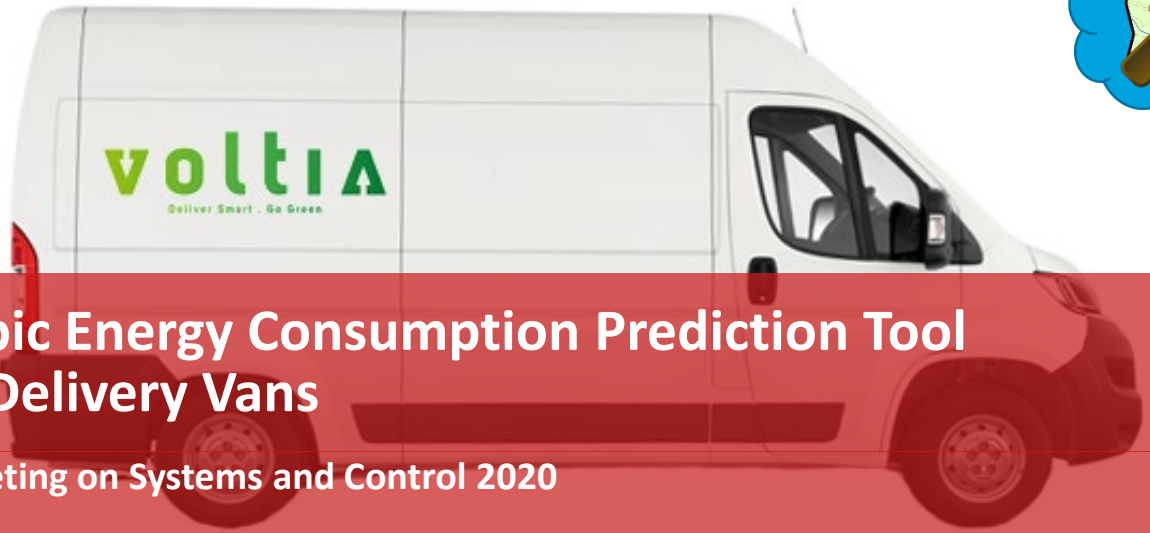

A Microscopic Energy Consumption Prediction Tool for Electric Delivery Vans

DISC Benelux Meeting on Systems and Control 2020

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Department of Mechanical Engineering, Dynamics & Control Group

