Health of Railway Infrastructure Based on AI

Estimating the railway track quality using a Machine Learning approach

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2. Objective
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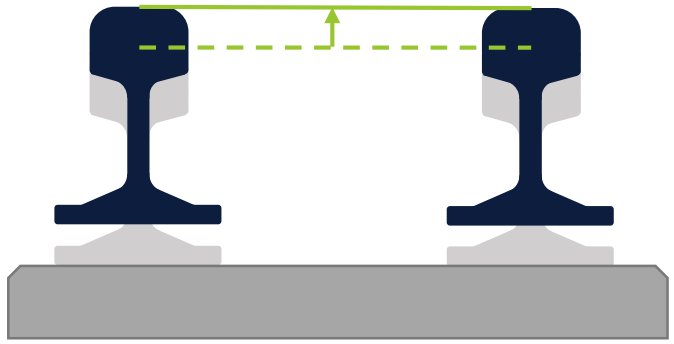
Introduction: Railway Track Quality

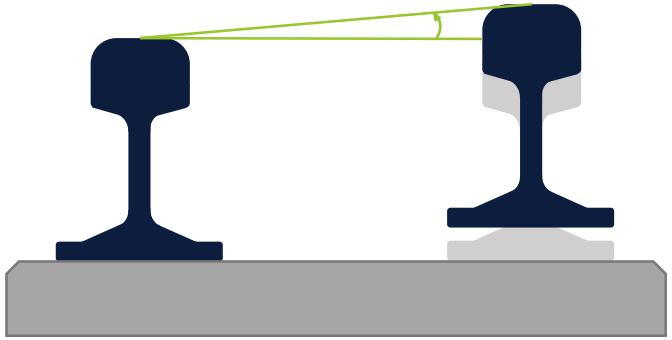
Track Irregularities: Geometric deviation from the original design.

