Prediction of energy consumption using VMC Usage Modeling and Simulation

35. Forum „Simulation in der Automobilindustrie“
Fraunhofer ITWM
Kaiserslautern, May 3rd, 2024

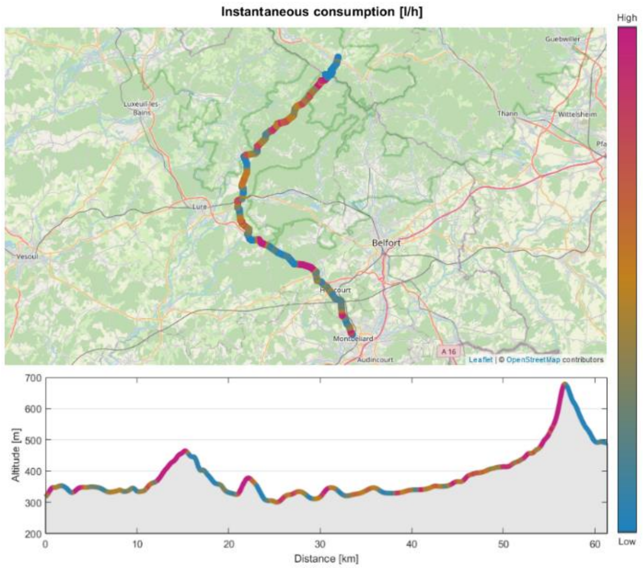
Challenge: Prediction of energy consumption

Prediction of energy consumption

Challenge

How to deal with different use cases?

- Drive Train Development
- Electrification
- Extensions
- Energy saving in fleet operation
- …



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Our solution: VMC® - Virtual Measurement Campaign

Goal:

Geo-referenced simulation of vehicle performance on the road with respect to durability and drive train performance e.g. fuel consumption and energy efficiency.

Typical applications / users (for any road vehicle such as passenger cars, VANs, trucks)

- **Drivetrain development**: Calculation of vehicle and drivetrain loads on routes in different regions of the world. Prediction of customer-specific usage profiles in terms of drivetrain characteristics (e.g. engine speed and gear collectives). Fast derivation of reference routes for analyzing **real driving emissions (RDE)** and developing **advanced driver assistance systems (ADAS)**.
- **Fuel Consumption and energy efficiency**: Estimation of fuel consumption, prediction of potential savings and assessment of constructive modifications
- **Durability**: Estimation of longitudinal, lateral and vertical loads for the development of chassis, suspension and other components

VMC® - Virtual Measurement Campaign

VMC

Database

Data layers synthesized in VMC

Regulations

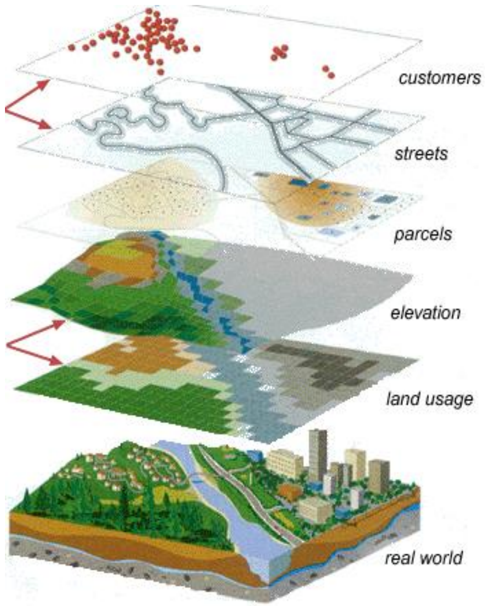
Road network

Traffic

Topography
- Slope
- Curves
- …

Climate
- Temperature
- Humidity
- …

Road quality
- Roughness
- Surface
- …



REDAR

Data sources include data from: OpenStreetMap, HERE Technologies; ASTER Global Digital Elevation Model, NASA SRTM, DLR and Airbus TanDEM-X Mission; University of East Anglia, Norwich(UK), University of California WorldClim - Global Climate Data; Swedish Transport Administration (Trafikverket); Finnish Transport Agency, Finnish Transport Agency, "Bundesanstalt für Straßenwesen" (BASt), Fraunhofer ITWM measurements, 3D Mapping Solutions GmbH ; Government of South Australia, Government of Western Australia, Department of Transport, Government of Victoria/Australia, Government of Queensland/Australia, Government of Northern Territory/Australia, New Zealand Transport Agency;…

VMC® - Virtual Measurement Campaign Software Suite

VMC Database
Data layers synthesized in VMC

Regulations
Road network
Traffic

Topography
- Slope
- Curves
- …

Climate
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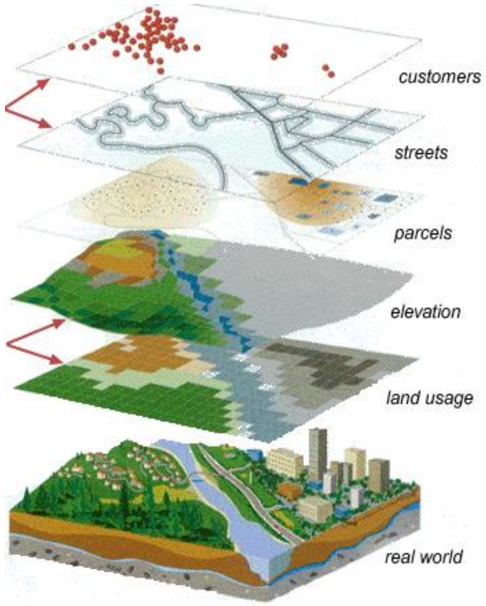


REDAR

VMC GeoStatistics
statistics of regions & routes

VMC GeoLDA
Load data analysis with geo-data

VMC Simulation
Road-profiles, speed-profiles, energy consumption, emission and loads

U·Sim
usage simulation, statistics and derivation of test schedules

VMC LinTim
Public Transport Planning

VMC MicroTraffic
Dynamic and stochastic traffic simulation on complex road networks

VMC Road & Scene - Generator
Roads, routes, environments and scenes for vehicle engineering

VMC Usage Modeler
Modeling vehicle usage for different customer groups

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VMC® Web Services (SaaS)

- Access to different modules of VMC via web solution hosted on Azure-Cloud, AWS interface available
- Current stage provides the
  - **Map Matching** (import of routes, e.g., measured data or reference routes)
  - **Route Analysis** (evaluation of geo-referenced factors → VMC GeoStatistics)
  - **Speed Profiles** (calculation of speed profiles based on route data as well as driver, traffic, and vehicle models)
- Ongoing development of the services
  - **Routing** (new routes, calculated by routing service)

