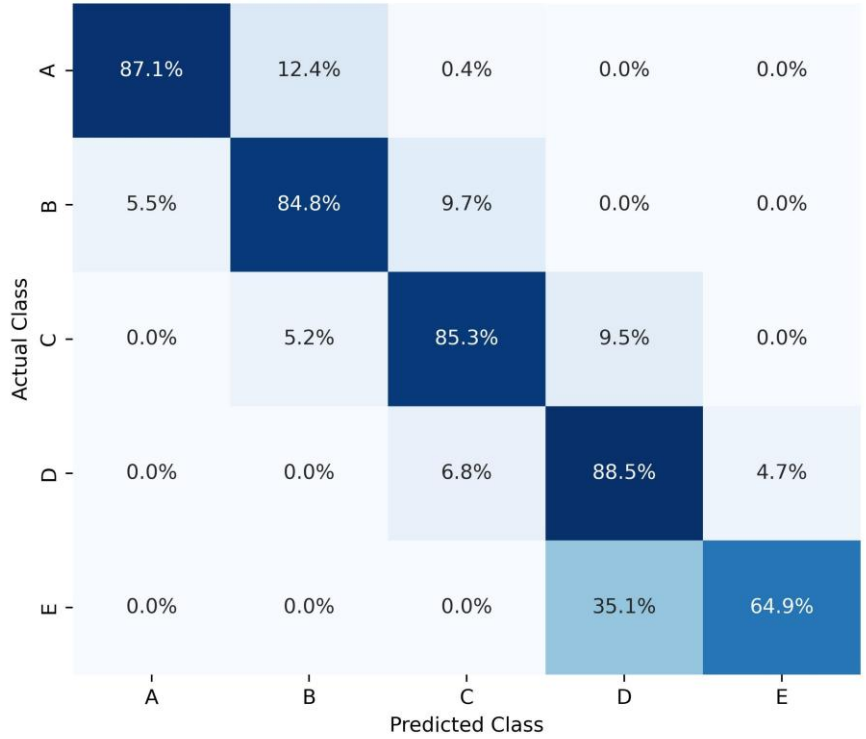




Alignment Quality Estimation

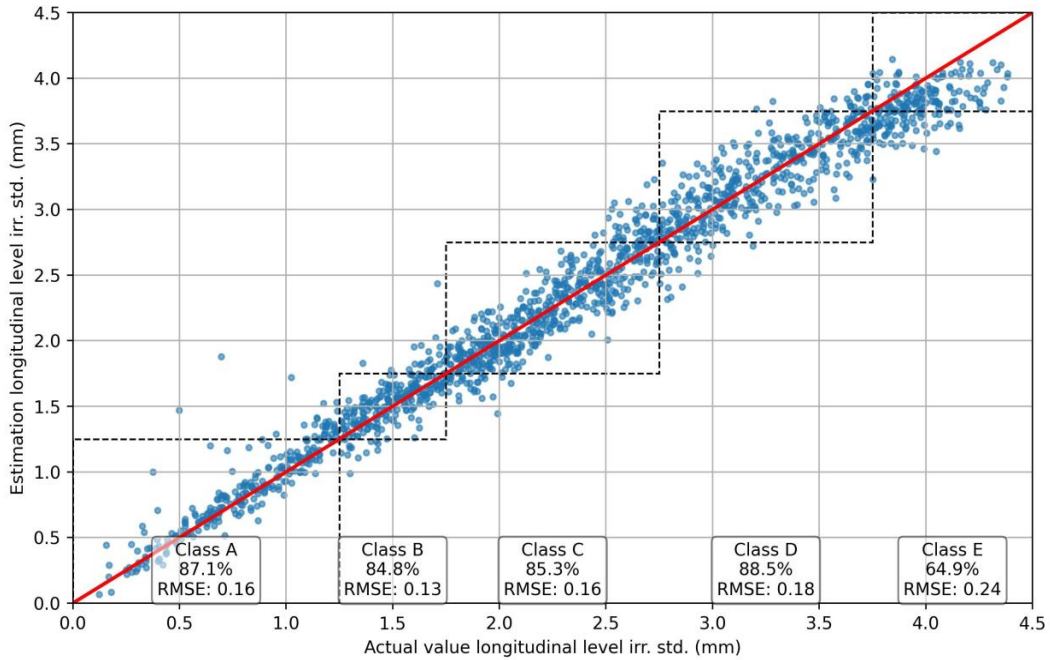
Longitudinal level

Vertical movement in consonance with vertical irregularities

Simpler dynamics

High correlation irregularities - accelerations

RMSE = 0,175 mm