Vertical irregularities

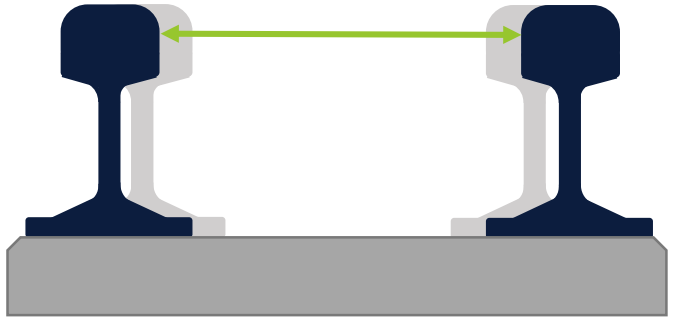


Lateral irregularities

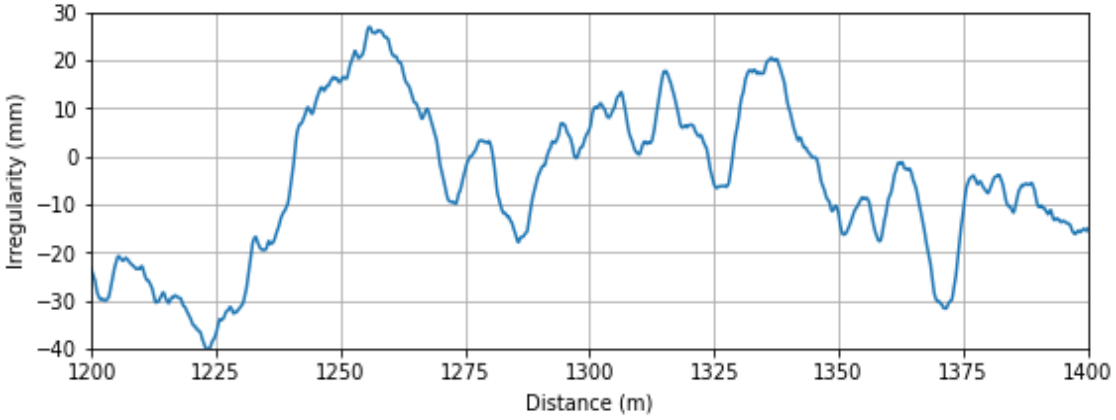
Cross-level irregularities

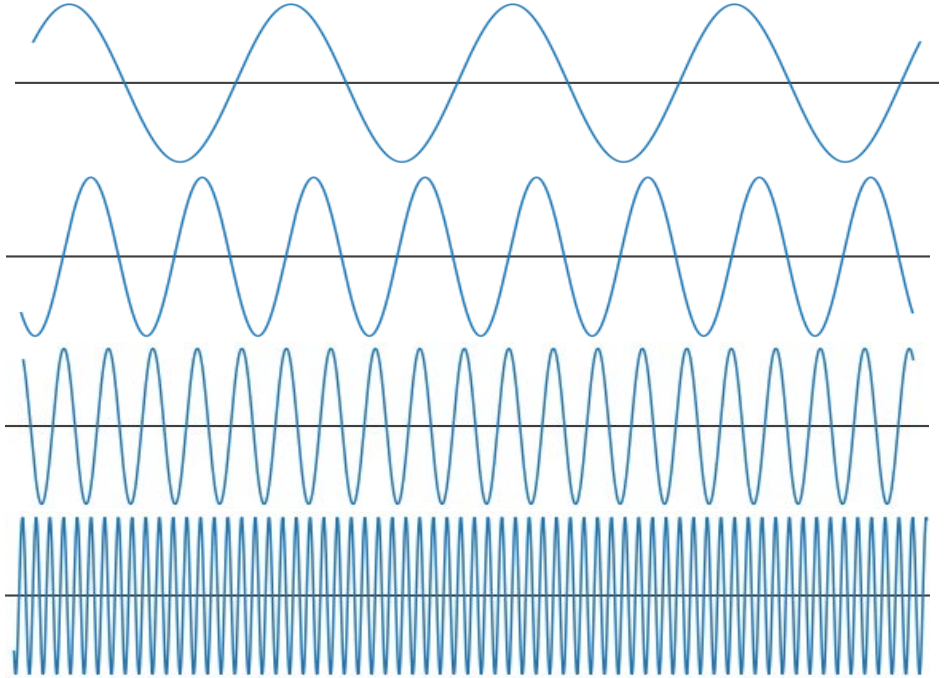


Gauge irregularities

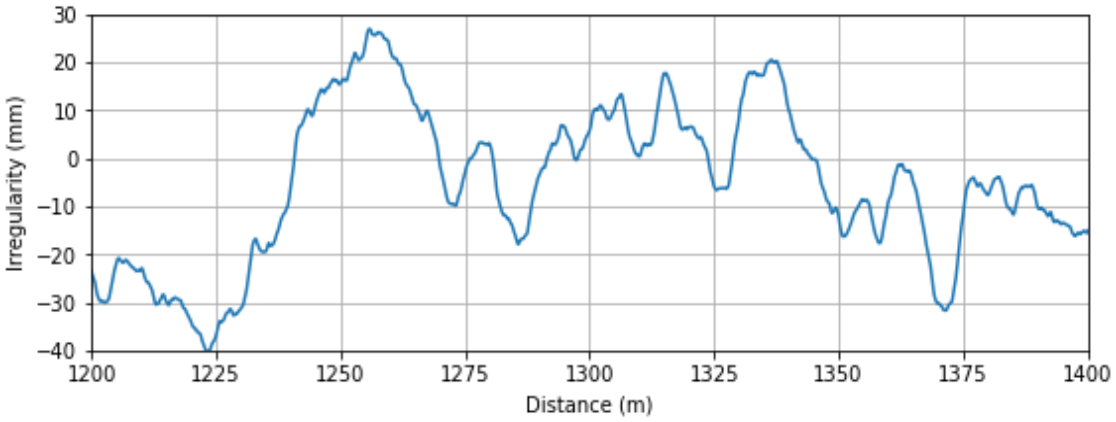


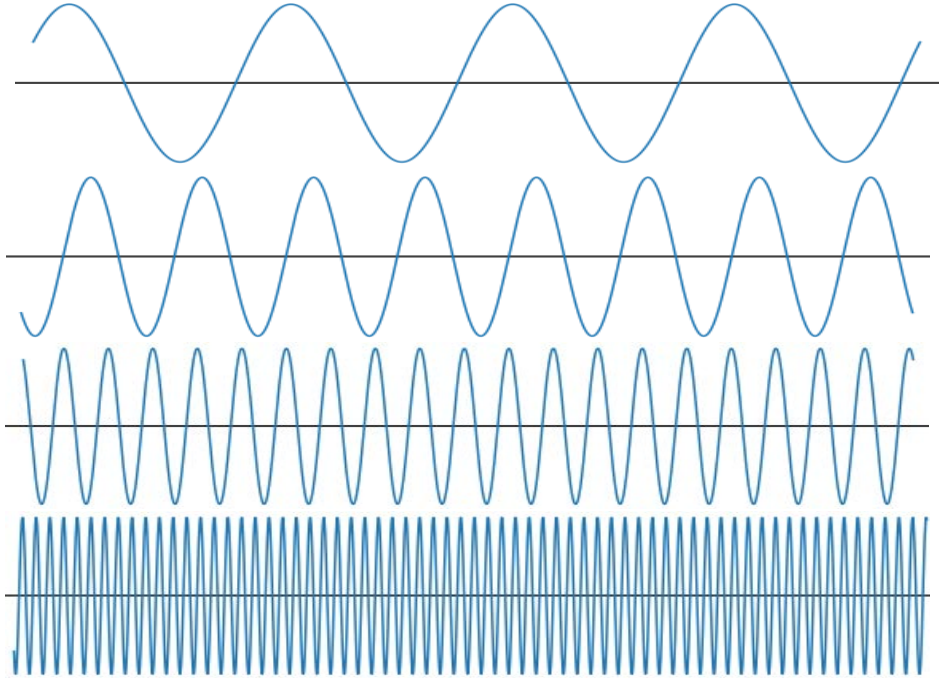
Introduction: Railway Track Quality





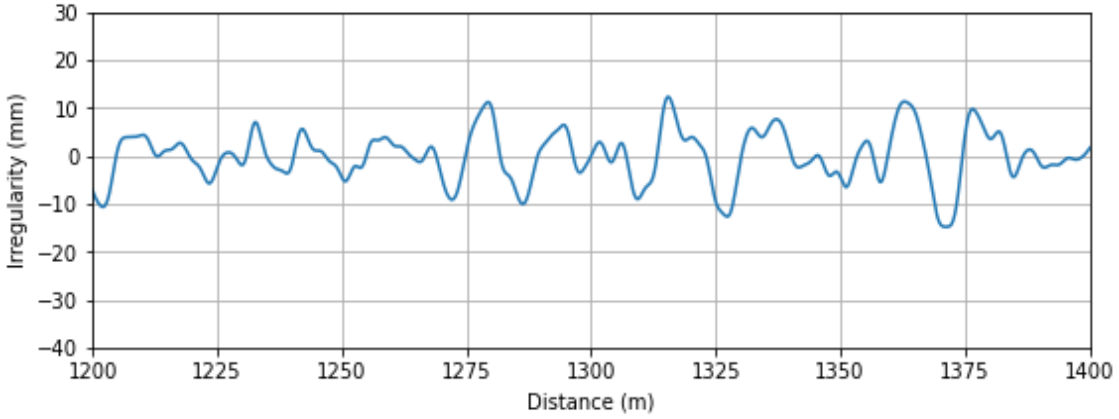
Introduction: Railway Track Quality

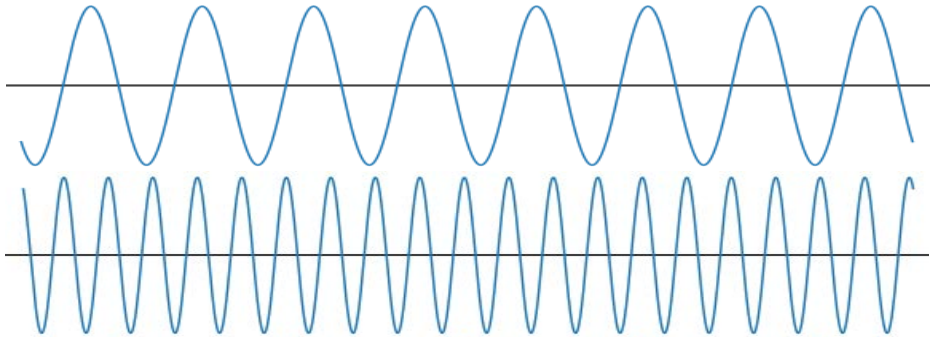




- Focus on relevant wavelengths for running safety:

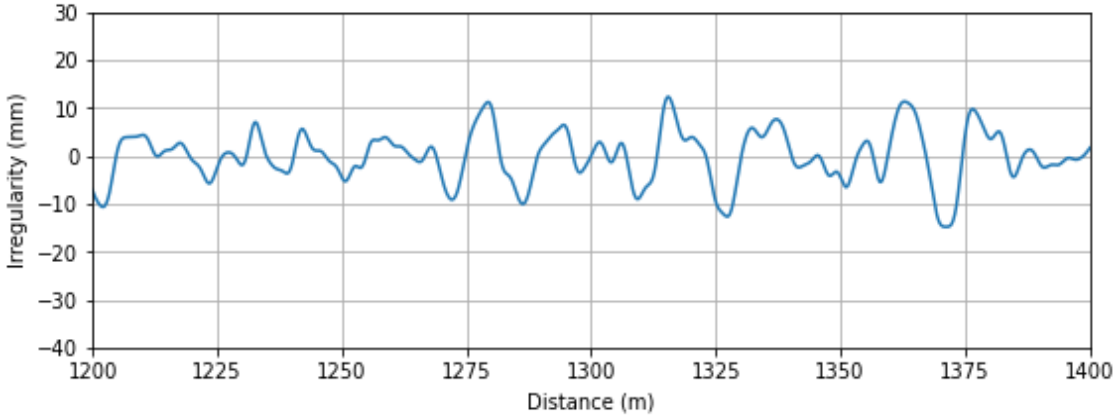
Introduction: Railway Track Quality

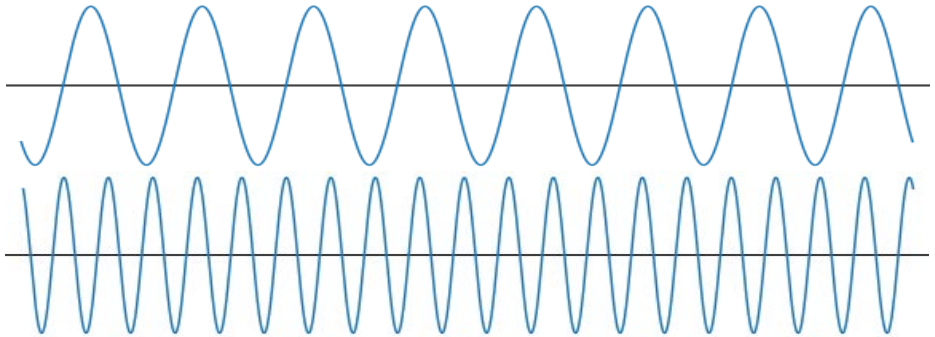




- Focus on relevant wavelengths for running safety: 3 m ⟷ 25 m (D1 range)

Introduction: Railway Track Quality





- Focus on relevant wavelengths for running safety: 3 m ⟷ 25 m (D1 range)
- Several different ways to define “track quality”

European standard EN 13848-6:

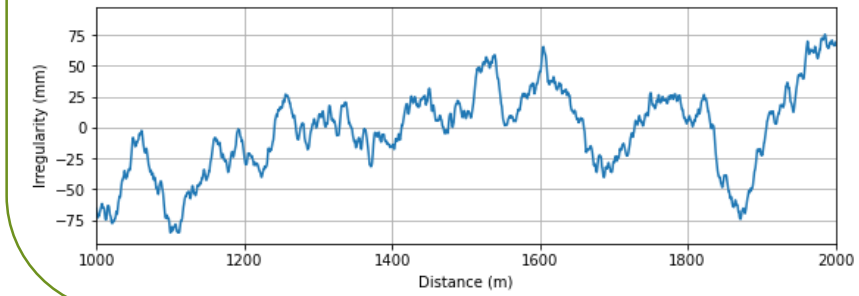
- Standard deviation of lateral and vertical irregularities
- 200 m sections
- Velocity of vehicles