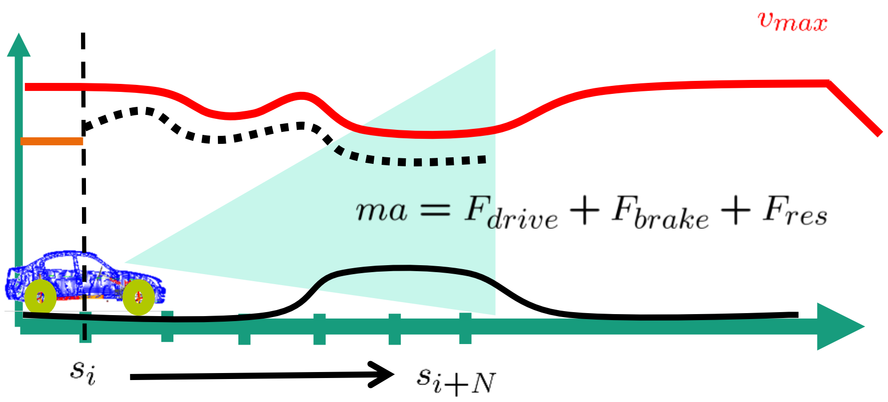
VMC Simulation

VMC Simulation

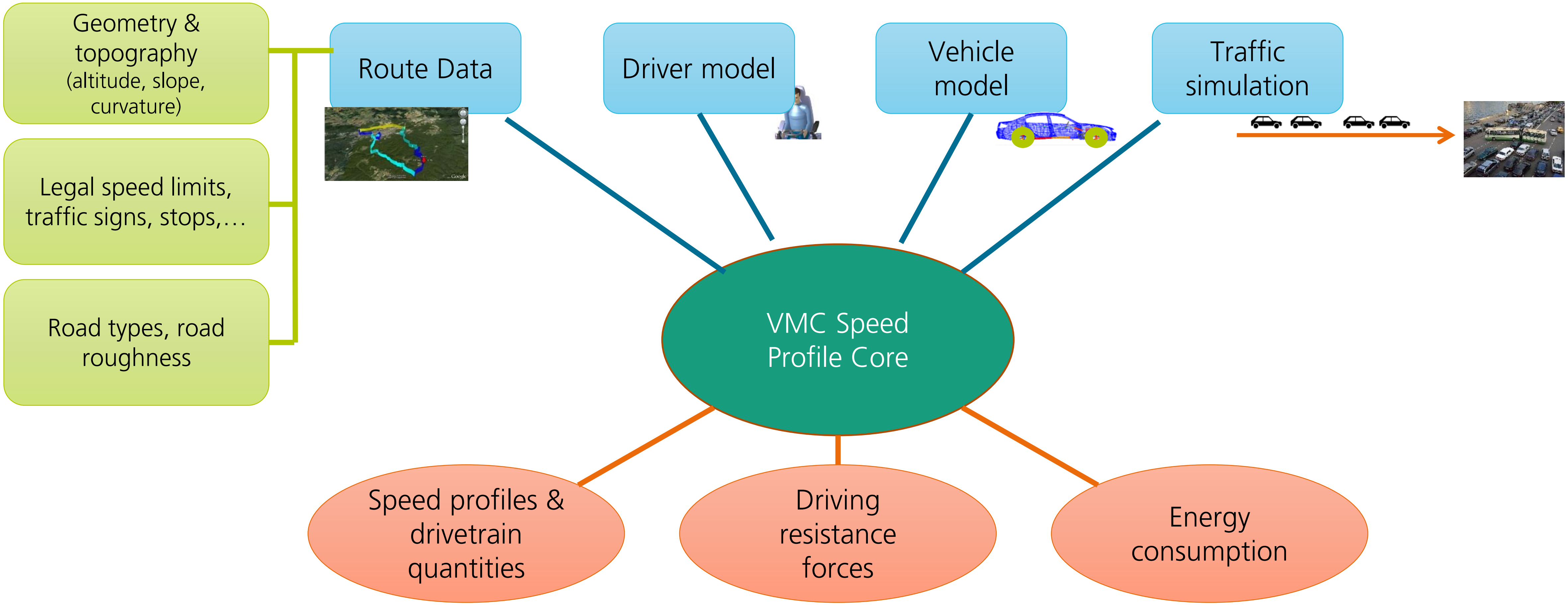
Basic idea:

Geo-referenced data + vehicle & driver model → deeper understanding of the vehicle performance with respect to durability or drivetrain performance.

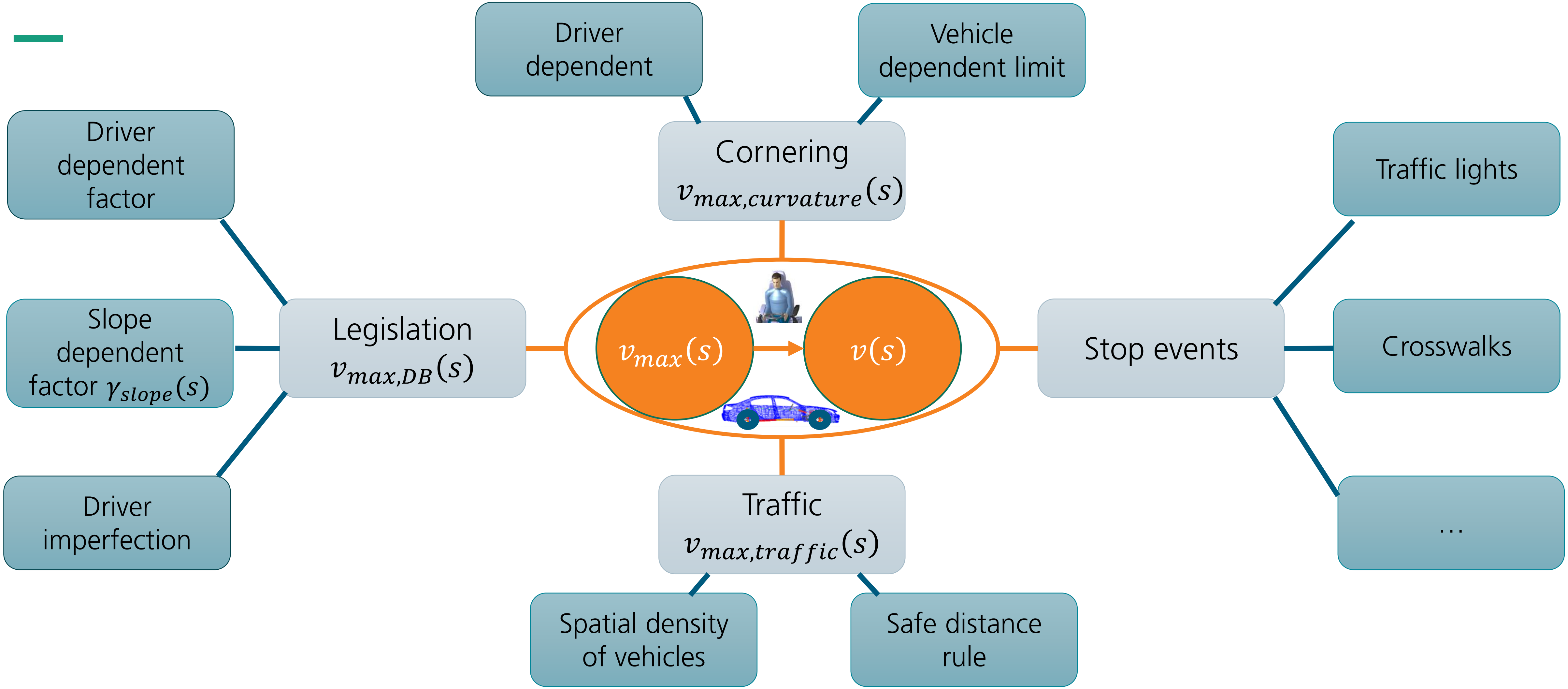
- Estimation of **speed profiles** on a given route.
  Total **vehicle loads** (Fx, Fy), required driving power etc.
- **Vertical loads -** Fz based on road profile models
- Road profiles for routes based on roughness indicators
- Calculation of roughness indicators for given road profiles



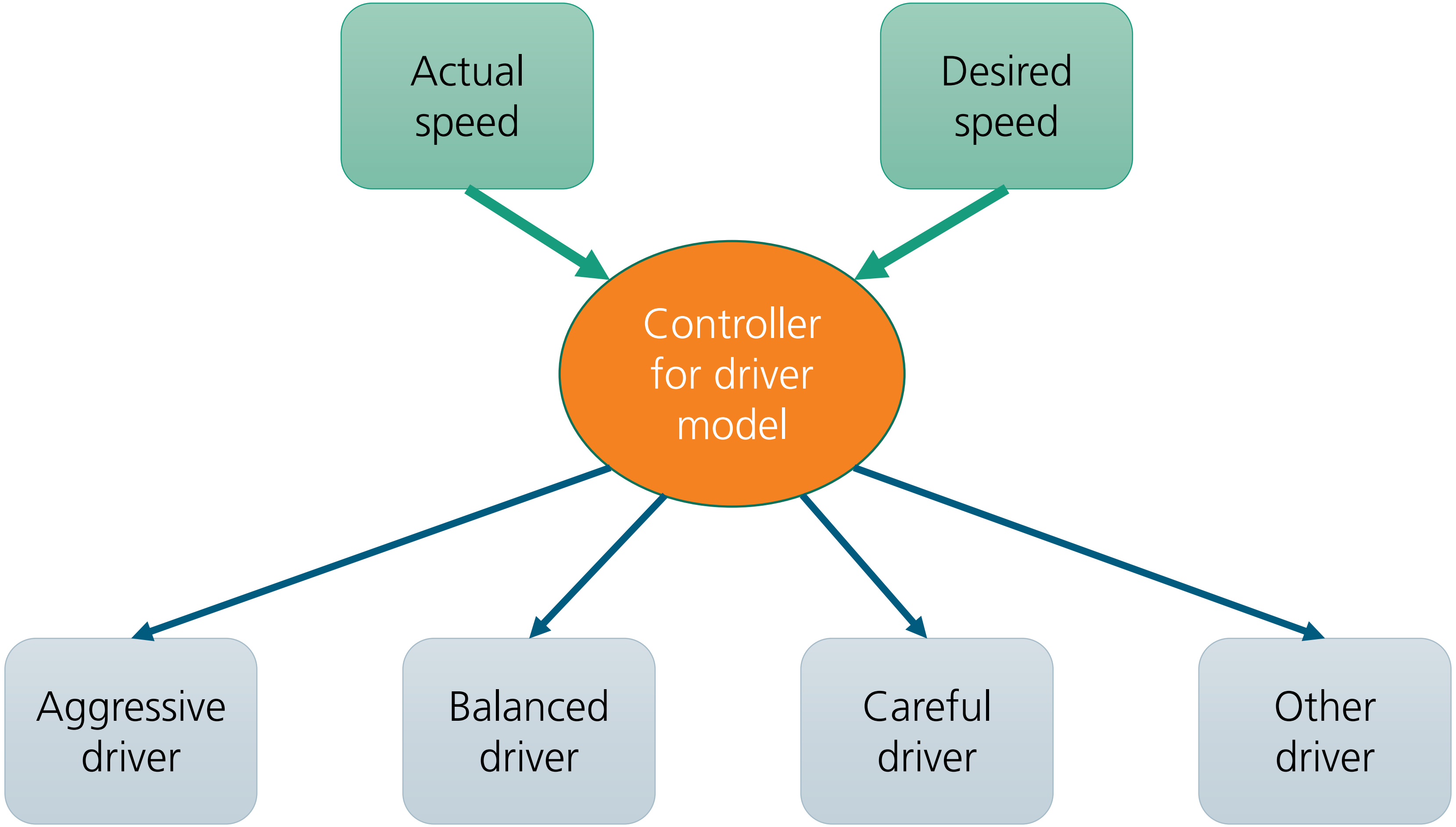
VMC Speed Profile Calculation considers various aspects