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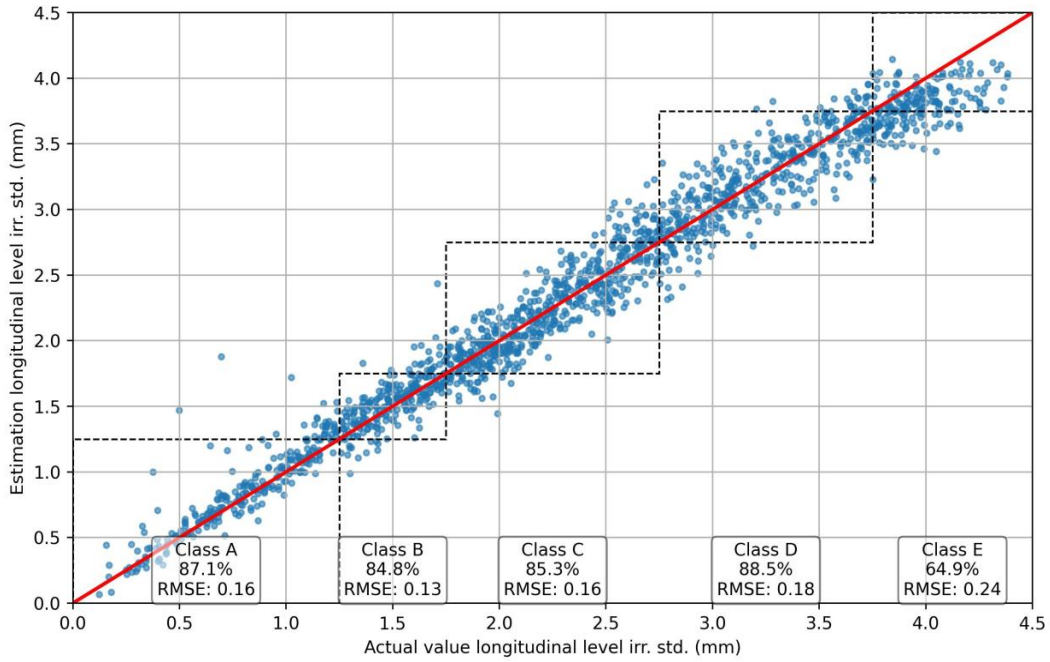

Alignment level

Wheels conicity

More complex dynamics

Low correlation irregularities - accelerations

Alignment Quality Estimation

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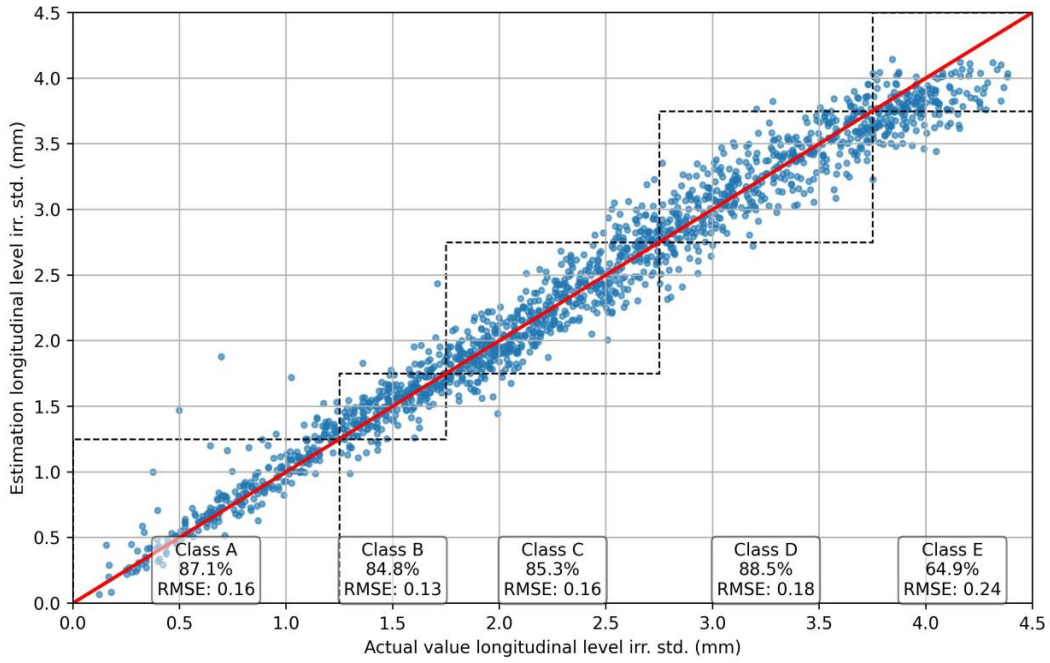