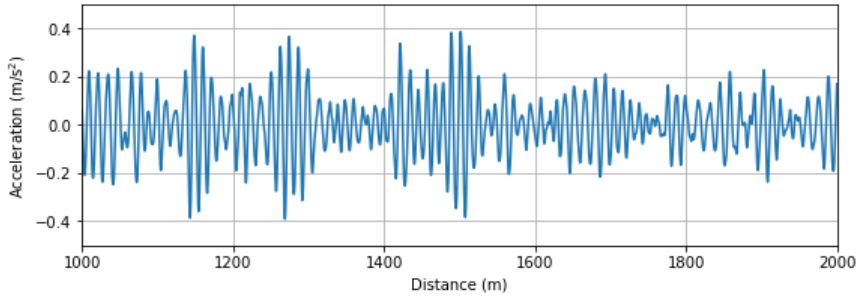
Objective: Track quality measurement

Measurement

https://www.euskotren.eus/es

Accelerometers



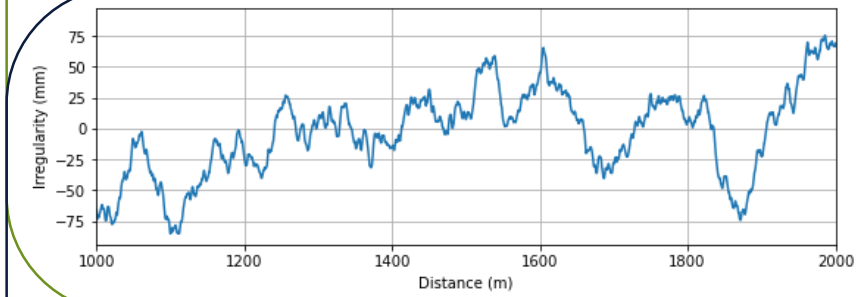


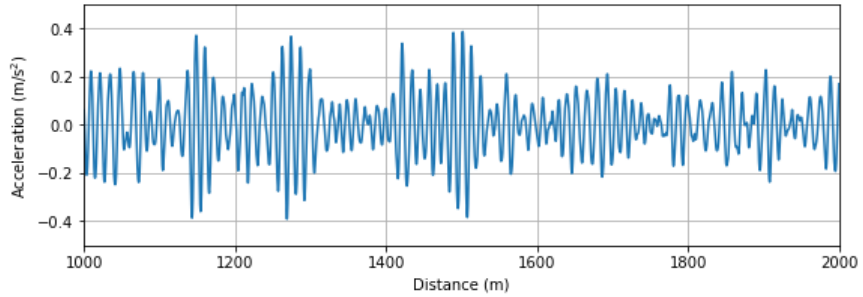
Objective: Track quality measurement

Measurement

https://www.euskotren.eus/es

Accelerometers





AI-Based Track Quality Estimation System

Estimation

Objective: Track quality measurement

Objective: Estimation of track quality from on-board acceleration measurements

Key points:

- Origin of data
- Sensors position
- Signal processing
- Algorithms applied for track quality estimation

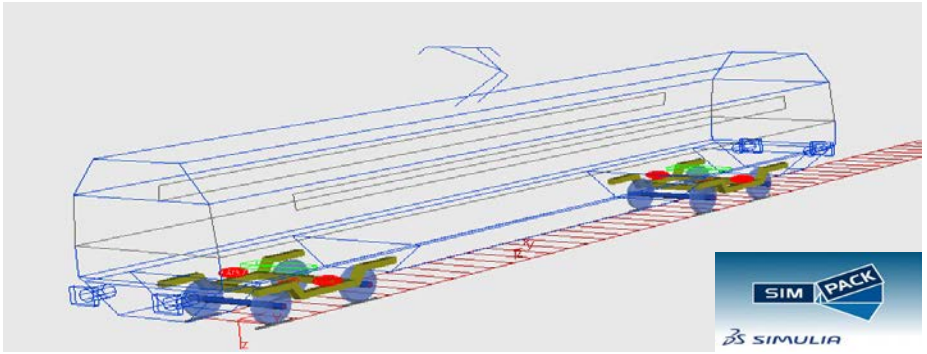
Origin of data

https://www.euskotren.eus/es

Real world data

+ Responses from a real train
+ Validation in conditions the methodology will be applied

- Homogeneity of data
- Not always available



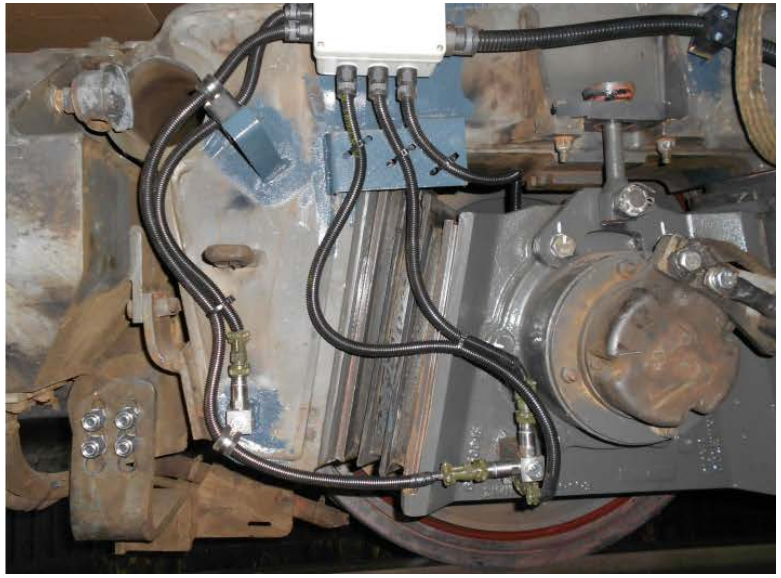
Simulation data

+ Data generation in controlled scenarios
+ Wider range of variables

- Need validation
- Methodologies should be adapted to the real system before being applied

Accelerometers position

Axle box



Chudzikiewicz et al. (2018).

Short wavelengths
Sensor range ±100 g and ~5 kHz

Bogie

Zanelli et al. (2023).

Primary suspension filter
Sensor range ±10 g and ~500 Hz

Car body

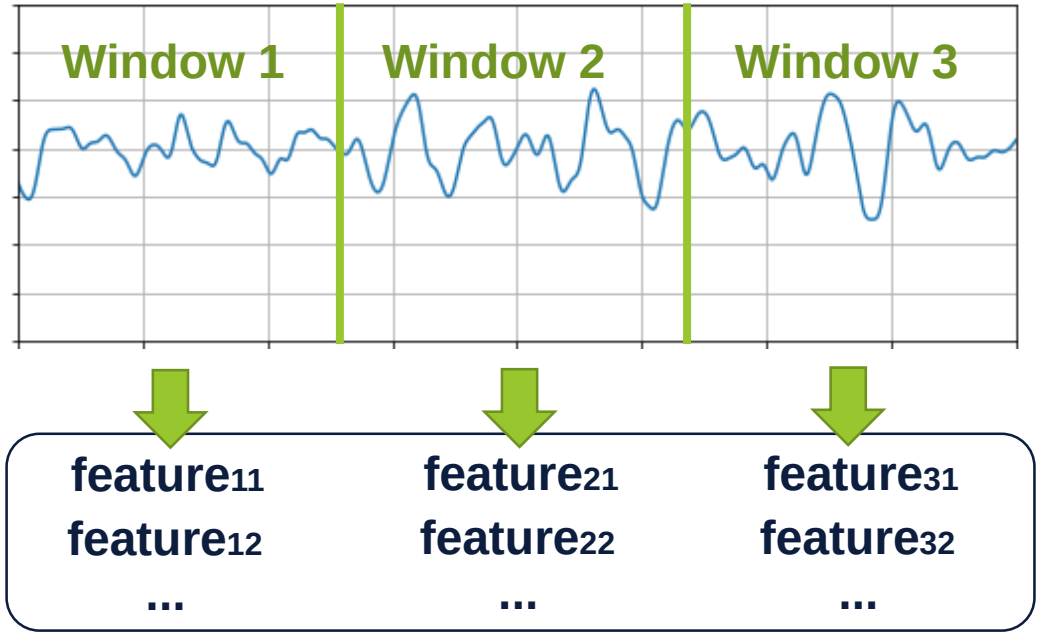
Odashima et al. (2017).