Vehicle speed is influenced by various inputs and constraints



Driver model controls acceleration and deceleration events



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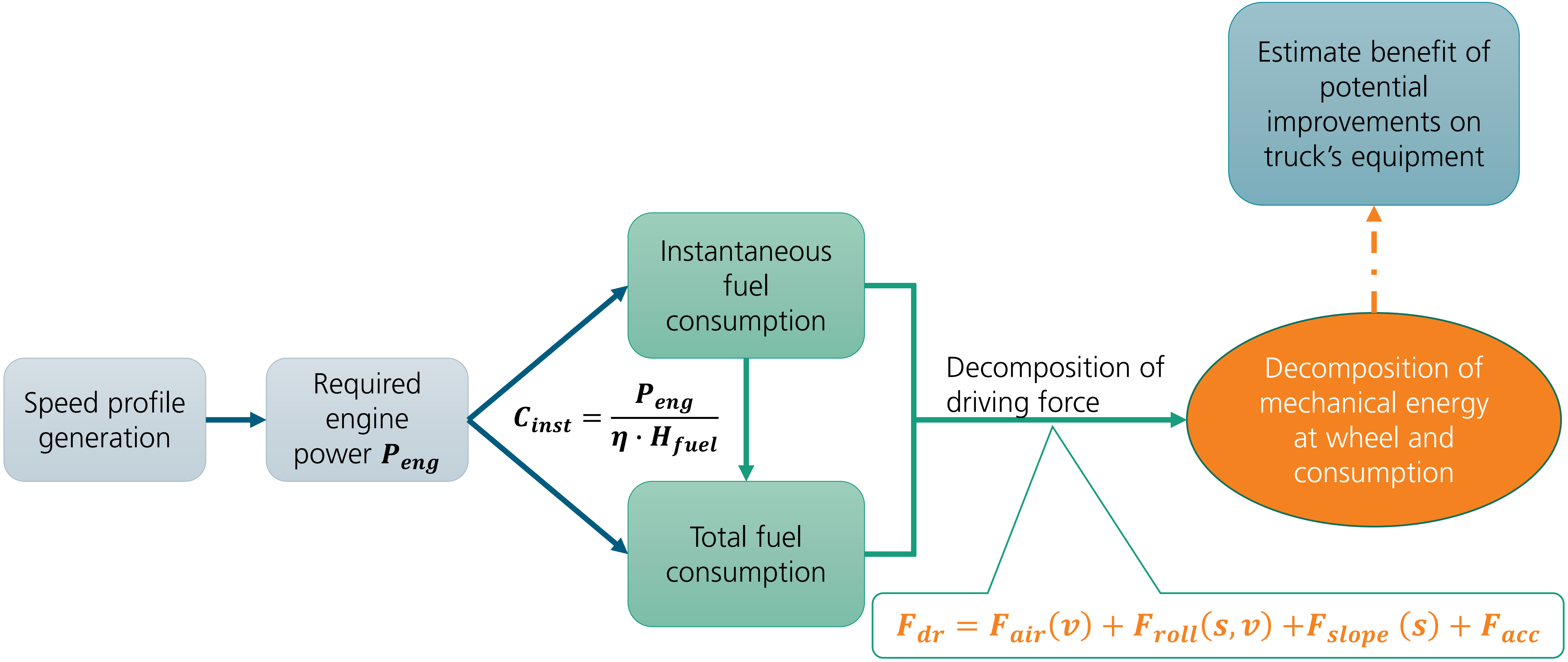
Fuel consumption can be computed for components of driving force



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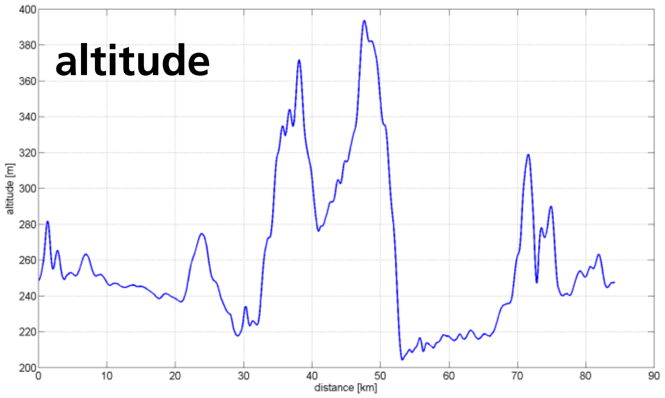
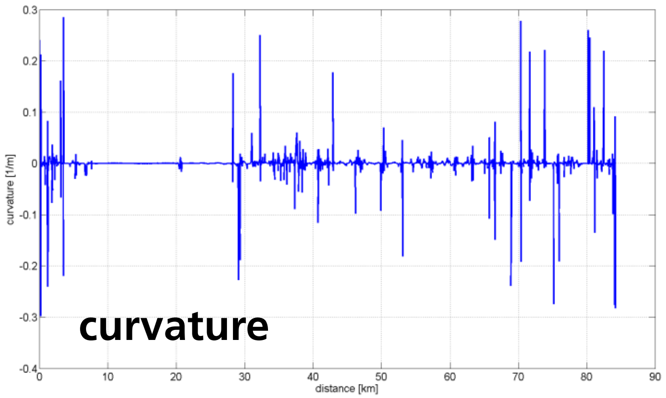
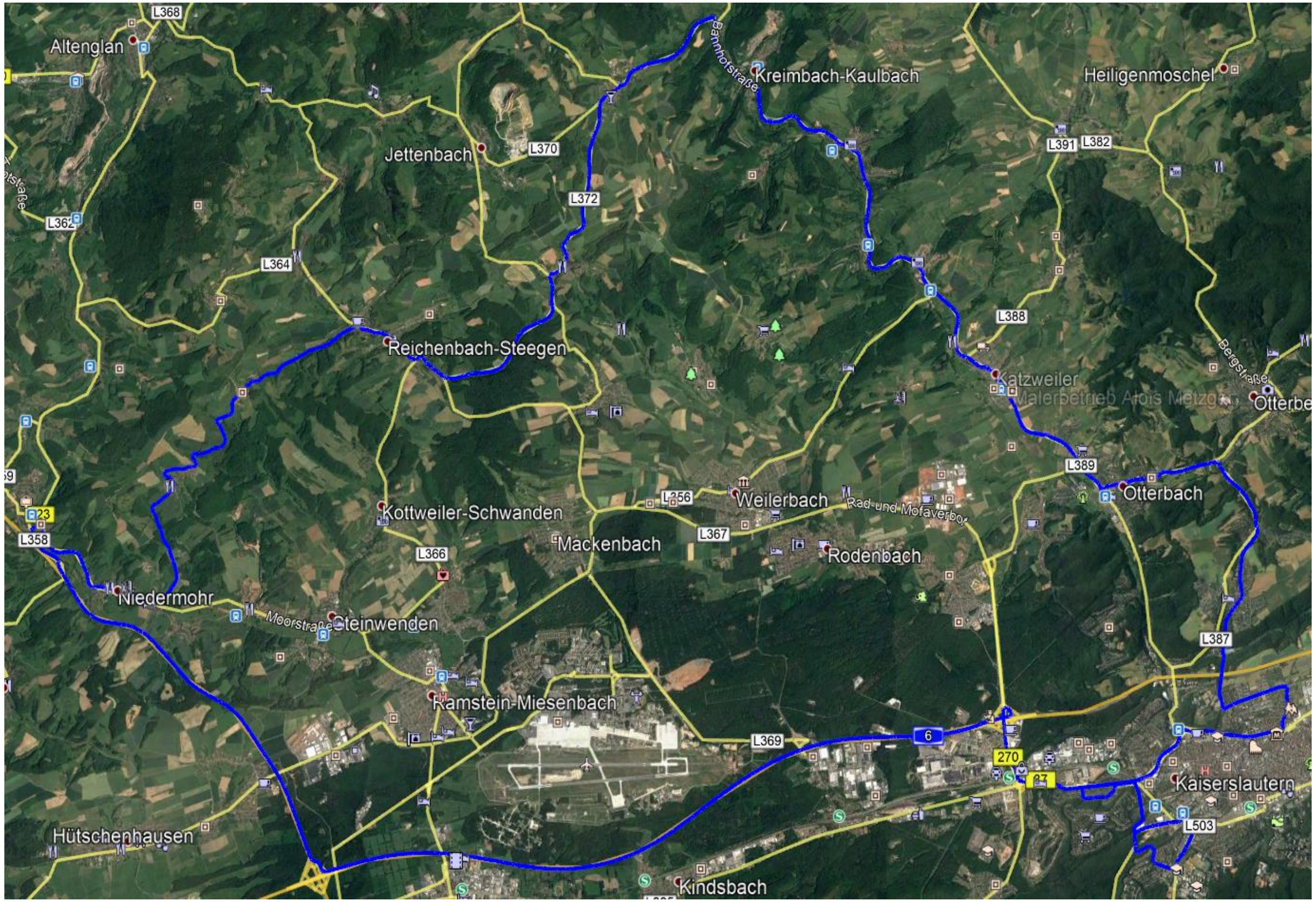
Example: Route around ITWM/Kaiserslautern