Alignment level

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More complex dynamics

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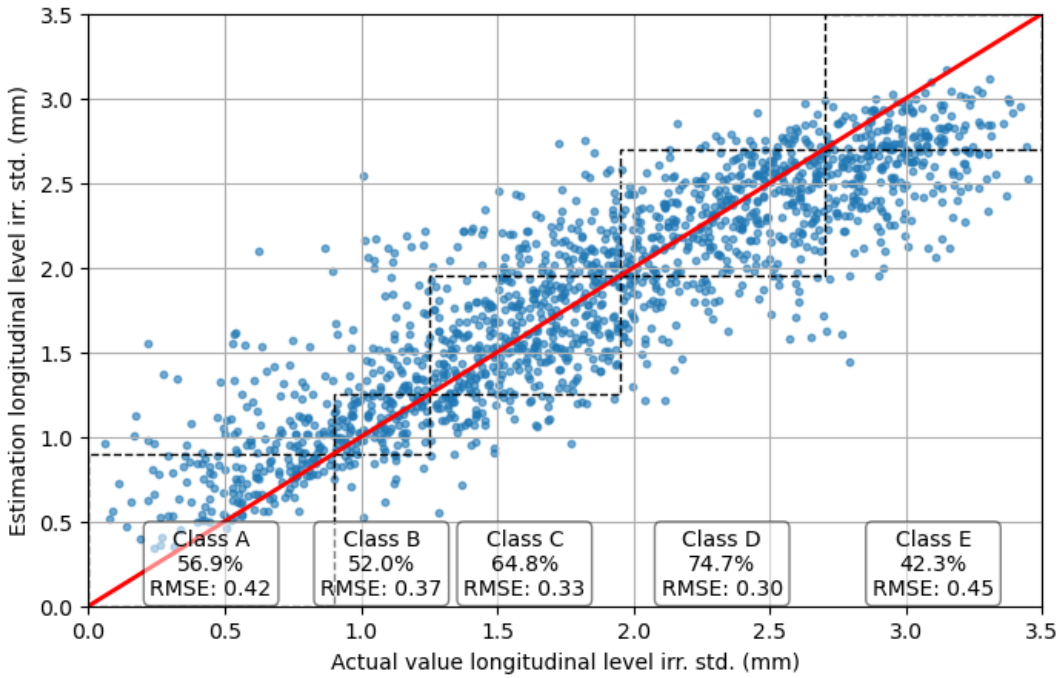
RMSE = 0,360 mm



Alignment Quality Estimation

New methodology implementation is required:

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~~Features~~

Wavelet Spectra

~~ML models for tabular data~~

Deep Learning

Alignment Quality Estimation

New methodology implementation is required:

~~Features~~

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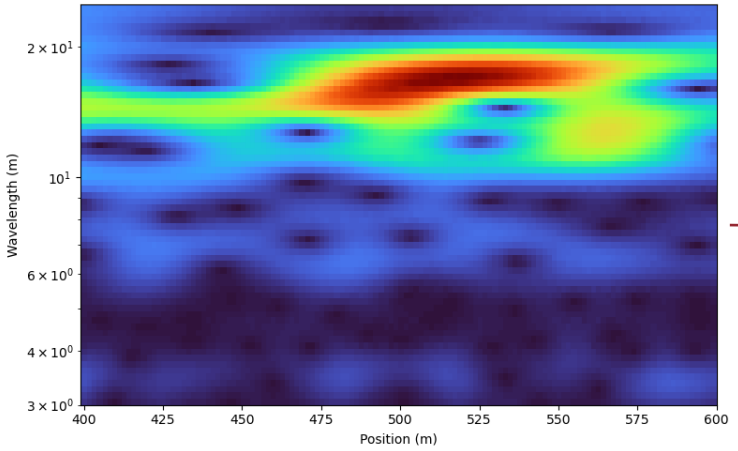
~~ML models for tabular data~~

Deep Learning

Wavelets (one channel per sensor)



1-2 Conv. layers
- Local patterns
- Short-range structure

Bi-LSTM
- Spatial dependency
- Sequence context
- Long-range dynamics

Fully Connected Regression Head

Track quality estimation

Vehicle speed

Alignment Quality Estimation

Sensor selection:

! Not a specific adaptation yet.