Secondary suspension filter
Sensor range ±2 g and ~250 Hz

Signal processing

- Integration and double integration
- Kalman filters
- High/Low pass filters

- Feature engineering:

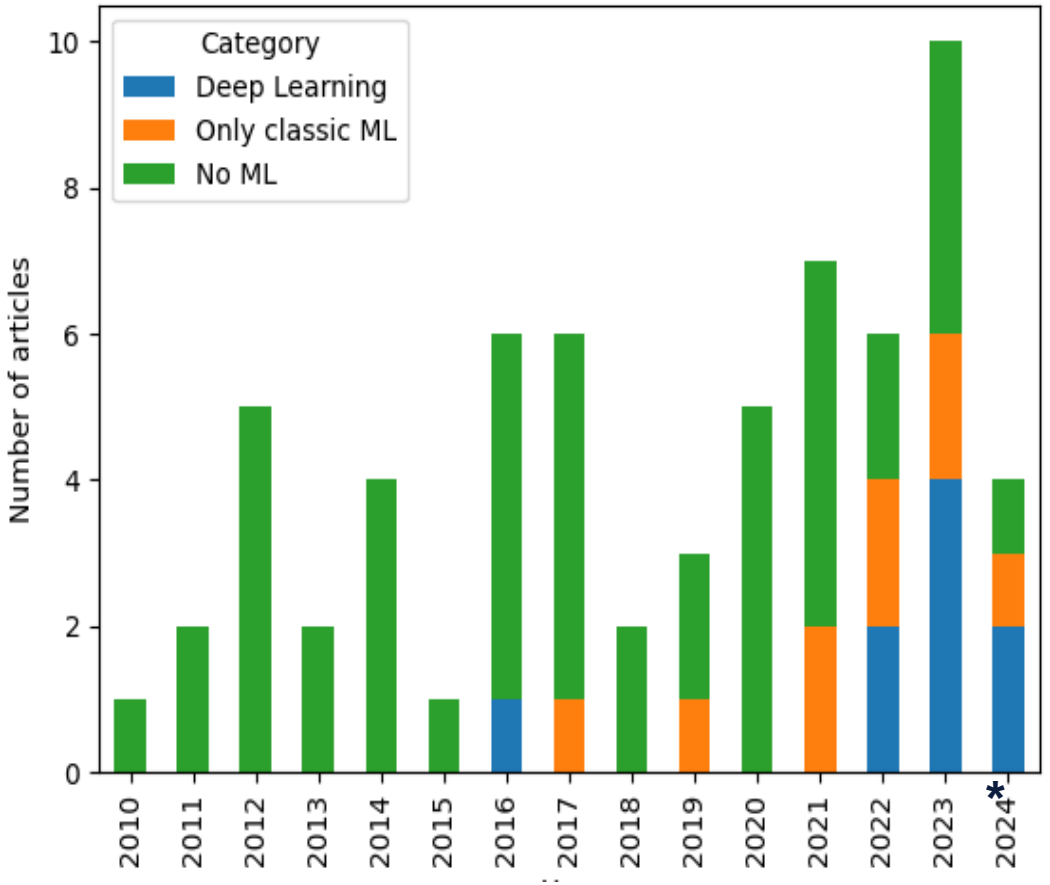


Signal processing will depend on the algorithms to be used and the objectives.

Train ML models

Design track quality indicators

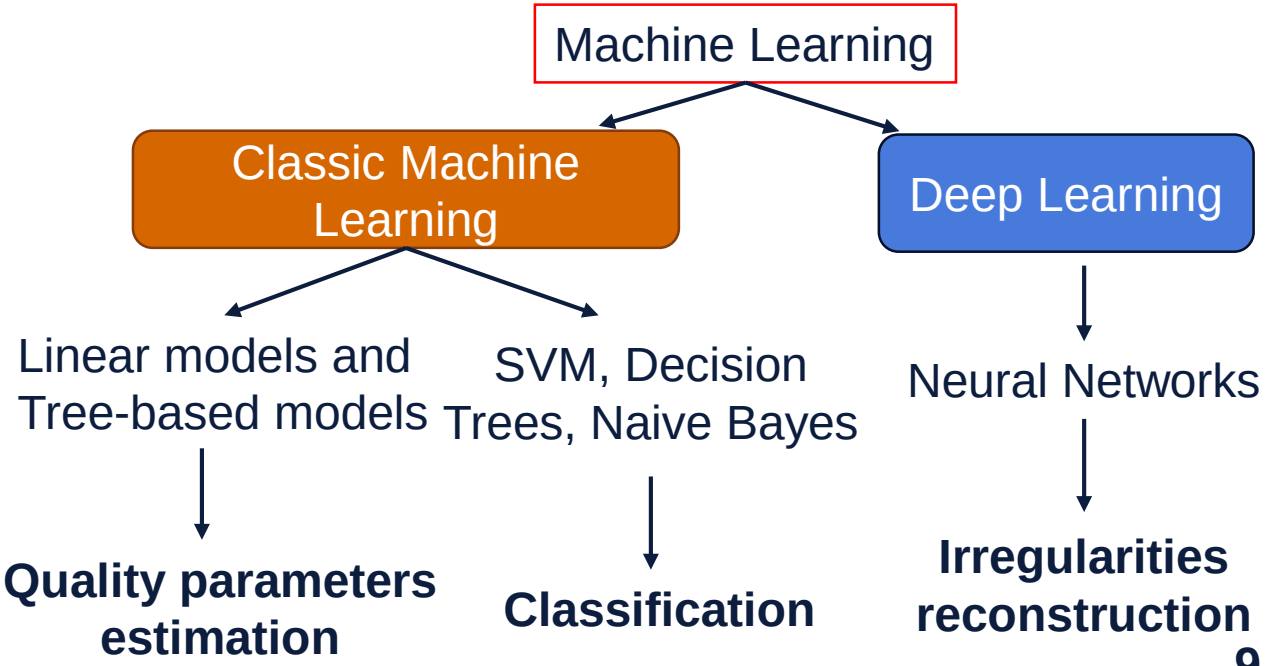
Algorithms for track quality assessment



*Publications until June 2024

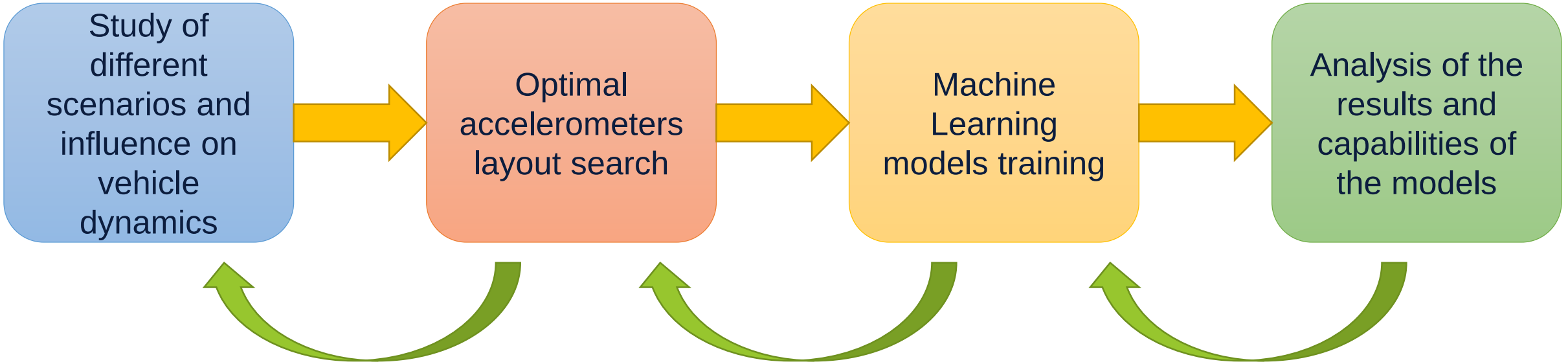
Common no-ML approaches:

- Double integration of accelerations in axle box
- Kalman filters
- Inversion of a mechanistic model



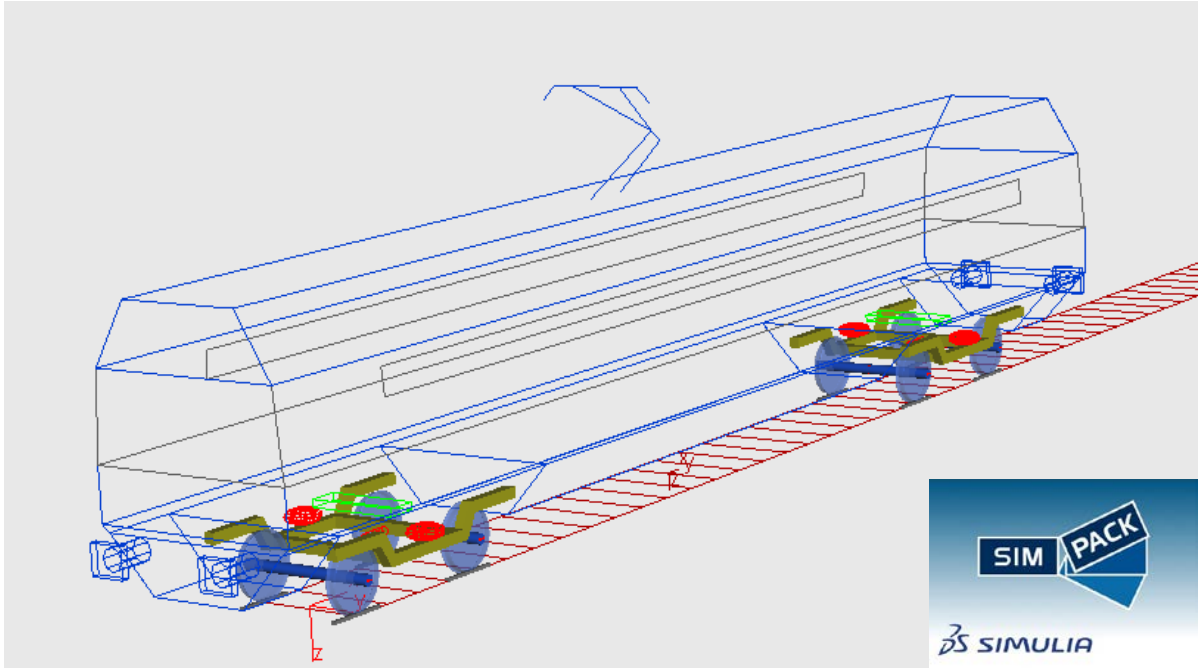
Methodology

Goal: Estimation of the standard deviation of vertical and lateral irregularities in sections of 200 m.