google maps



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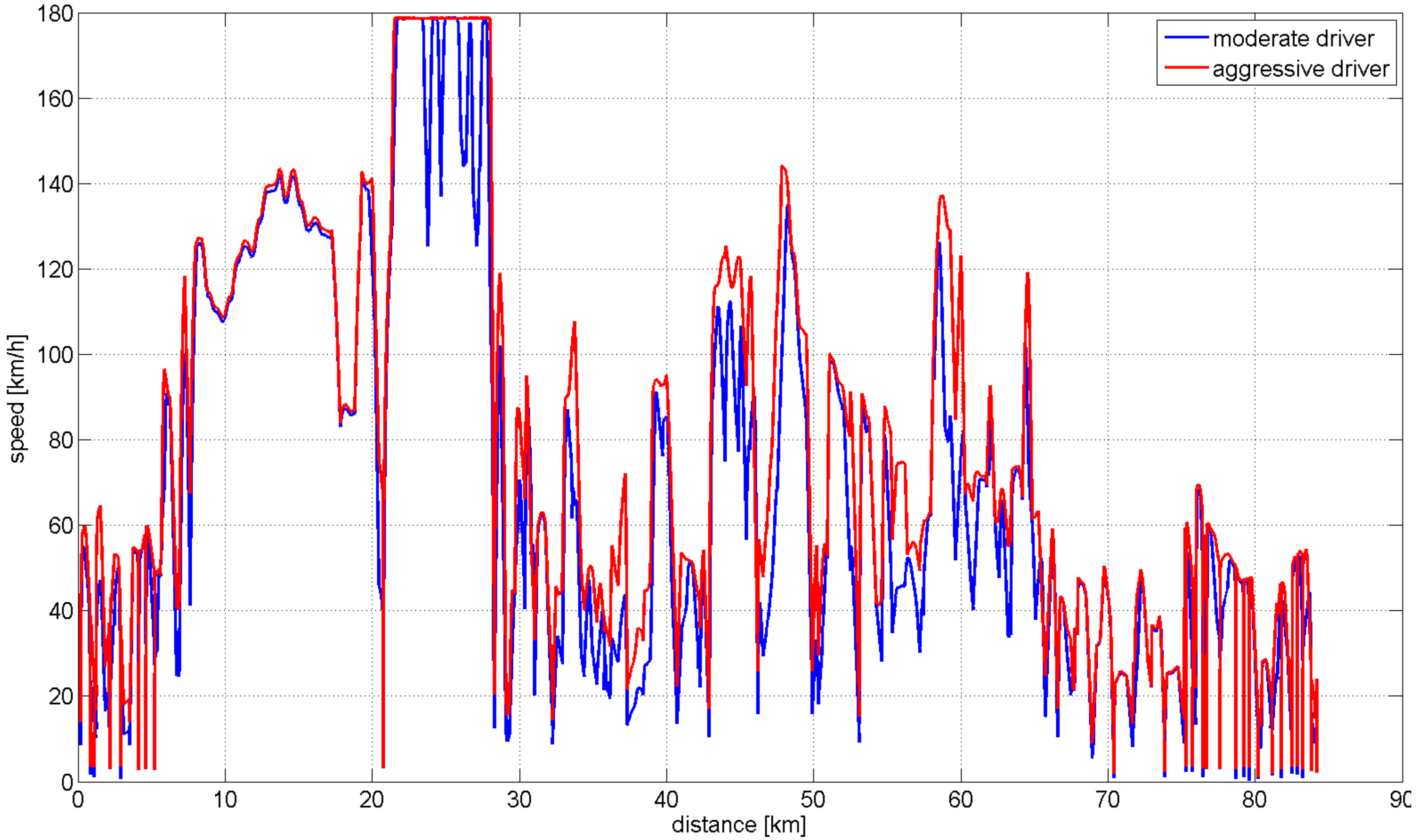
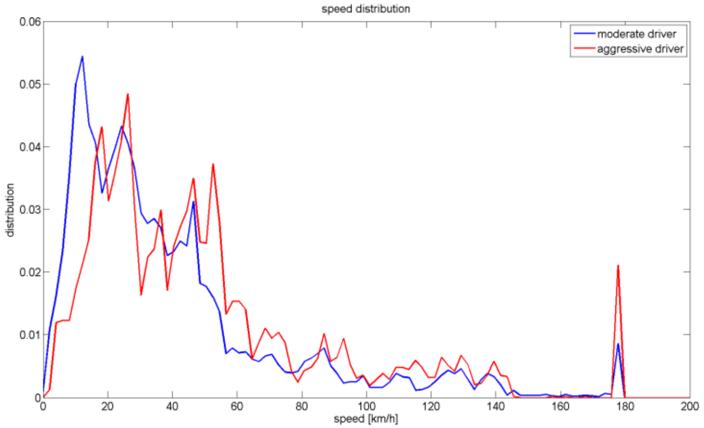
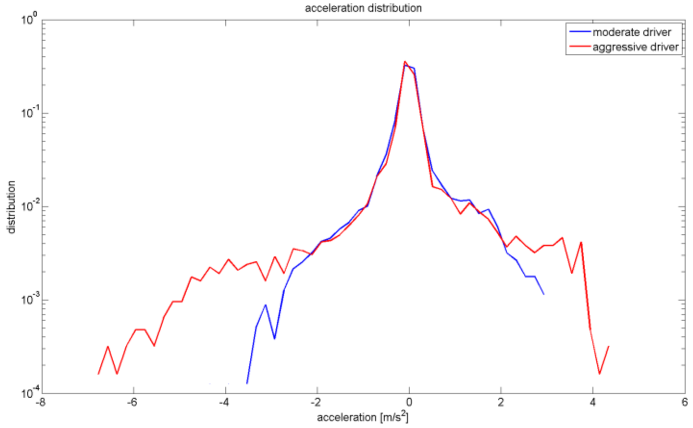
Example: Route around ITWM/Kaiserslautern

Speed and Acceleration







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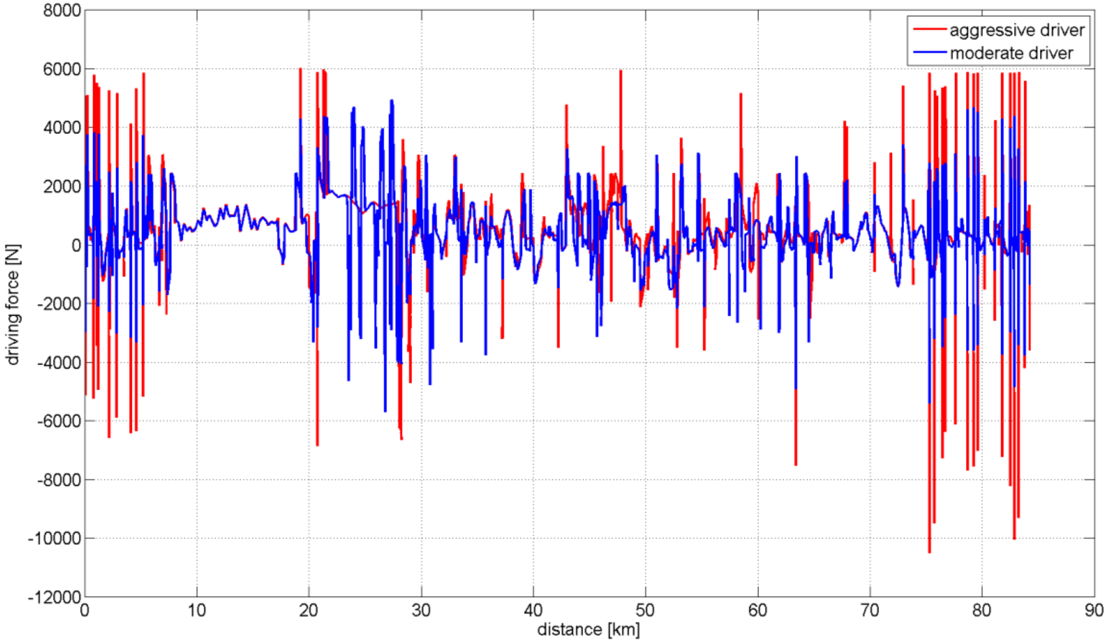
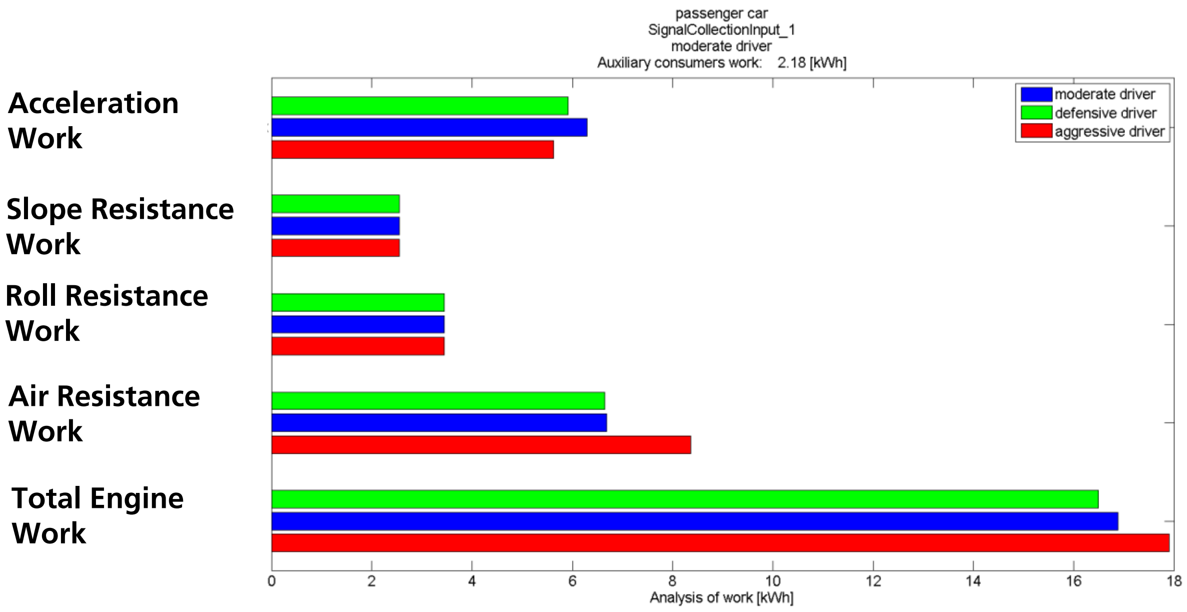
Example: Route around ITWM/Kaiserslautern