Similar to longitudinal level case: XGBoost and features

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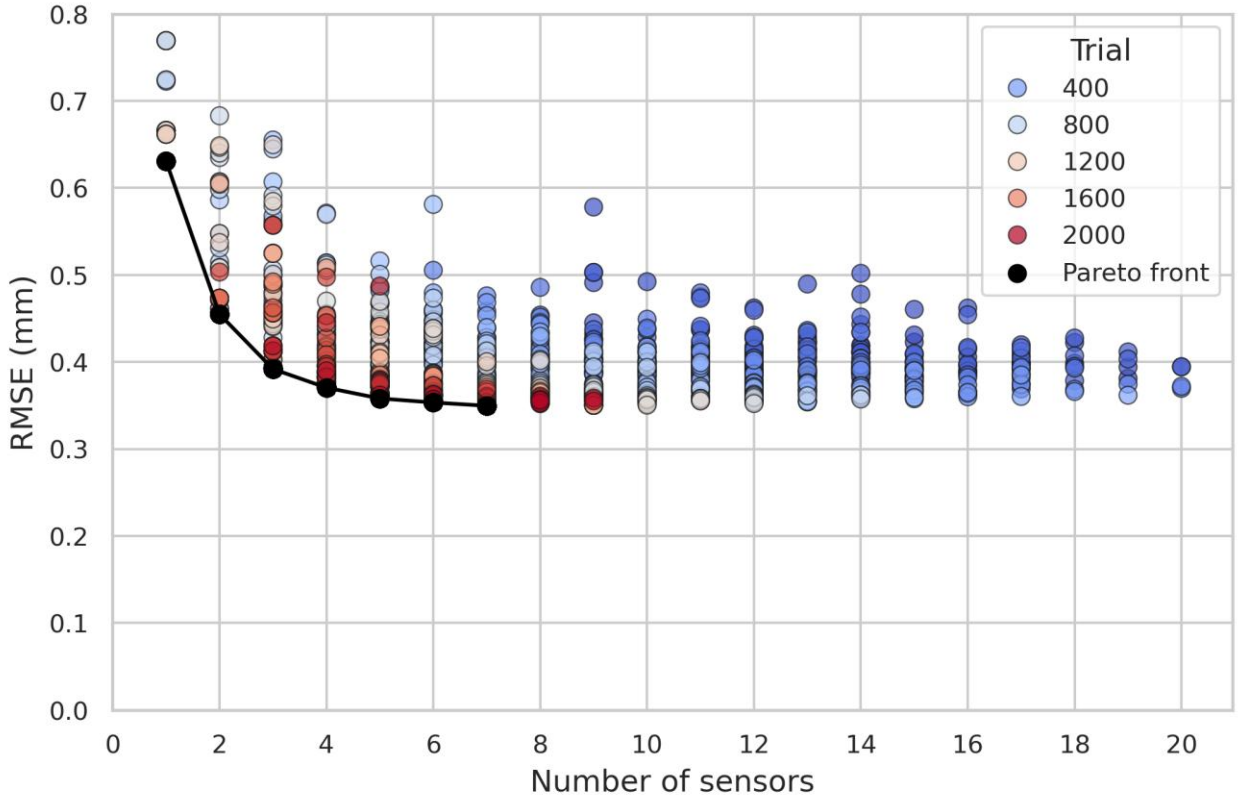