Simulations model

- Multibody simulations in SIMPACK software
- Passenger car with several acceleration sensors



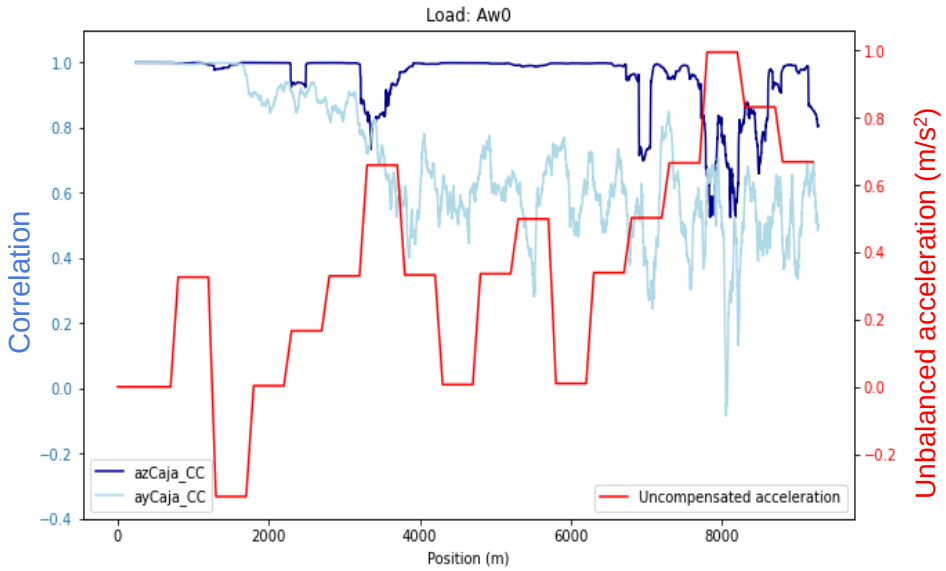
- Random irregularities are generated from PSD
- Model parameters studied so far:

Track irregularities level,
velocity, track design, load,
friction coefficient and wheels wear level

Influence of variables on vehicle dynamics

Analysis of:

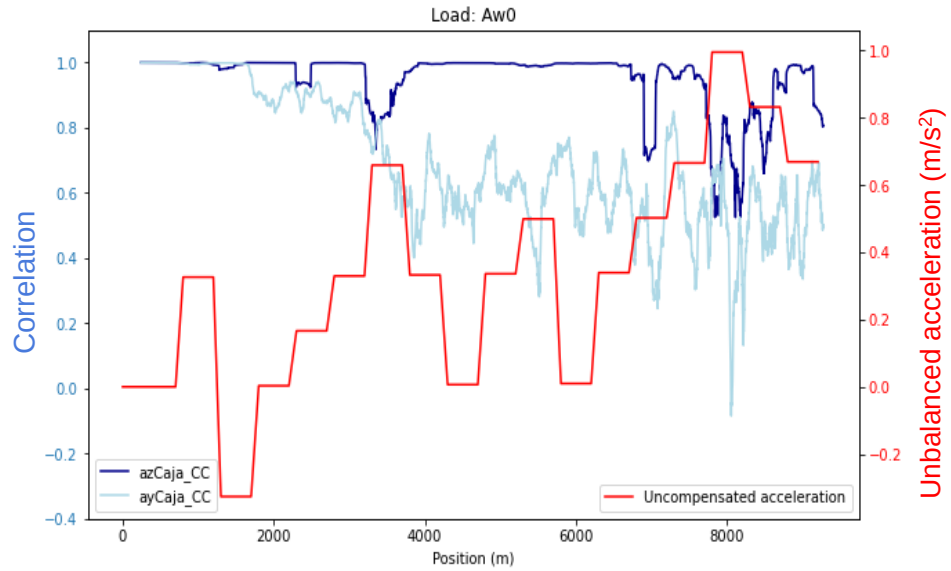
Changes in acceleration signals

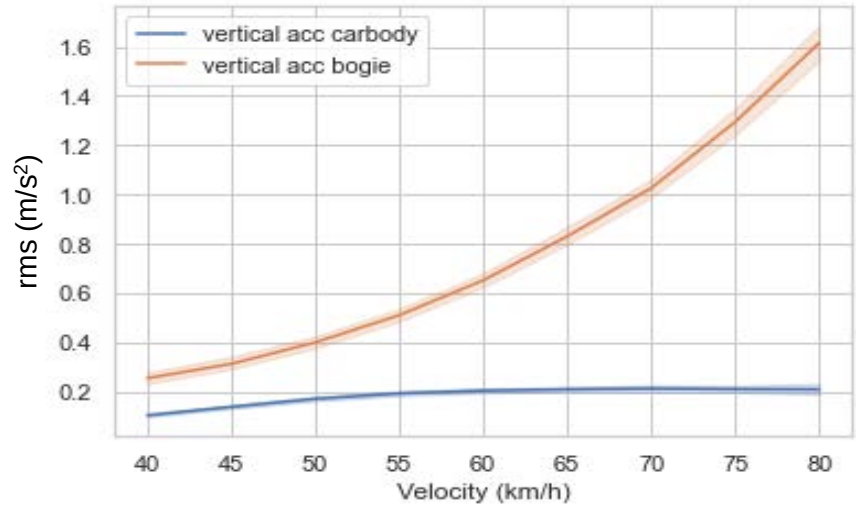


Influence of variables on vehicle dynamics

Analysis of:

- Changes in acceleration signals
- Variability of extracted features

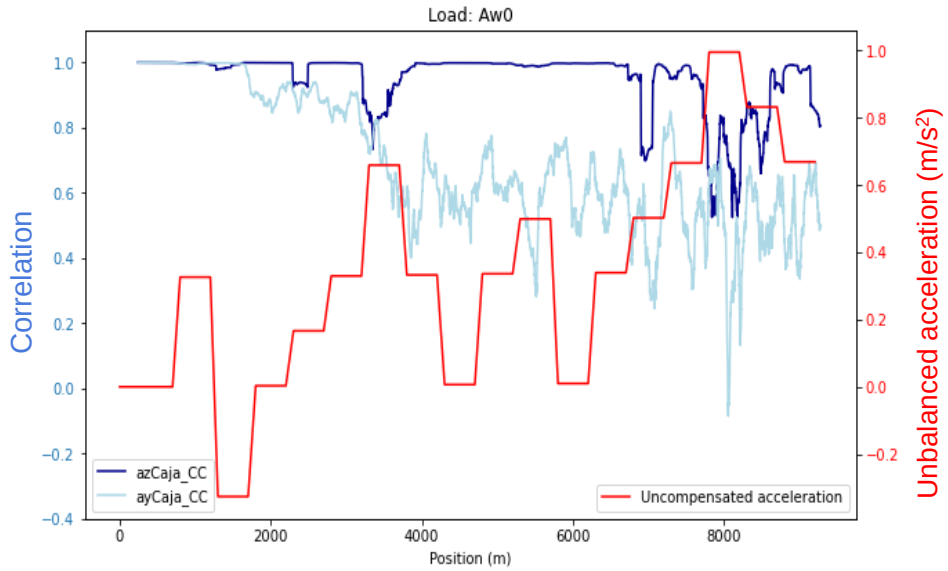




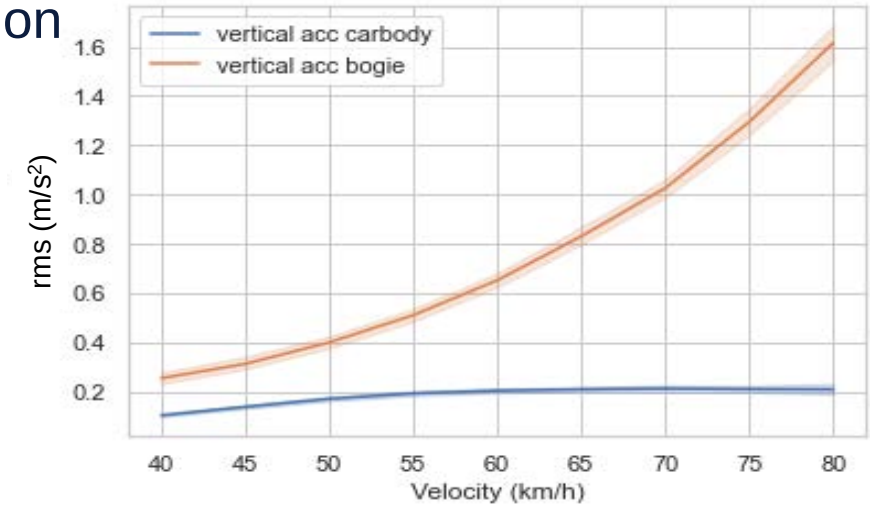
Influence of variables on vehicle dynamics