Driving Force & Energy Demands





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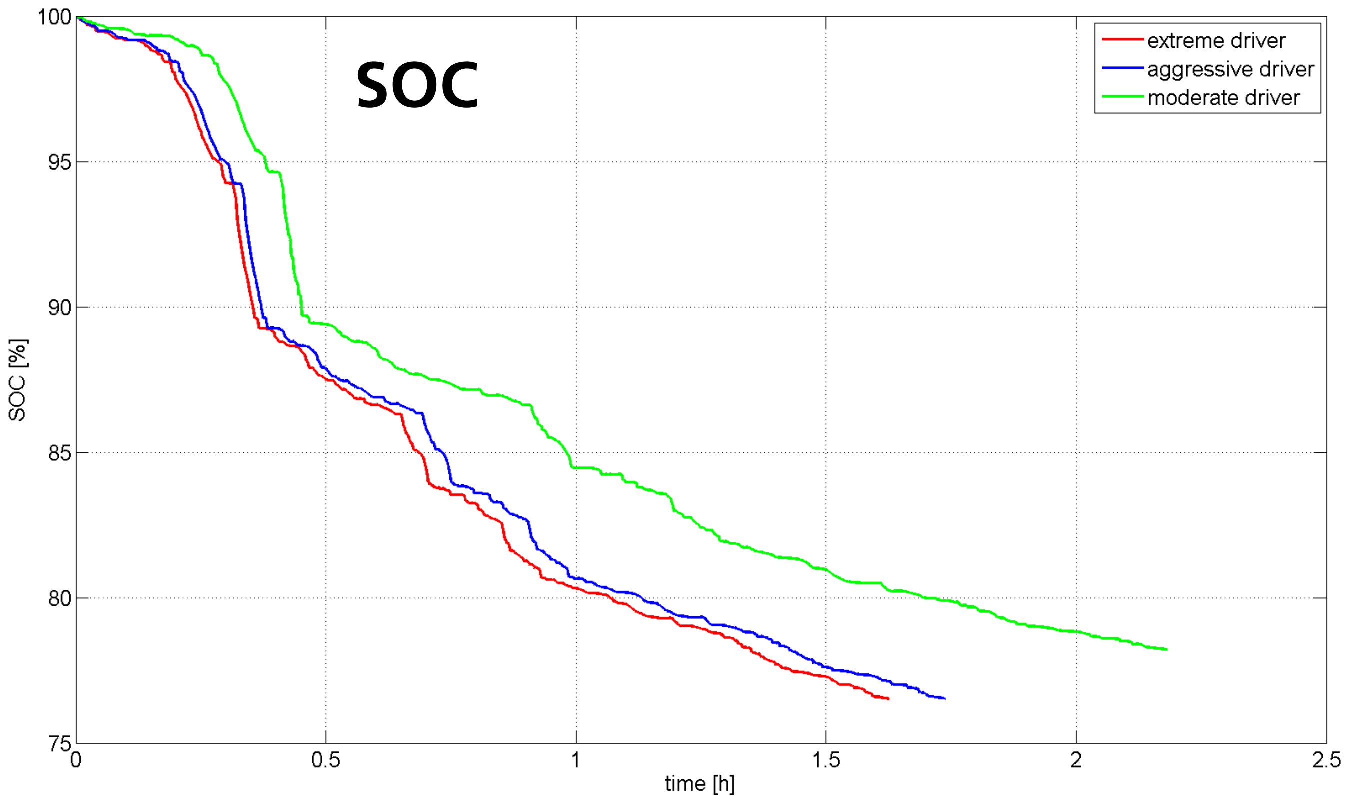
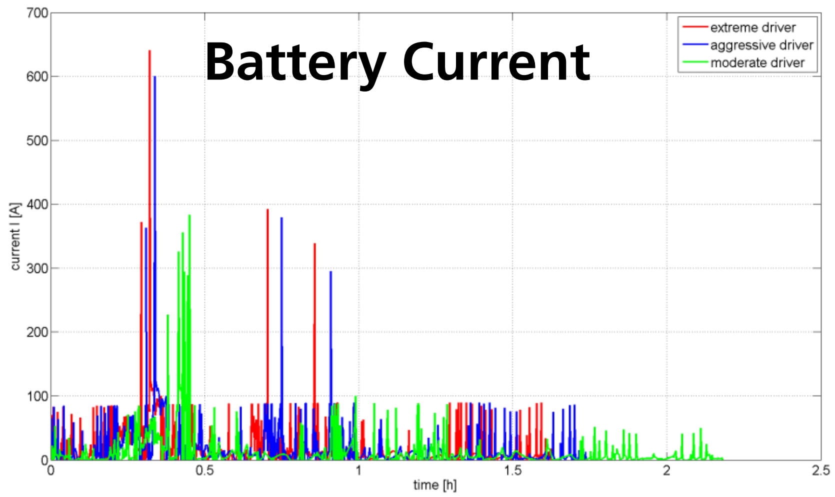
Example: Route around ITWM/Kaiserslautern
…with an electric vehicle





Simulation of vehicle usage profiles

Challenge: Statistically valid distribution of real usage in specific region

Application example: Users of trucks

Statistically valid distribution of real usage

Challenge

How will the vehicle be used in specific region?

- Mathematical models for different "usage types" (distribution transport, long haul, hazardous goods,…)
- Specific geographic data of region
- Simulation of single profiles
- Weighting to obtain results for population

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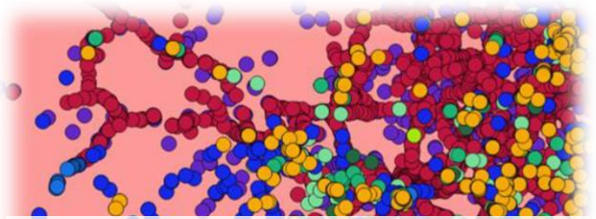
Our solution: VMC® UsageModeler



Usage modeling
(VMC Usage modeler)

Usage model

- 14% city, 28% motorway, …
- 29% half, 71% full
- 60% flat, 40% hilly
- …

Challenge	▪ Statistically valid distribution of real usage for specific customer types in specific geographic regions is required
Solution	**VMC® UsageModeler** ▪ Mathematical models combined with specific geography. ▪ Simulating vehicle lives for thousands of customers ▪ Cover all possible operational states
Benefit	▪ Not restricted to specific vehicle or usage type ▪ Not restricted to specific region ▪ Not restricted to specific component

Energy saving in fleet operation

Use case: Estimate the energy consumption and the saving potential for a fleet of distributor trucks

The analysis of transferability and replicability of results consists of four main tasks:

1. Identification of relevant transport missions and setting up adequate models.
2. Creation of single tasks given by reasonable starting and destination points on the map combined with the mass of the truck-trailer combination including load on the trip.
3. Application of the VMC Web Services to compute possible routes for the different trips, determining speed-profiles and thus travel time as well as fuel consumption of the different alternatives.
4. Computation of the possible savings for each mission when using the fuel saving route instead of the fastest or shortest one.