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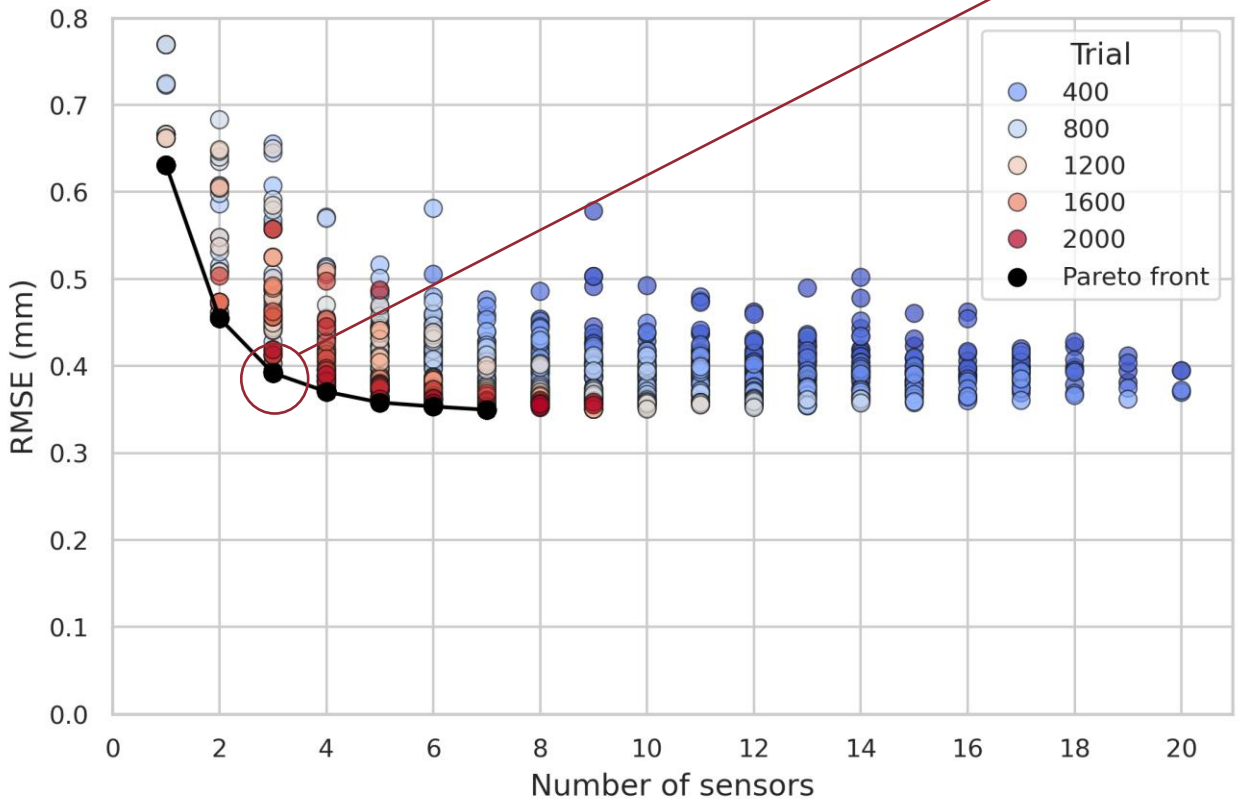
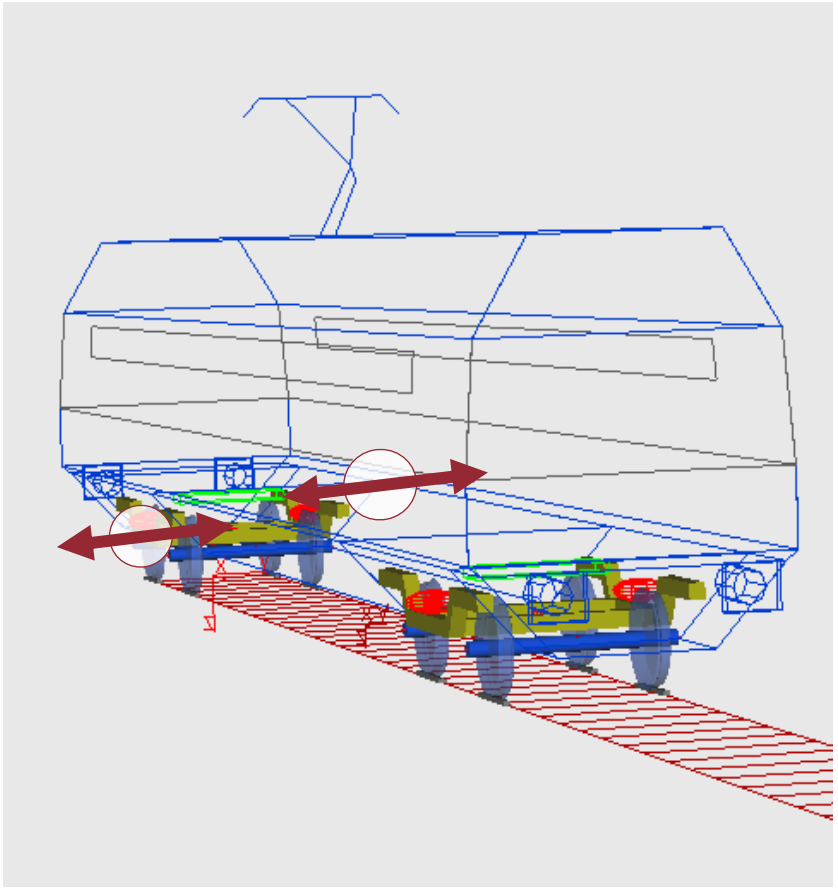