Analysis of:

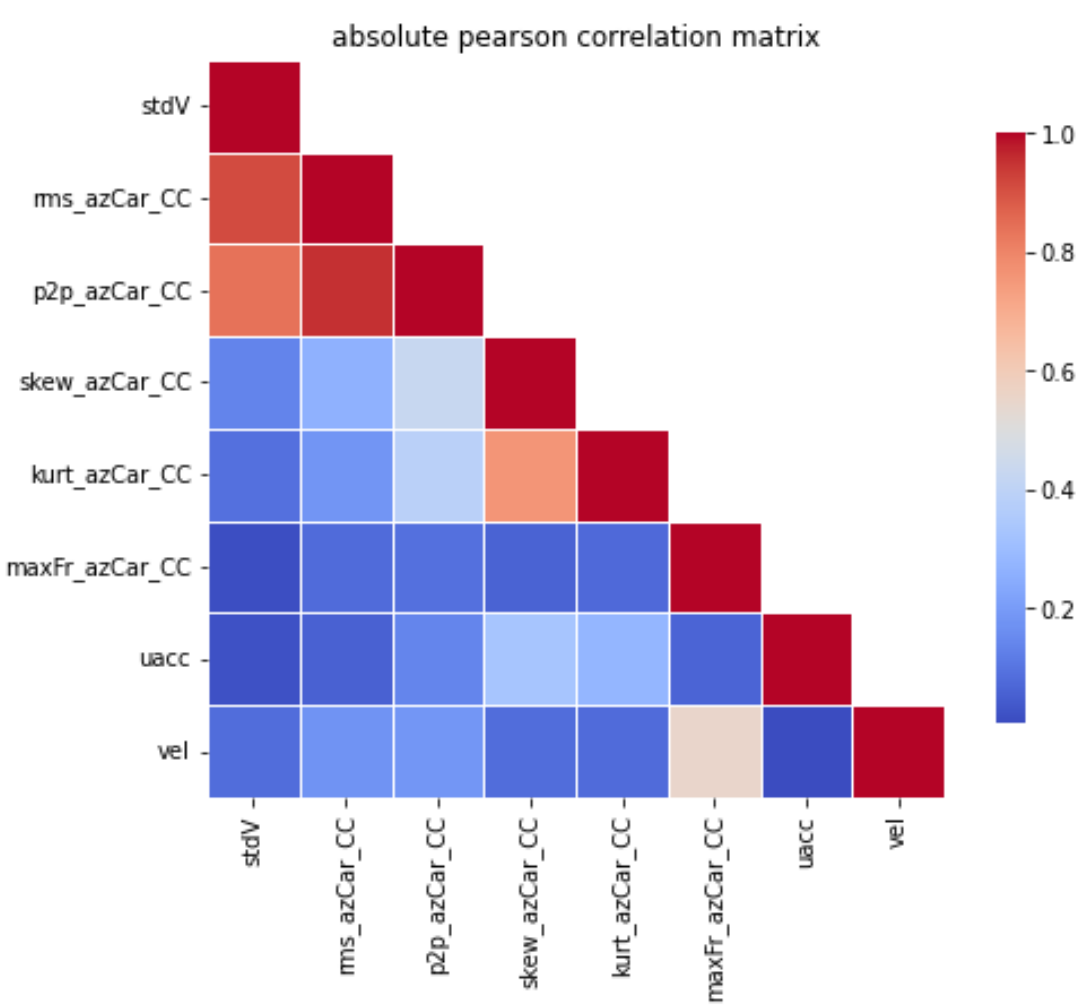
- Changes in acceleration signals
- Variability of extracted features
- Sensitivity of trained models

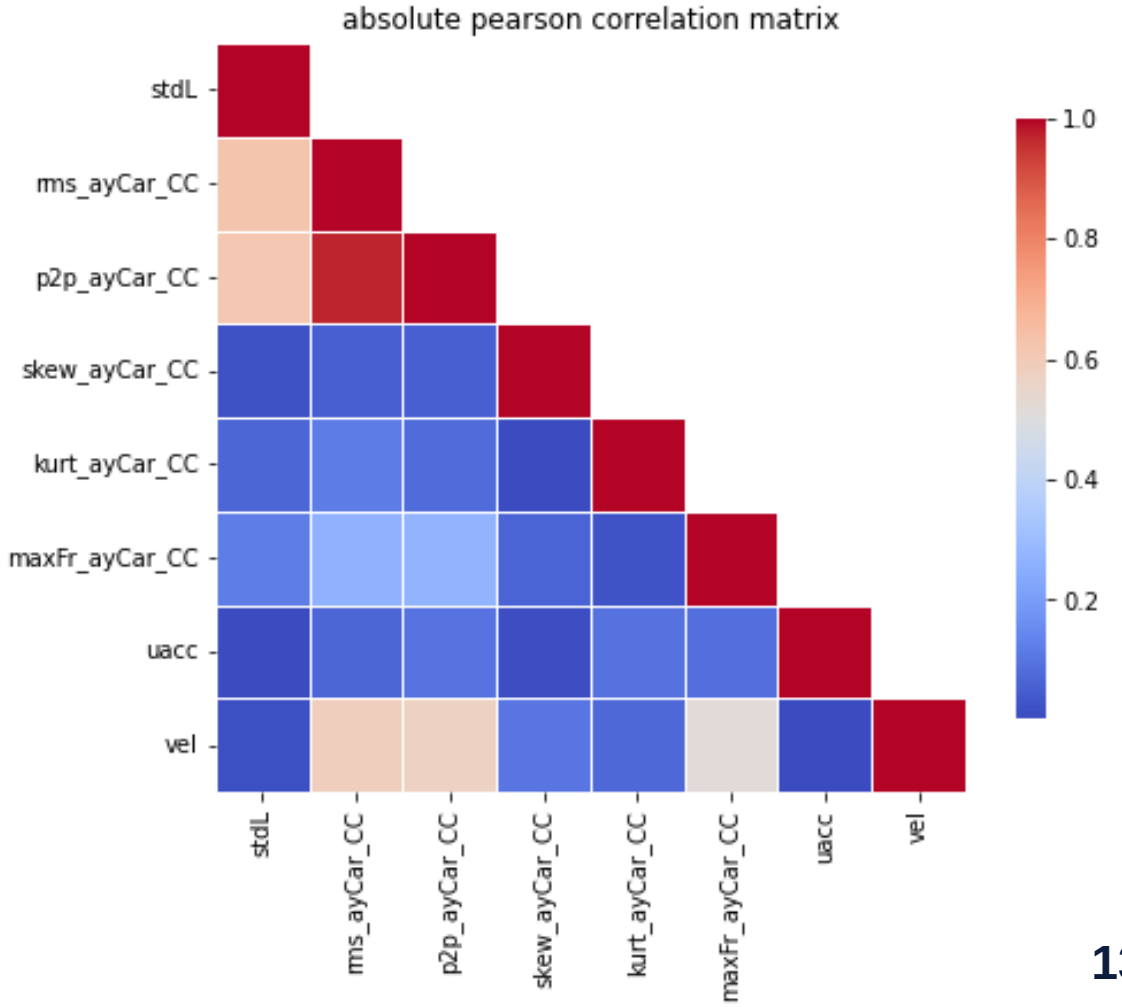


- Evaluation of the system sensitivity to changes in simulation parameters
- Include/Discard parameters according to their importance or influence
- Understanding the machine learning models results
- Feature engineering



Influence of variables on vehicle dynamics





Sensor Selection

9 positions in car-body
4 positions in each bogie
1 positions in each axle box

x3 directions (x, y, z) → 75 sensors (acceleration signals)