Tuesday, March 17, 2020

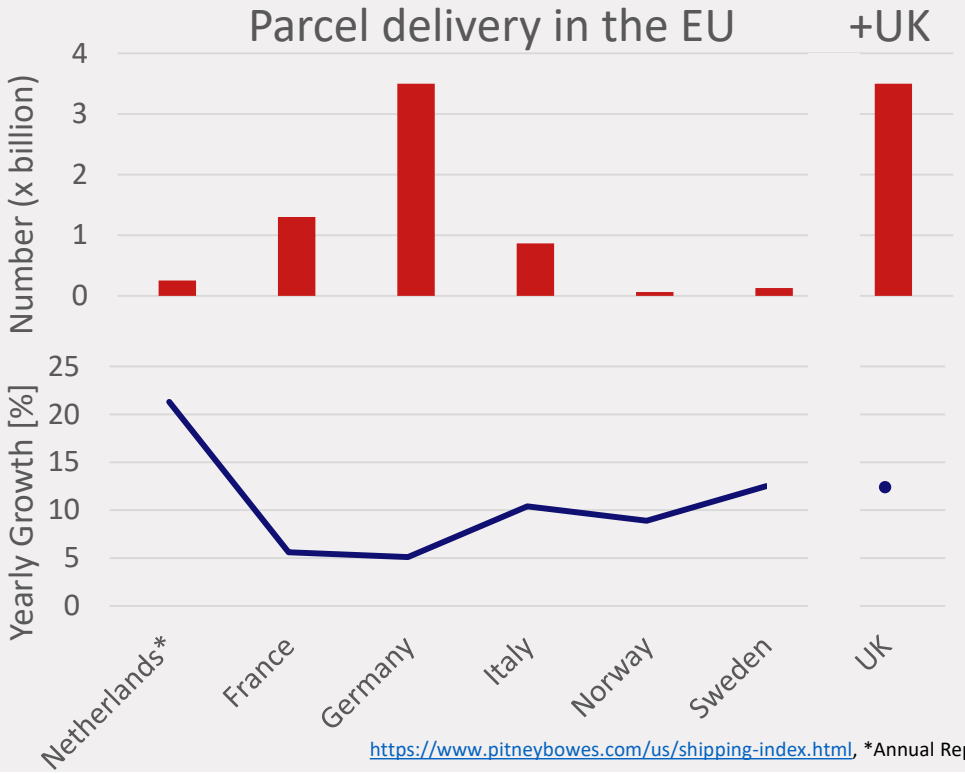
Motivation - Parcel Delivery

- Large market
- Increases 10% yearly

Delivery vehicles:

- Short distances
- Many stops per trip

Ideal for electrification



https://www.pitneybowes.com/us/shipping-index.html, *Annual Report PostNL

Voltia eVan

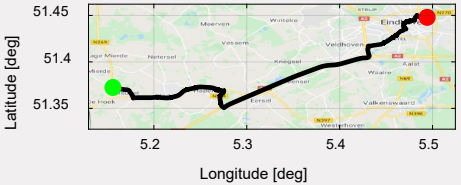
- Citroën Jumper retrofit
- 160 kW electric motor
- 40-90 kWh swappable battery
- 120-270 km range

- Advantage: Continuous operation (no recharging)
- Challenge: Trip scheduling due to uncertain range

Research Question

How can we predict the energy consumption of an electric vehicle for a previously undriven route?

Framework Overview



Planned route (coordinates)

Physics-based model

Energy Consumption Prediction [kWh]

[1] Jiquan Wang, Igo Besselink, and Henk Nijmeijer. Battery electric vehicle energy consumption prediction for a trip based on route information. Proc. Inst. Mech. Eng. Part D J. Automob. Eng., 232(11):1528–1542, September 2018.

Contents

- **Energy Consumption Prediction**
- Velocity Profile Prediction
- Vehicle- and Environmental Parameters
- Energy Consumption Prediction Results

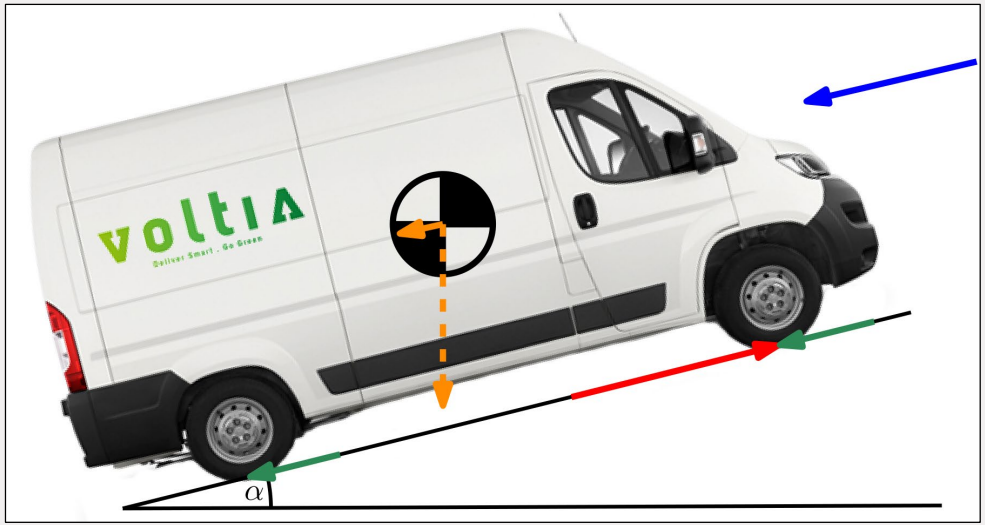
Energy Consumption Prediction

Physics-based approach:

- Model all road-load forces

Model depends on:

- Vehicle velocity
- Model parameters

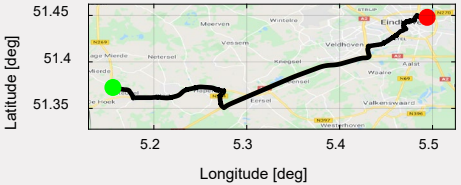


$$P_{pt} = \left(m_{eff} \frac{dv}{dt} + F_{roll} + F_{aero} + F_{grav} \right) v + P_{loss}$$

Framework Overview

Free online data services

Dedicated vehicle measurements



Planned route (coordinates)

Physics-based model

Velocity Profile Prediction

Energy Consumption Prediction

Energy Consumption Prediction [kWh]

Used icons:

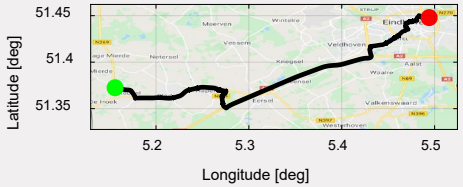
Contents

- Energy Consumption Prediction
- **Velocity Profile Prediction**
- Vehicle- and Environmental Parameters
- Energy Consumption Prediction Results

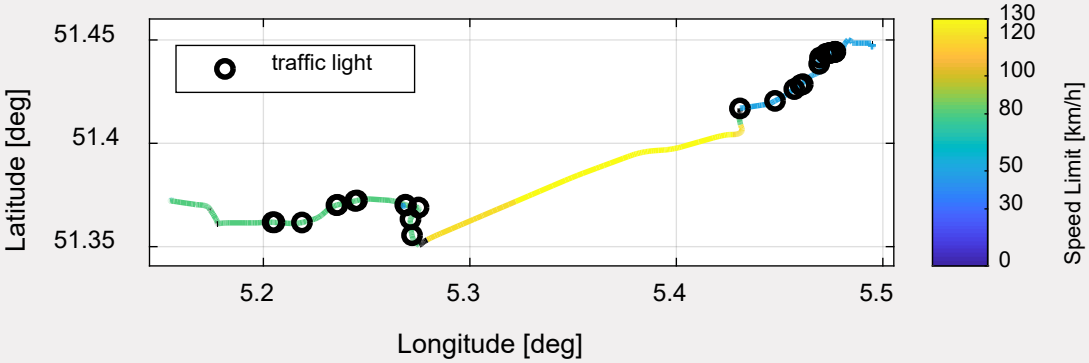
Input data

Relevant data:

- Max speed limit
- Traffic sign locations
- Corner radius

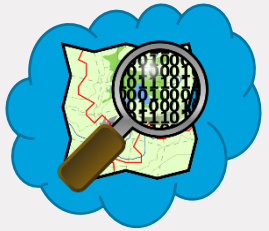


Planned route (coordinates)