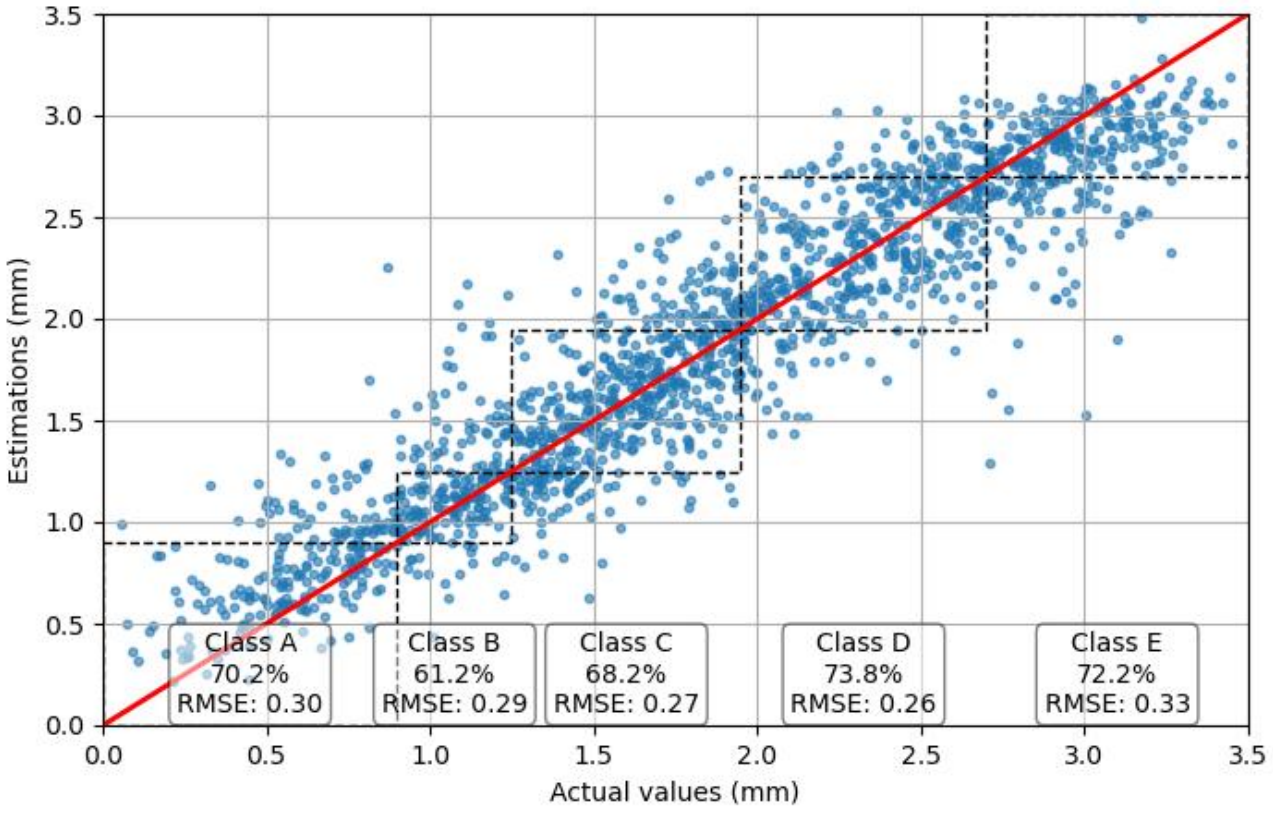
Train speed
Acc. Lateral Rear Bogie
Acc. Lateral Center of Car-Body