+ Velocity
+ Unbalanced acceleration

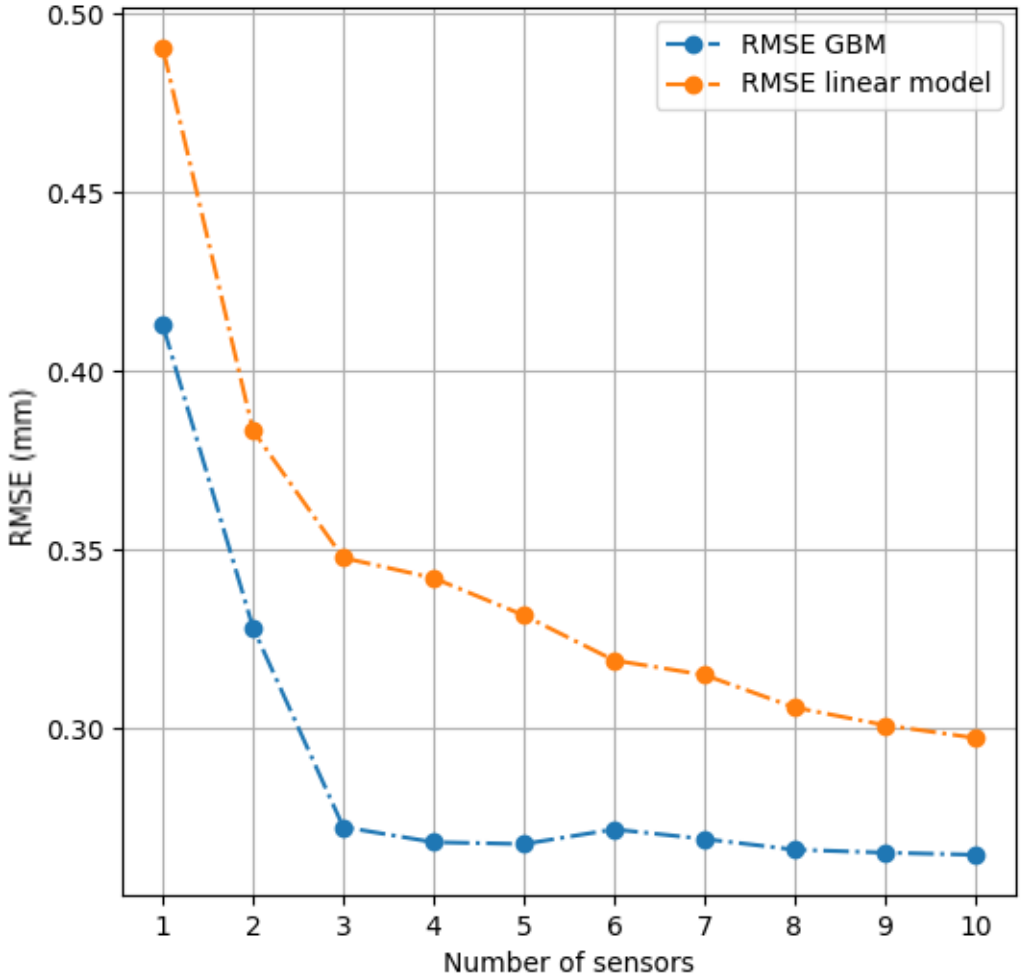
In real life, we are interested in using as few sensors as possible.

Sensor selection strategy:

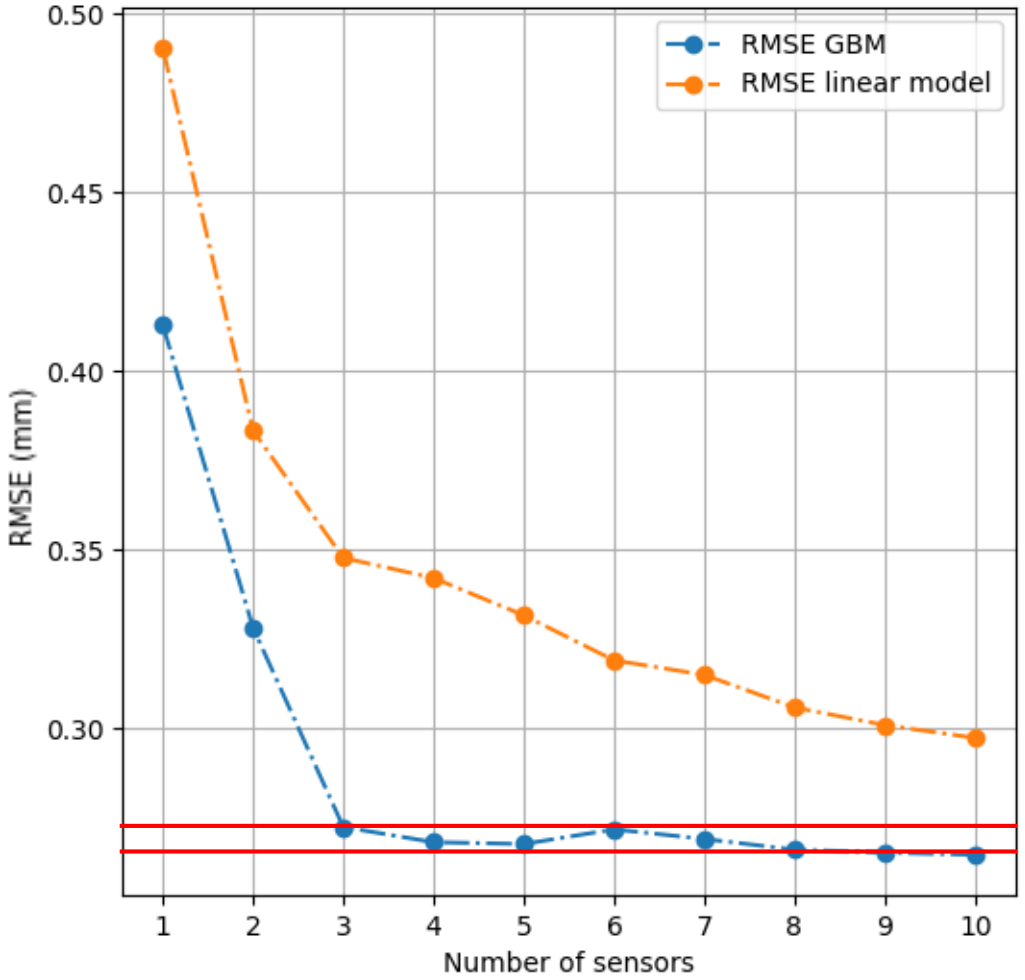
1. For a given number of sensors, find optimal sensor placement.
   Genetic algorithm: linear regression models are trained with signals from different sensors layouts. Root Mean Square Error (RMSE) of model is used to evaluate the layout.

2. Compare the results for different number of sensors to find the most suitable one.
   Gradient Boosting Machine (GBM) are used in this step.

Sensor Selection (vertical irregularities)