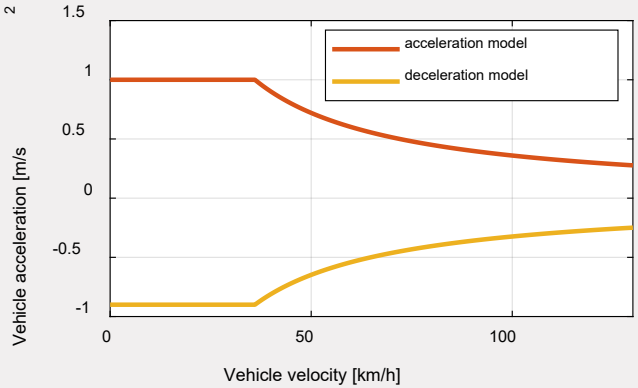


OpenStreetMap

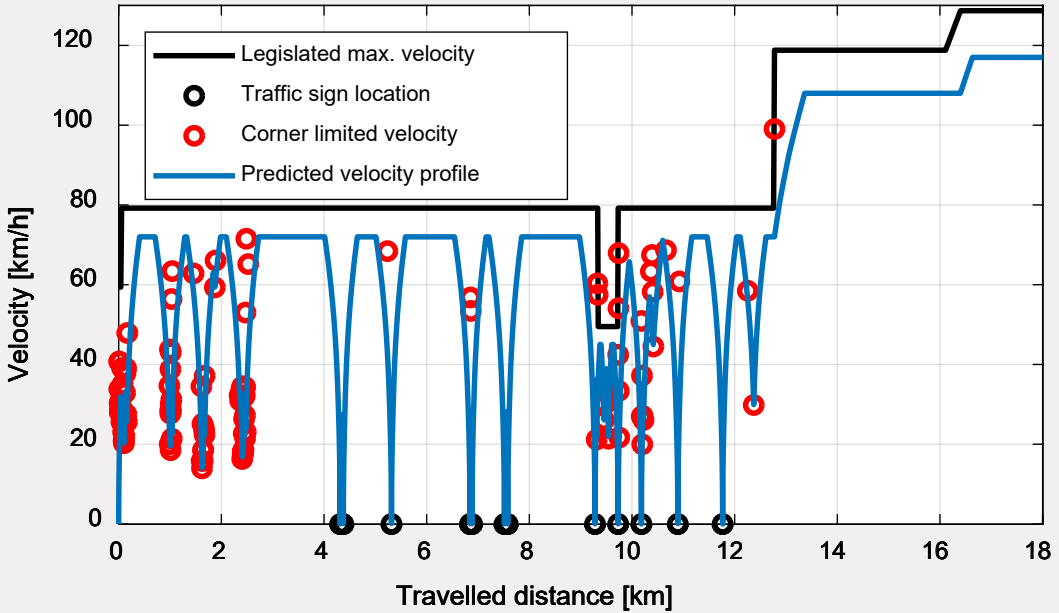
Velocity Profile Construction



Driver Model:



- Allows for some tuning

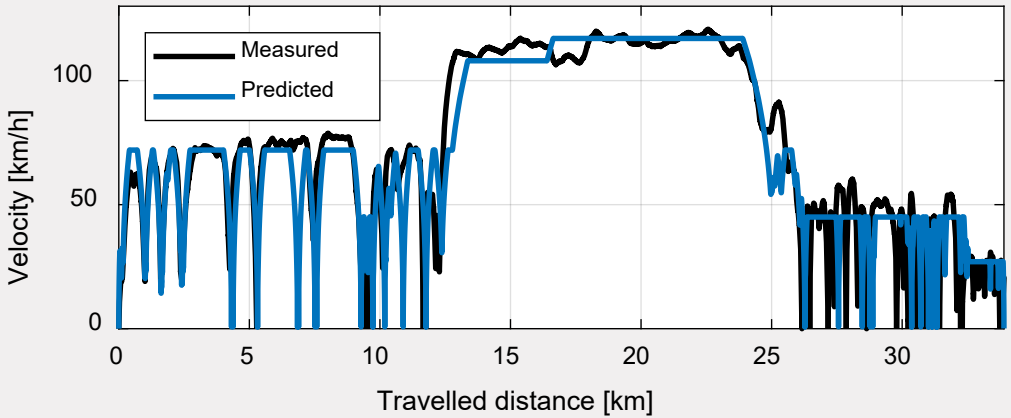


TU/e

Predicted Velocity Profile

Predicted velocity:

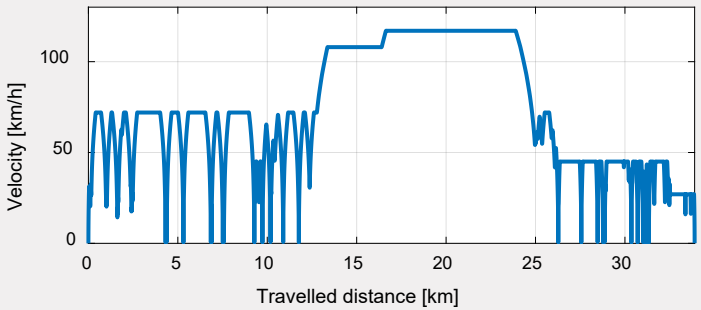
- Roughly similar
- Not all fluctuations are captured