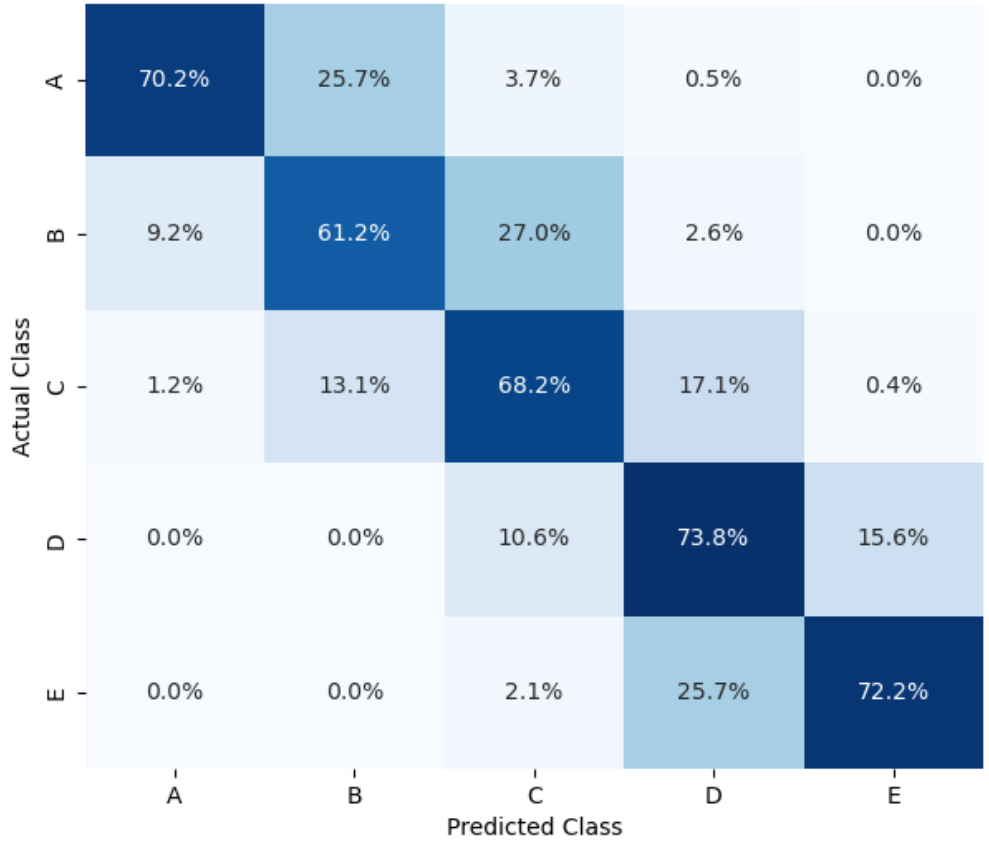


Alignment Quality Estimation

Track Quality Estimation:

3 sensors combination: RSME = 0,29 mm

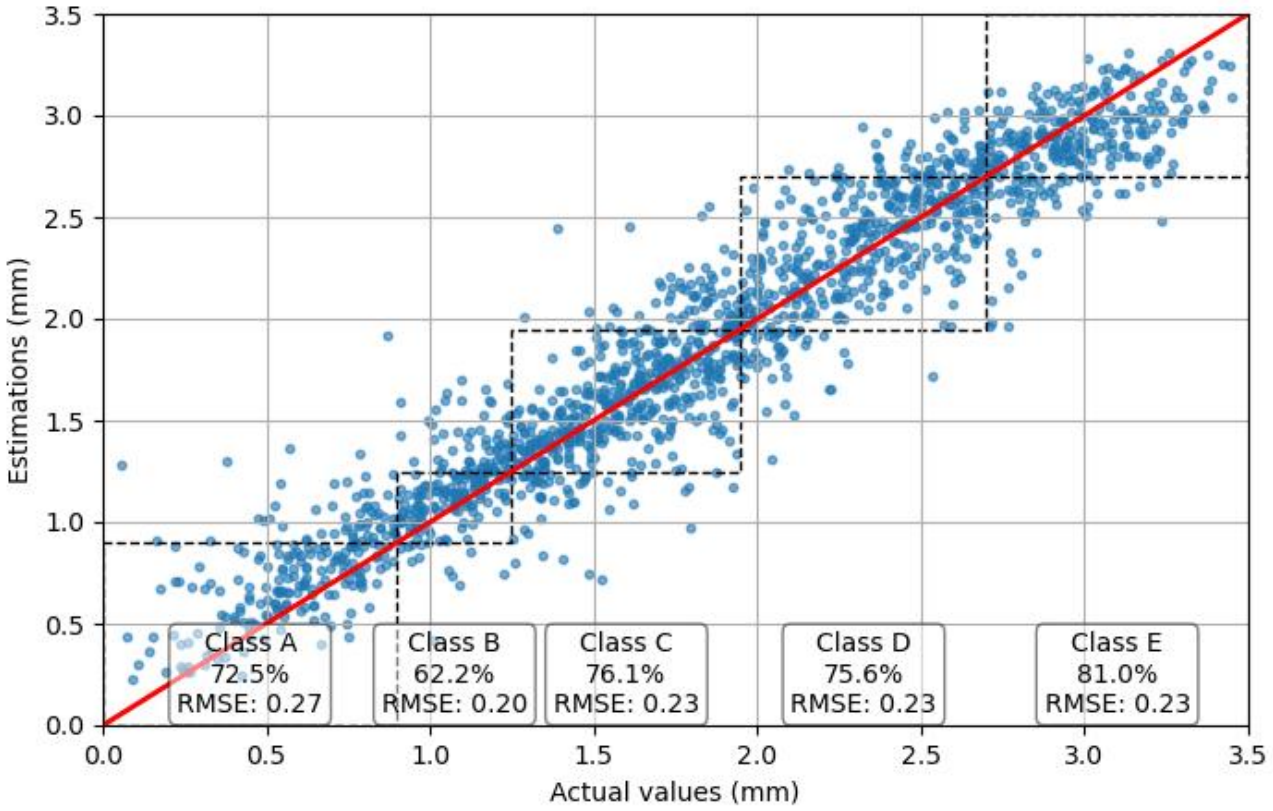


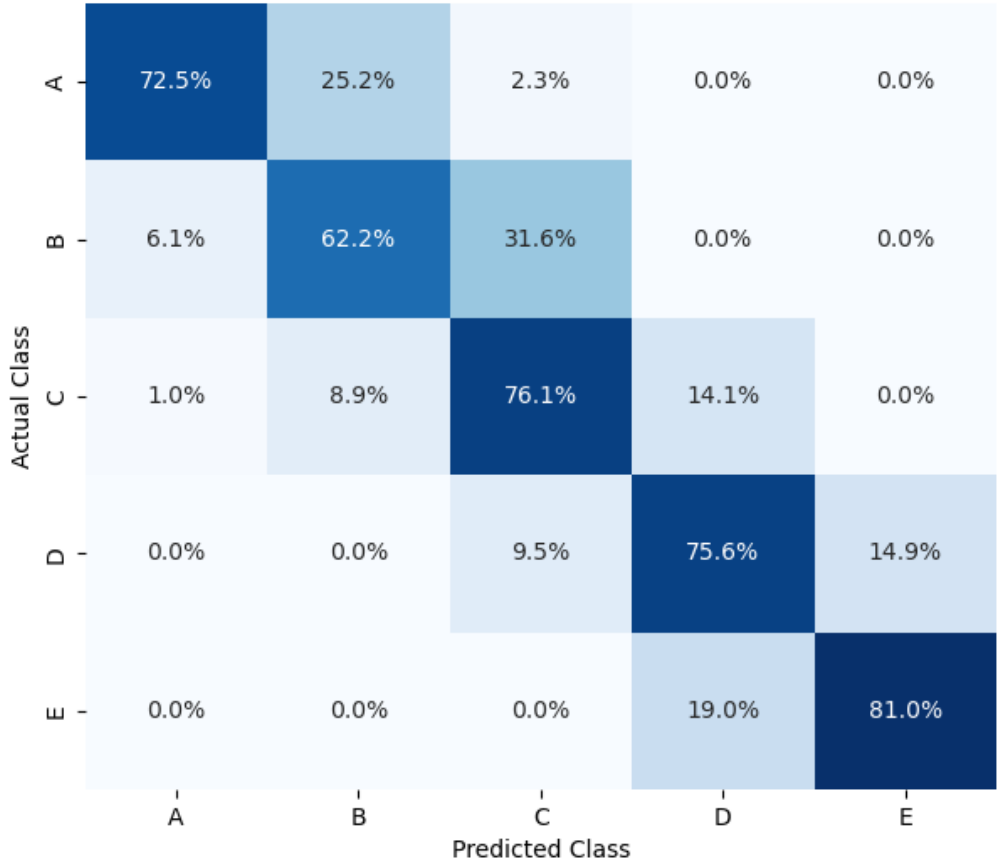


Alignment Quality Estimation

Track Quality Estimation:

5 sensors combination: RSME = 0,23 mm





Conclusions and Next Steps

Conclusions

- General and modular systematic methodology leveraging simulations
- Focus on sensor selection
- Longitudinal level: mature and validated
- Alignment: harder, richer, more interesting

Conclusions and Next Steps

Conclusions

- General and modular systematic methodology leveraging simulations
- Focus on sensor selection
- Longitudinal level: mature and validated
- Alignment: harder, in progress

Next Steps

- Alignment estimation:
  - Model refinement.
  - Integration with sensor selection.
  - Physical-mechanical interpretation of the results.
- Transfer learning to other environments with scarce data.
- Ideally, validation on real data.

Thank you for your attention!

Funded by the European Union. Views and opinion expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Europe's Rail Joint Undertaking. Neither the European Union nor the the granting authority can be held responsible for them. The FP1-MOTIONAl and FP1-IAM4Rail projects are supported by the Europe's Rail joint undertaking and its members.