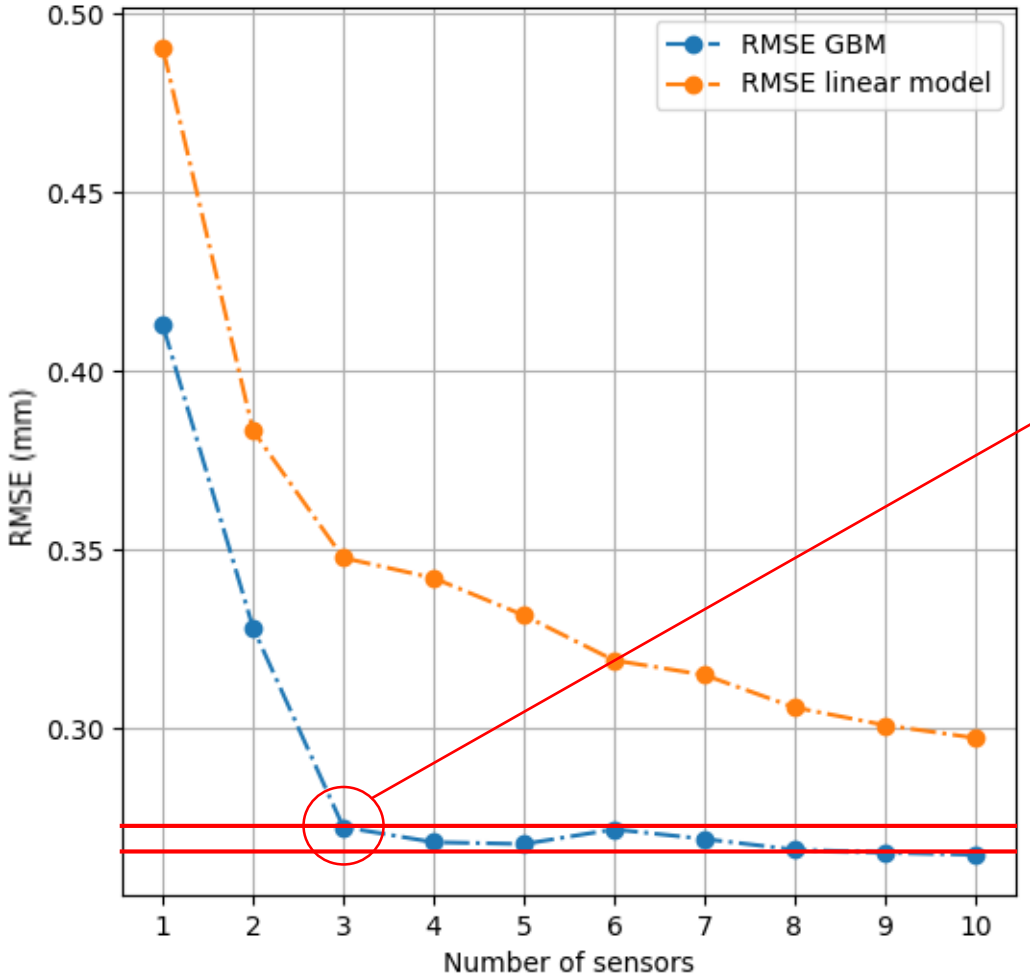


Sensor Selection (vertical irregularities)



Very little improvement with more sensors

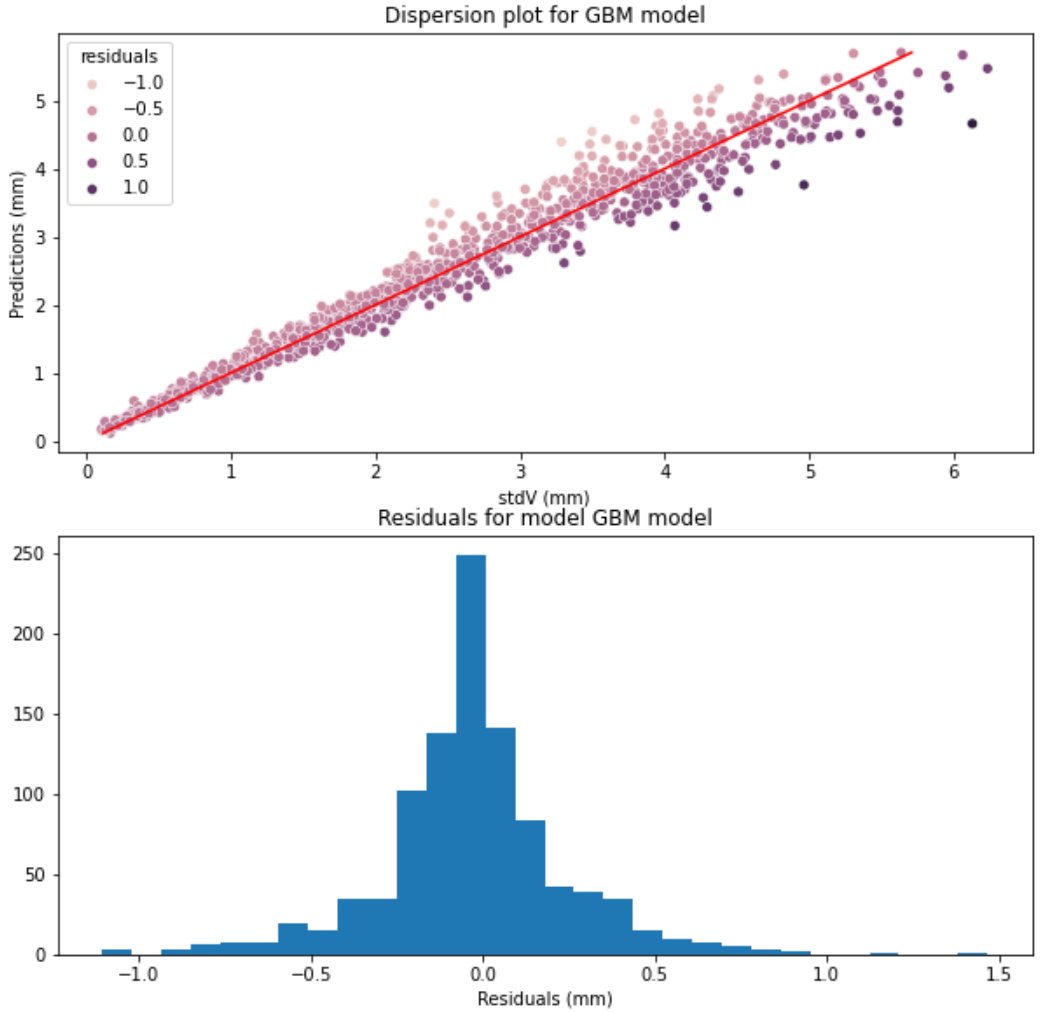
Sensor Selection (vertical irregularities)

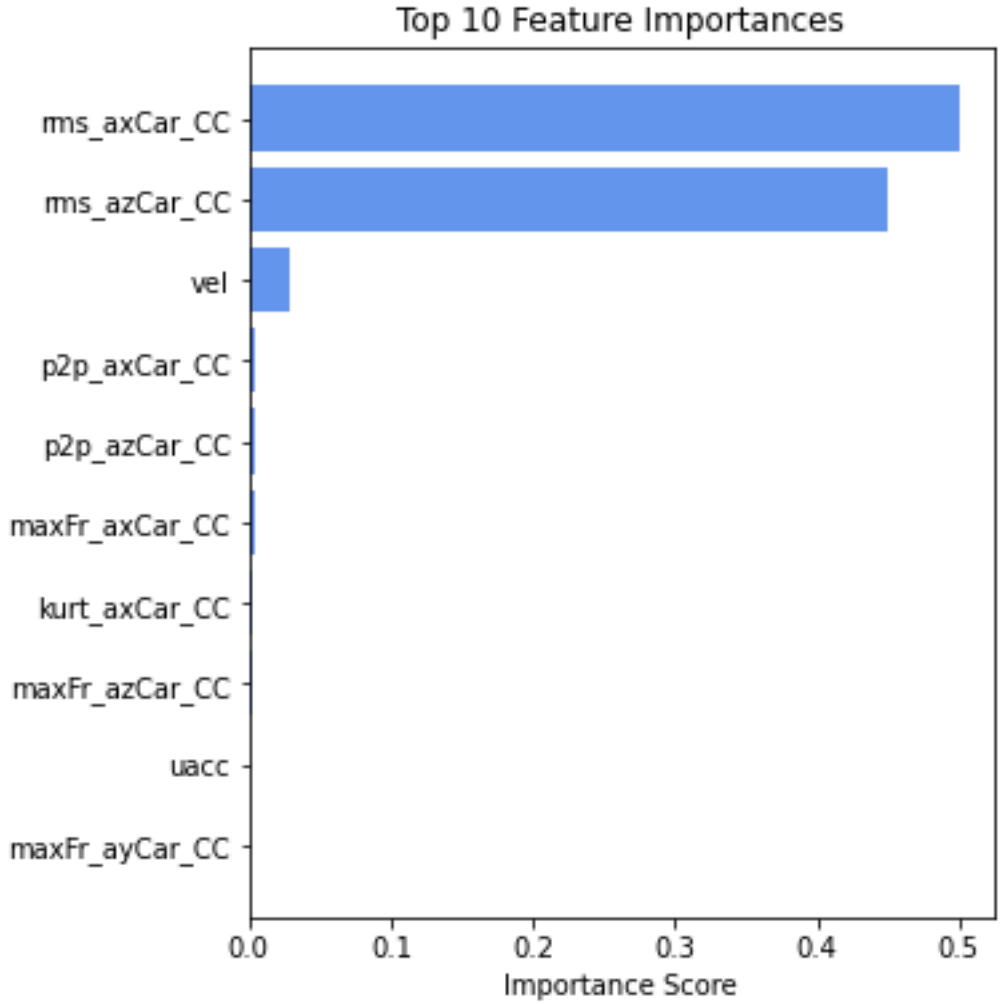


- Z acceleration centre of car body
- X acceleration centre of car body
- Velocity

Very little improvement with more sensors

Machine Learning results (vertical irregularities)





Future work

- Estimation of lateral irregularities.
- Further feature engineering.
- Application and analysis of more machine learning models and creation of specific model architectures.
- Study of a larger number of scenarios and simulation parameters.
- Validation of the methodology with real measurements.

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Thank you for your attention!

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