Saving potential Study: Task 1: Identification of relevant transport missions and setting up adequate virtual models

Selected scenarios:

- Petrol distribution
- Supermarket delivery
  - Hub-to-hub
  - Hub-to-supermarket

(Hub ≅ distribution hub)

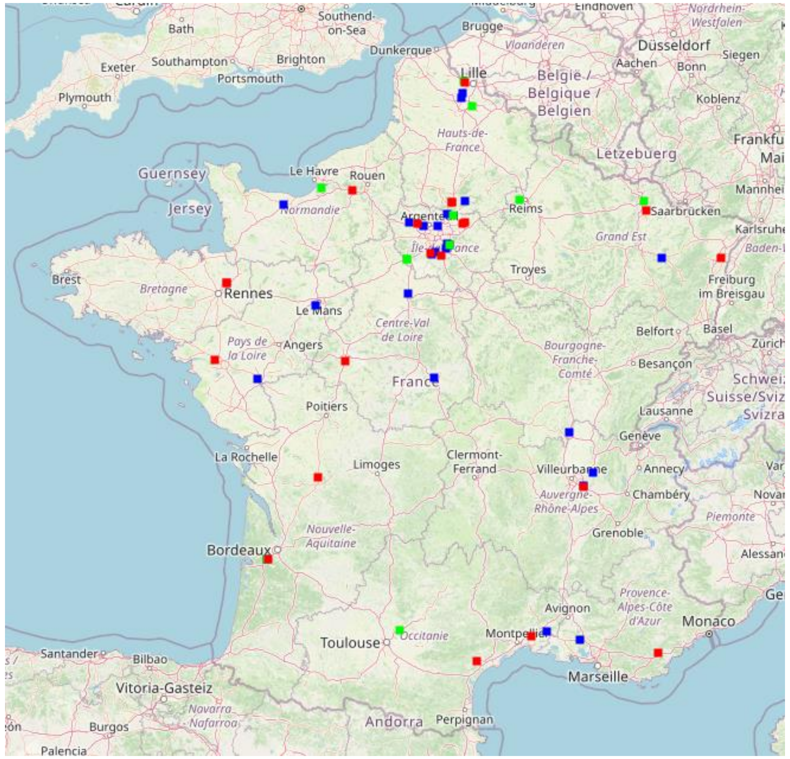
Advantages of chosen models:

- Simple and easy to understand
- Model known concepts in logistics
- Generation of thousands of ton-kilometers distributed evenly over whole country is possible
- Can be modelled using geographical data only without necessitating explicit distance distributions
- Differ in several aspects:
  - Including vs. excluding last mile
  - Hazardous and non-hazardous material
  - …
- Clustering in different sub-categories possible (operator, regions,…)

Saving potential Study: Task 1: Data research and preprocessing

Data sources used:

- VMC database
- OpenStreetMap
- Europétrole
- Homepages of supermarket operators to check completeness
- …

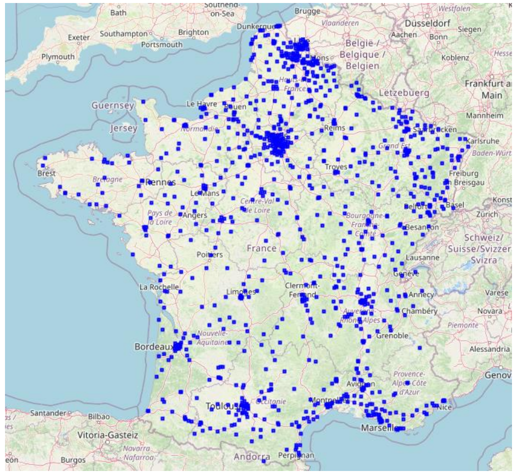


Preprocessing of data:

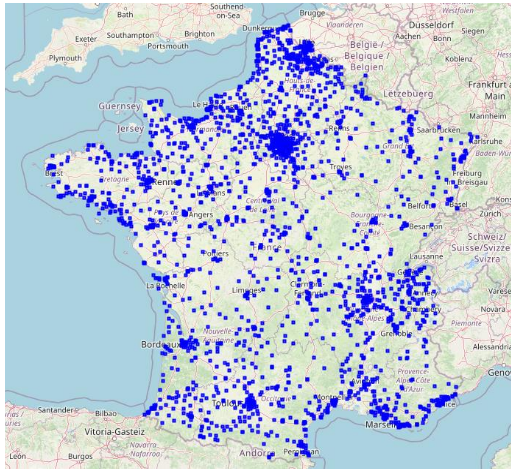
- Assignment of supermarkets to hubs resp. fuel stations to refineries/ depots
- Use shortest distance

Saving potential Study: Task 1: Data research and preprocessing - results

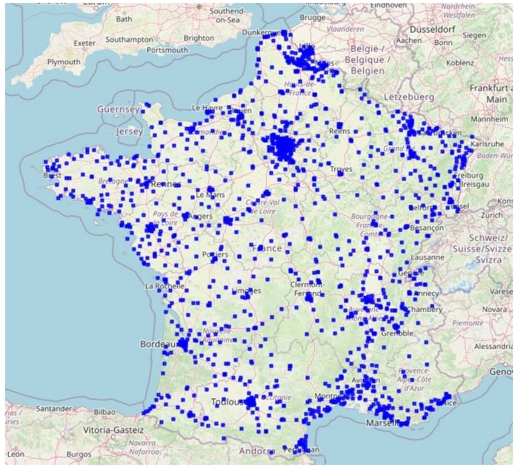
Aldi



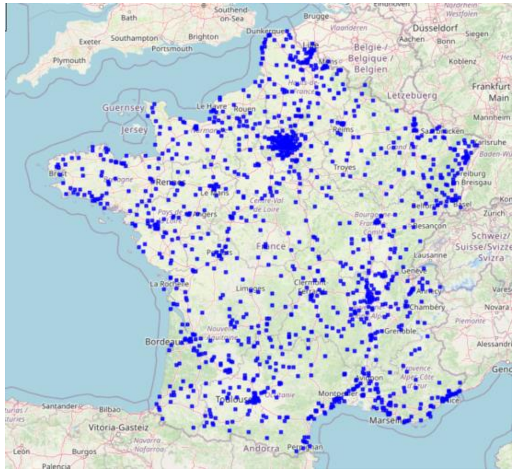
Carrefour



Lidl



TotalEnergies



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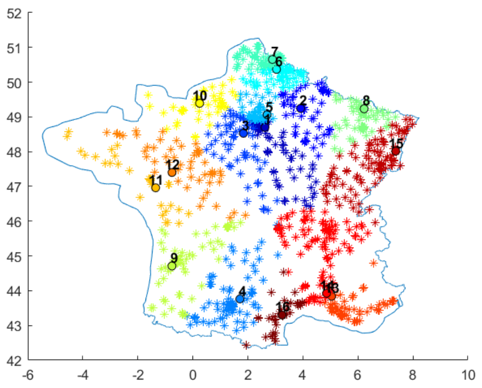
Saving potential Study: Task 2: Creation of single transport tasks

Computation of single routes is done in several steps:

- Assignment of supermarkets and fuel stations to hubs and refineries/ depots
- Trip calculation:
  - Hub-to-hub: Find shortest roundtrip between all hubs by solving traveling salesman problem
  - Hub-to-supermarket: Employ multiple traveling salesman problem restricting number of stops on individual tours
  - Petrol distribution: Connect each fuel station with refinery or storage and add return trip

Aldi



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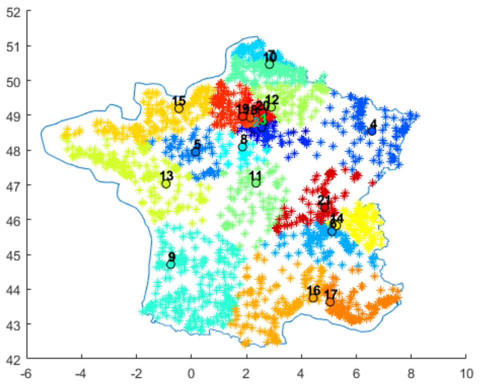

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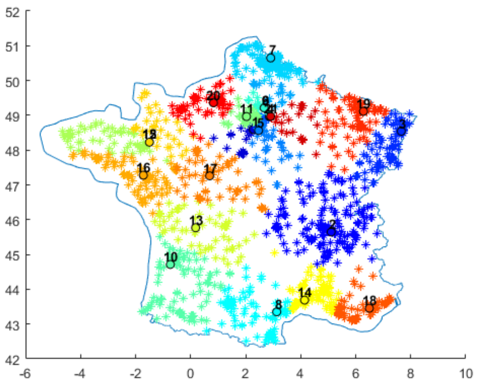
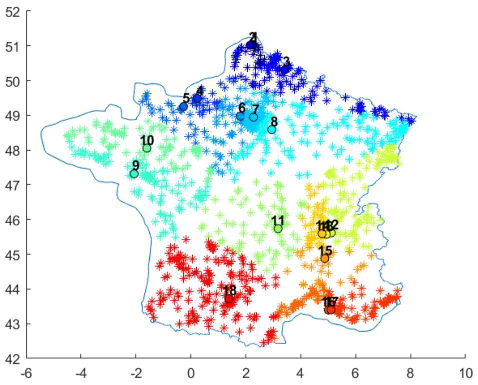


TotalEnergies



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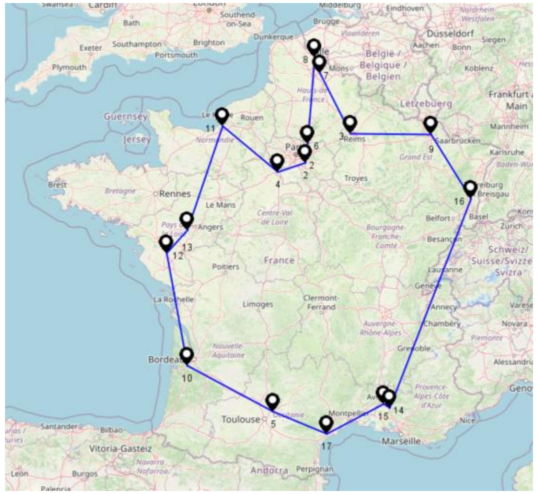
Saving potential Study: Task 2: Results of trip calculation (extract)