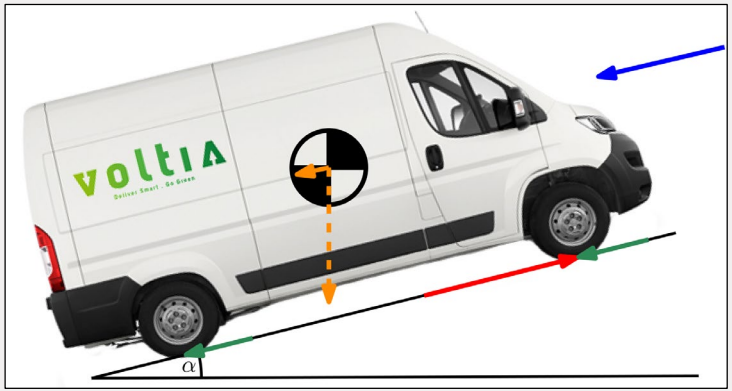
- Traffic influence not included
- Driver influence is requires data of some route

Energy Consumption Prediction

Velocity Profile Prediction



Energy Consumption Prediction



$$P_{pt} = \left(m_{eff} \frac{dv}{dt} + F_{roll} + F_{aero} + F_{grav} \right) v + P_{loss}$$

TU/e

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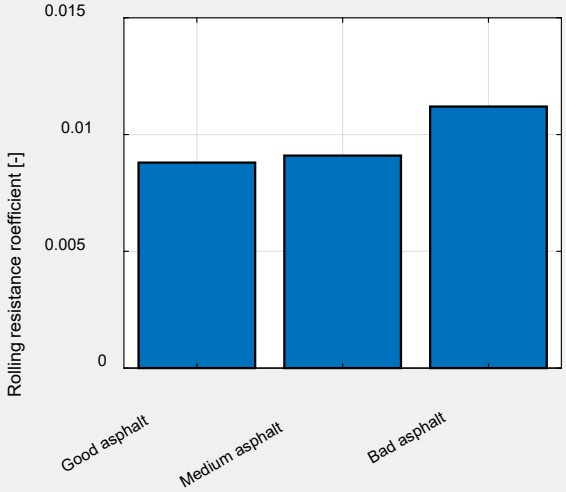
Rolling Resistance

$$F_{roll} = f_r mg\cos(\alpha)$$

Vehicle Tests

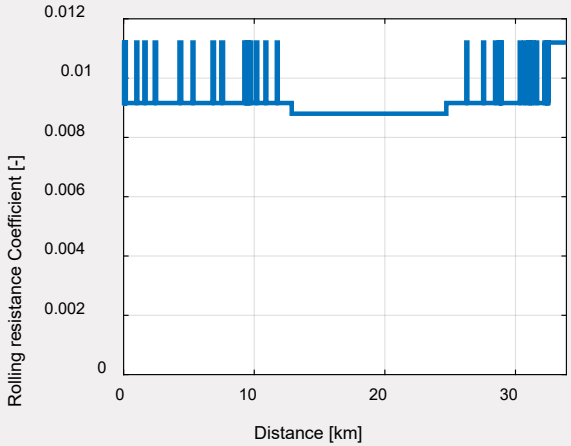
From experiments:

- Road-surface dependency



In the model:

- f_r is velocity dependent



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Aerodynamic Force

$$F_{aero} = \frac{1}{2}\rho C_d A_f v_{wind,rel}^2$$

Real-time-weather data:

- Temperature
- Humidity

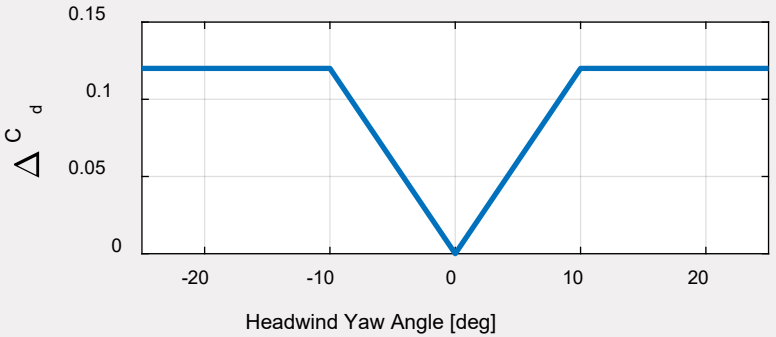
} Air density ρ

- Relative wind speed $v_{wind,rel}$
- Headwind yaw angle β

$$C_d = 0.36 + \Delta C_d(\beta)$$

OpenWeatherMap

Vehicle Tests



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Local Road Slope

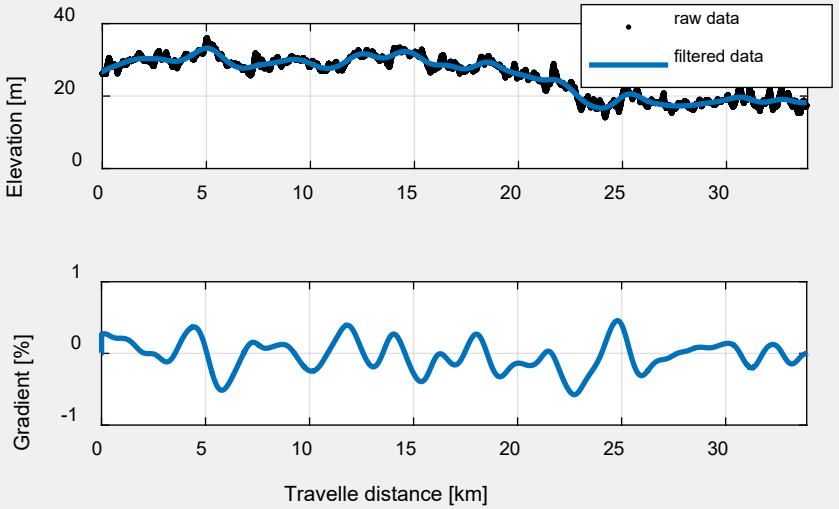
$$F_{grav} = mg\sin(\alpha)$$

SRTM

- SRTM elevation map
- Low-pass filter $\lambda_c = \frac{1}{2000}$ [1/m]
- $\frac{d}{ds}$ ➡ Gradient

Mass:

- Average, constant value for trip



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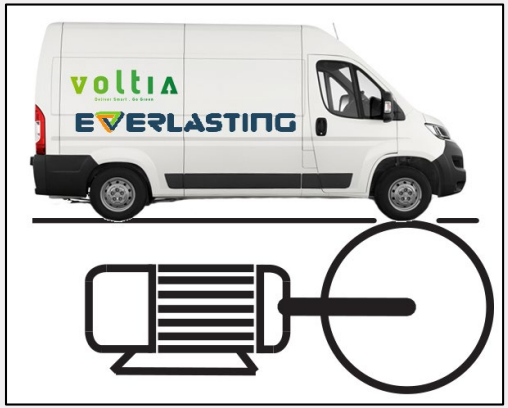
Powertrain Losses