Aldi



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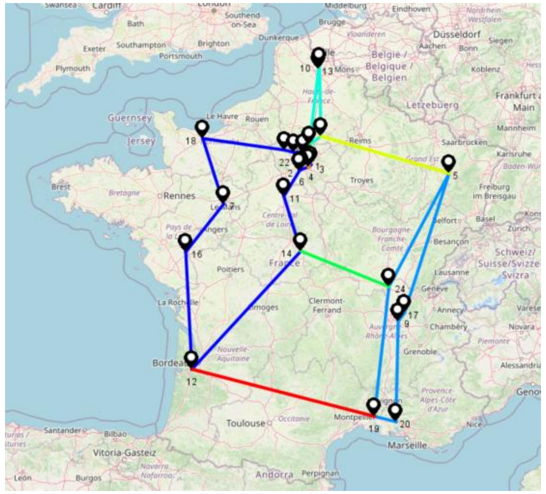

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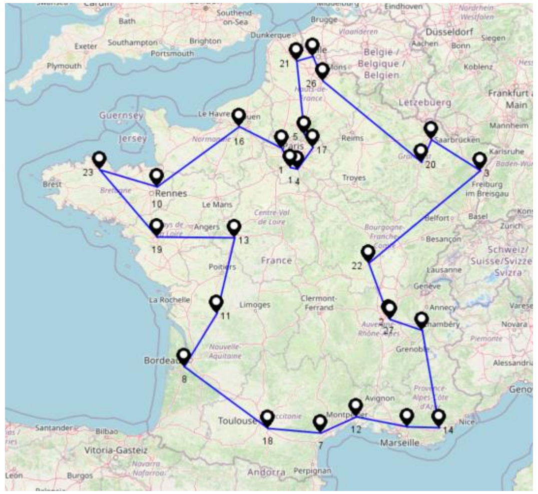
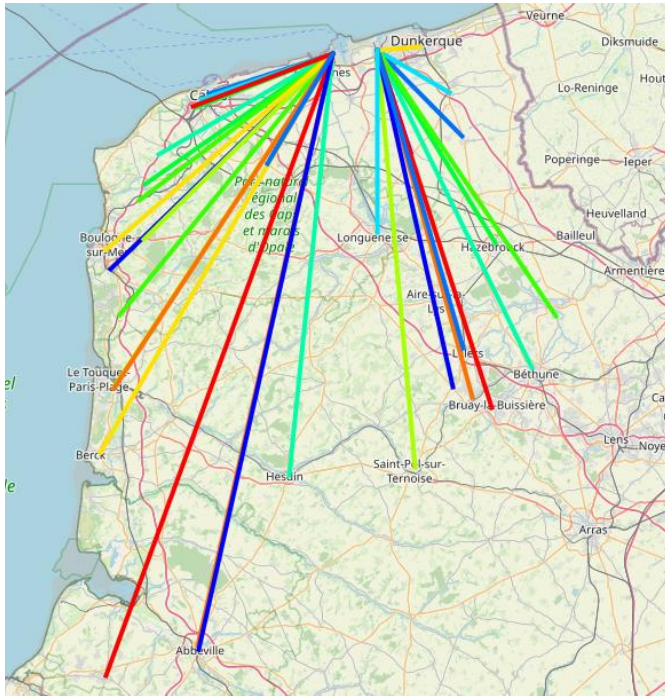
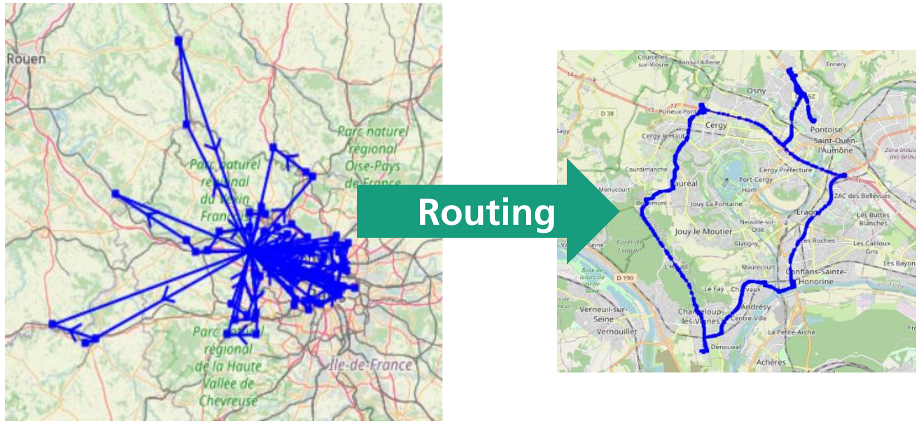


TotalEnergies





Trip calculation for Hub-to-supermarket includes several steps per hub:

1. Further clustering of stores to get feasible starting solution
2. Configuring multiple traveling salesman problem (mTSP)
3. Solving mTSP

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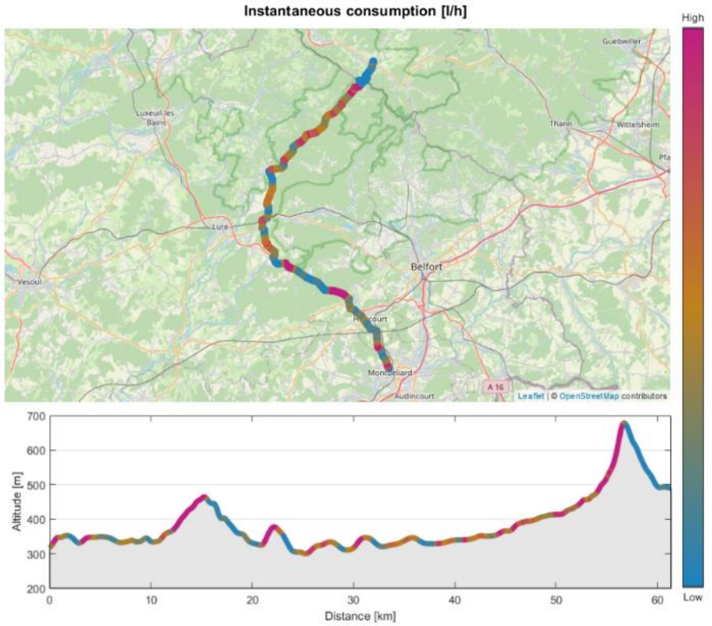
Saving potential Study: Task 3: Application of VMC Web Services

The VMC Web Services were called using truck settings depending on the scenario:

- Hub-to-hub: “Standard” truck, mass always set to 44t
- Hub-to-supermarket: Same truck model, mass decreases from 44t to 16t during tour, high mass truck in routing service
- Petrol distribution:
  - Full trailer for delivery routes, thus hazardous material classification
  - Empty trailer for return trips, hazardous goods classification is not longer required



Obtained results:

- Course of alternative routes
- Trip length, duration and expected consumption

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Saving potential Study: Task 4: Computation and analysis of savings

Computation and analysis of savings:

- Application of shortest traveling time as standard route
- Computation of decision score for each route part based on standard and fuel-optimized route
- Split results in different ways and compare expected savings:
  - Scenario
  - Operator
  - Regions
- Different splits include different numbers of route segments and kilometers
- Decision score $r = \frac{c_{orig}}{c_{opt}} * \frac{t_{orig}}{t_{opt}}$ supports the choice of a route alternative (consumption c, travel time t)

Scenario	Operator	Region	Share of better alternatives resp. fuel savings	
			$r > 0$	$r > 1$
Hub-to-hub	**all**	**France**	**23.0%, 1.16%**	**10.8%, 0.90%**
	Aldi	France	20.0%, 0.79%	16.0%, 0.75%
	Carrefour	France	22.2%, 0.65%	7.9%, 0.46%
	Lidl	France	25.5%, 1.88%	11.8%, 1.42%
Hub-to-supermarket	**all**	**France**	**42.1%, 2.48%**	**18.8%, 1.68%**
	Aldi	France	41.9%, 2.22%	18.2%, 1.43%
	Carrefour	France	43.0%, 2.98%	19.5%, 2.05%
	Lidl	France	41.3%, 2.50%	19.5%, 1.83%
Petrol distribution	**TotalEnergies**	**France**	**43.7%, 2.39%**	**14.0%, 1.27%**
	TotalEnergies	Northwest	43.0%, 2.75%	17.4%, 1.62%
	TotalEnergies	Southeast	44.7%, 2.02%	9.8%, 0.91%

Drive Train Development, Electrification and Extensions

Use Case: Analysis of saving potential of an electrified trailer axle

An electrified trailer axle for recuperation resp. generation of electric energy for a cooling unit (CU)

- Questions: How much energy can be recuperated and how does this depend on the properties of the specific mission (e.g., payload and topography)?