$$P_{loss}(\omega_{wheel}, T_{wheel})$$

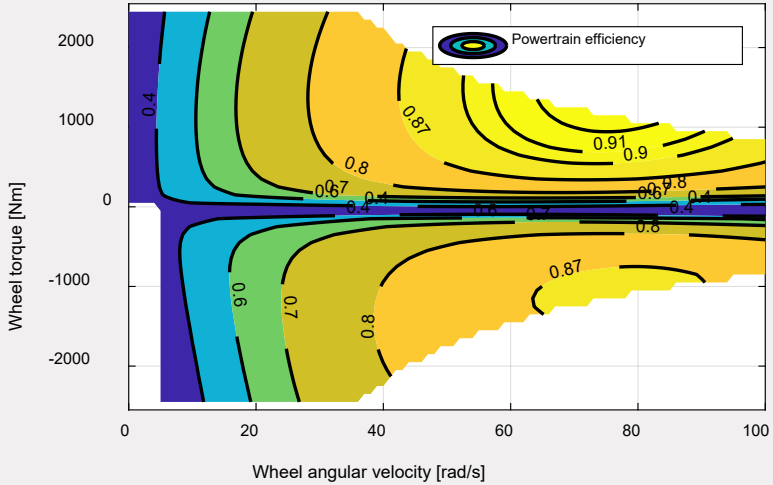
Vehicle Tests

Dynamometer tests:



In the model:

- Empirical equation



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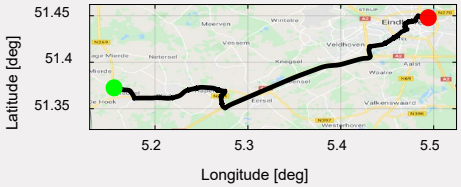
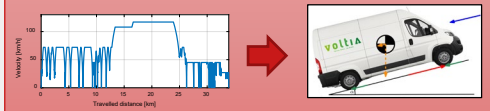
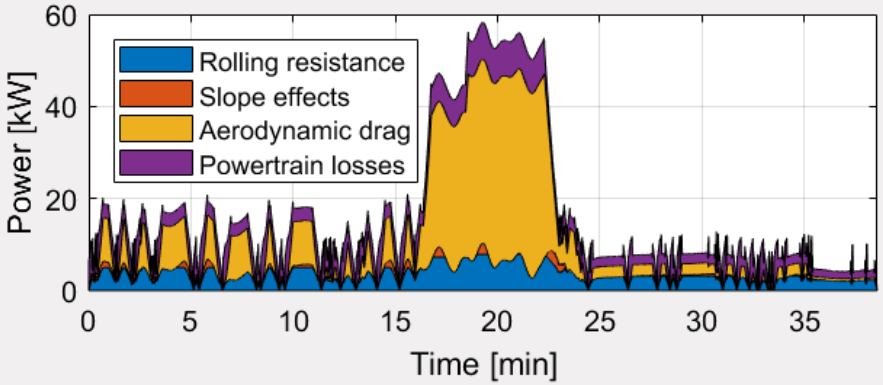
Energy Consumption Prediction Results