Approach of the exemplary study

- Setup a simple model for E-motor and battery.
- Calculate the potential savings for a selection of routes out of missions part of Ecotravid project
  - 595 selected routes (~58,000 km in total) between February 2020 and June 2021
  - Payload observed (approximately 50% empty and 50% close to full payload of 44t)

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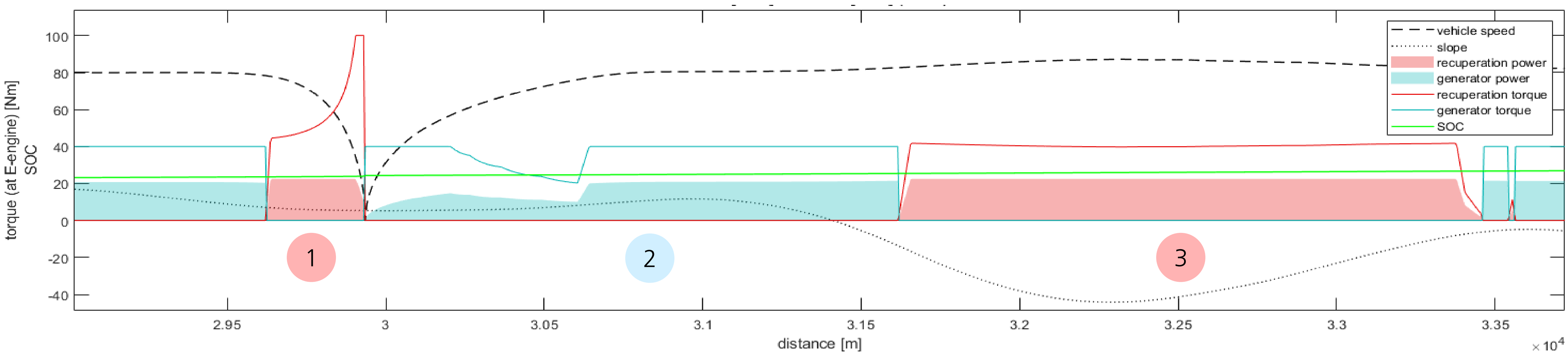
E-axle study: exemplary simulation results

- Mechanical work at truck engine output shaft =220 kWh
- Recuperated energy =7.0 kWh (3.2%)
- Some selected events are highlighted:

1 Recuperation at max. power (from medium to maximum torque) due to braking

2 Generator mode mostly at max. torque due to low SOC

3 Recuperation at max. power due to downhill driving



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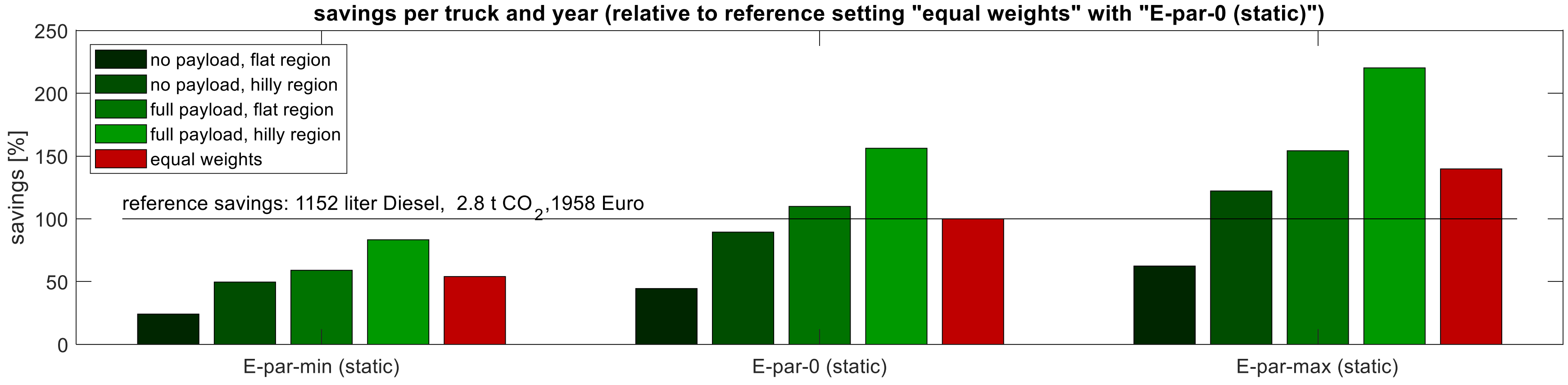
E-axle study: Summary of results

Savings are considerable and clearly depend on the operating conditions and the axle parameters

- The saving potential for the default e-axle setting in the mixed application is 1152 litres per truck and year
- The payload as well as the topography have a high impact on the recuperation potential.
  - The factor between empty and full is approx. 2.5 resp. 1.8 in the flat resp. hilly region.
  - The factor between flat and hilly is approx. 2.0 resp. 1.4 for empty resp. full payload.
- The parameters of the e-axle have a high impact too: 1.8 between min and default, 1.4 between default and max.



- CO_2 emissions: ~2.41 [kg/litre]
- Fuel costs: ~1.70 [€/litre]

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Use Case: Saving potential of optional attachments

A trailer can be equipped with optional attachments reducing aerodynamic resistance. Truck and trailer can be equipped with tires with reduced rolling resistance.

- Questions: What influence do the various options for reducing fuel consumption have in real traffic?

Approach of the exemplary study

- Setup a model for a reference trailer truck without attachments and default tires
- Calculate the potential savings for a selection of routes by
  - Reducing air drag coefficient due to attachments
  - Reducing rolling resistance using fuel-efficient tires

  on the trailer

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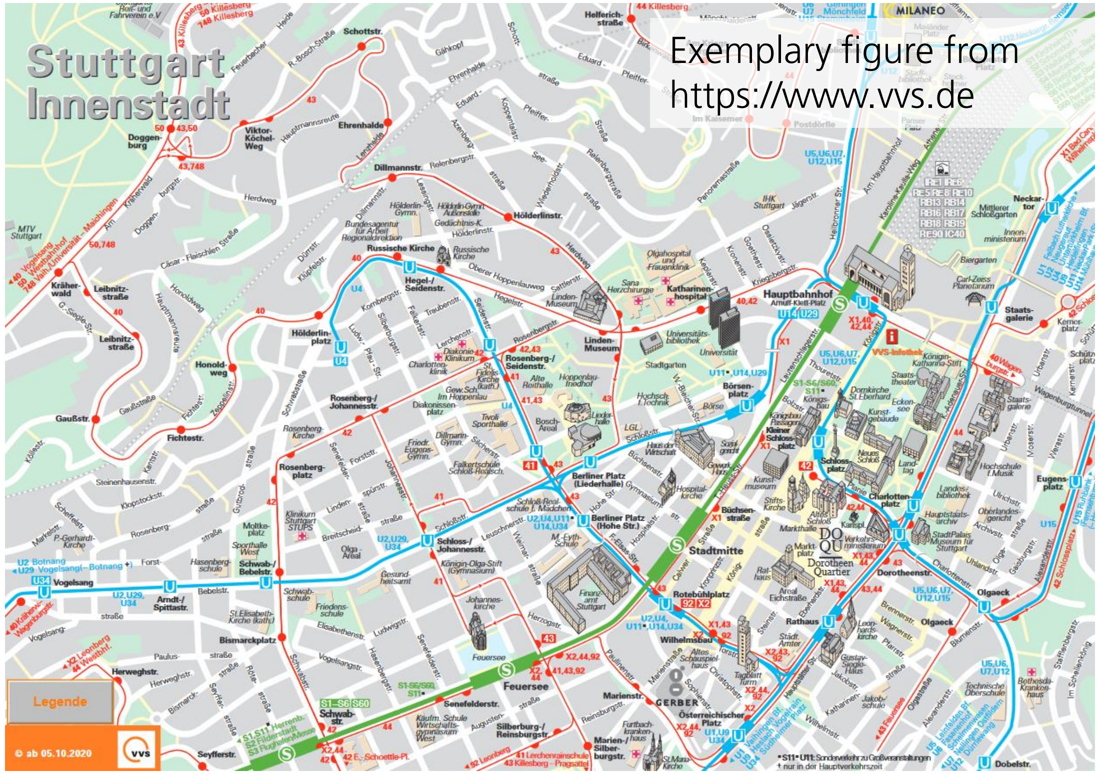
Use Case: Establishing E-drives in operation of busses on line networks

Commonly desired goal

- Especially in cities, it is of great interest to reduce emissions of combustion engines.
- Public transportation should contribute

Task

- Bus manufacturers and operators need to check the capabilities of alternative driveline concepts against the requirements of the local line network.



Exemplary figure from https://www.vvs.de

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Summary

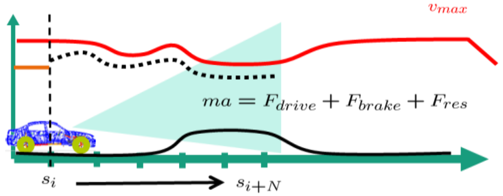
The key to solving the initial tasks …

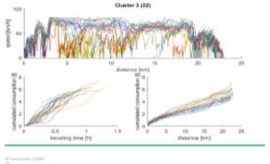
… has been the combination of

The availability and usage of detailed road network data

The knowledge of the transport mission resp. the capability of modelling and simulating vehicle usage

The vehicle simulation capabilities based on measurement-calibrated models





… as well as the development and application of the corresponding web services

- Fleet management
  - Ecotravid
- Vehicle development
  - E-mobility applications
  - Drivetrain
  - …
- …

VMC

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Fraunhofer ITWM

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