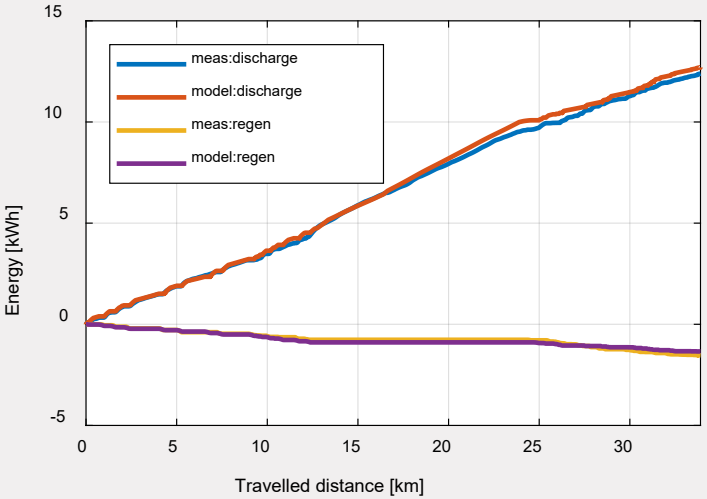


Physics-based model

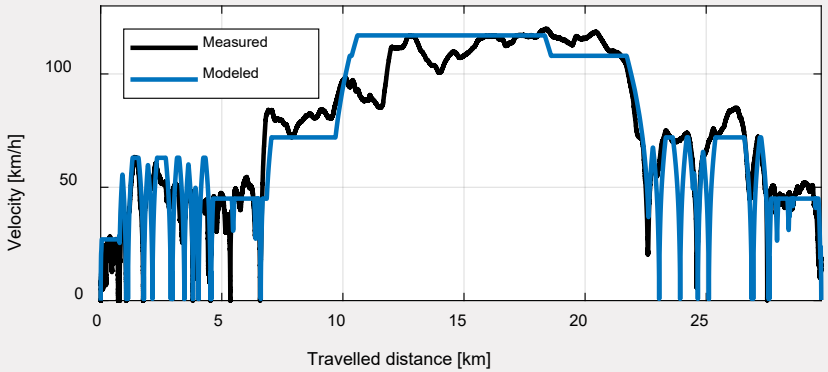


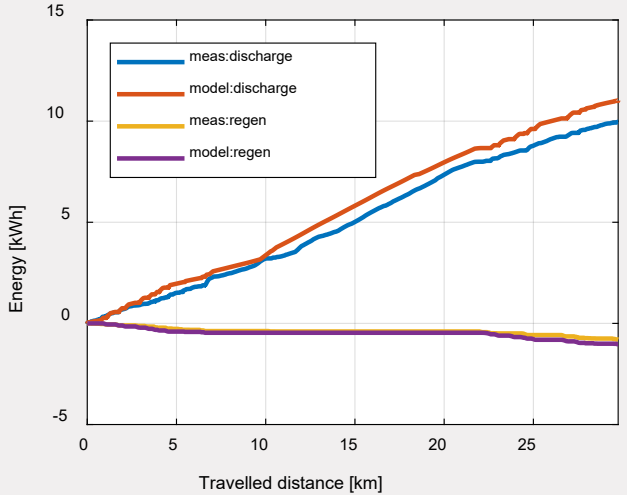
Energy Consumption Prediction [kWh]



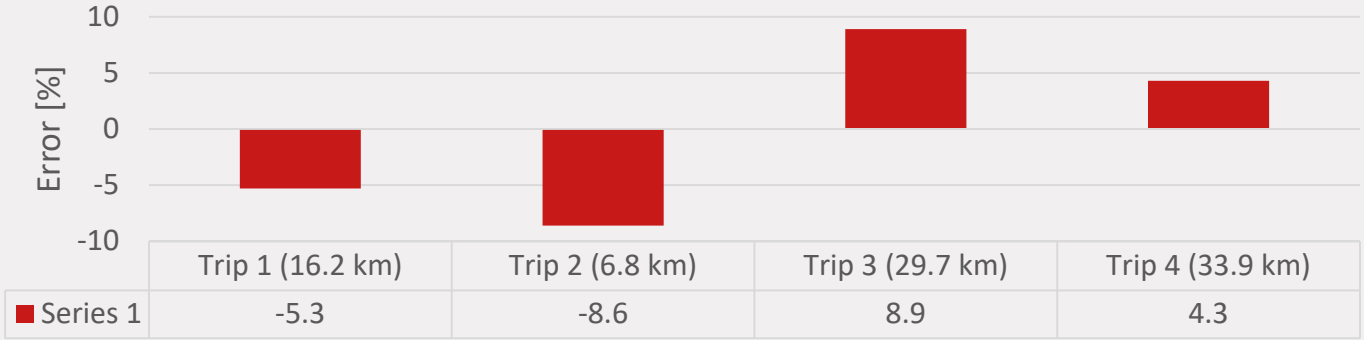


Prediction Results: a different trip





Prediction results: overview



Conclusions

- Successful energy consumption prediction for undriven trip
- Errors below 10%
- Sufficient filtering of height profile is essential

Future Work

- Validation in more extreme slope and weather conditions
- Improved (variable) mass model
- Inclusion of traffic influence on the velocity profile prediction
- Find structural method to determine tuning factors

Thank you for your attention

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