ESTIMATING CO_2 EMISSIONS THROUGH TRAVEL TIME

Michael Ortgiese

Here GIS Day 2025, November 20th 2025

DLR

Agenda

- Motivation
- Simulation Laboratory
- Context Model
- Detection Infrastructure
- Evaluation and Roll-Out

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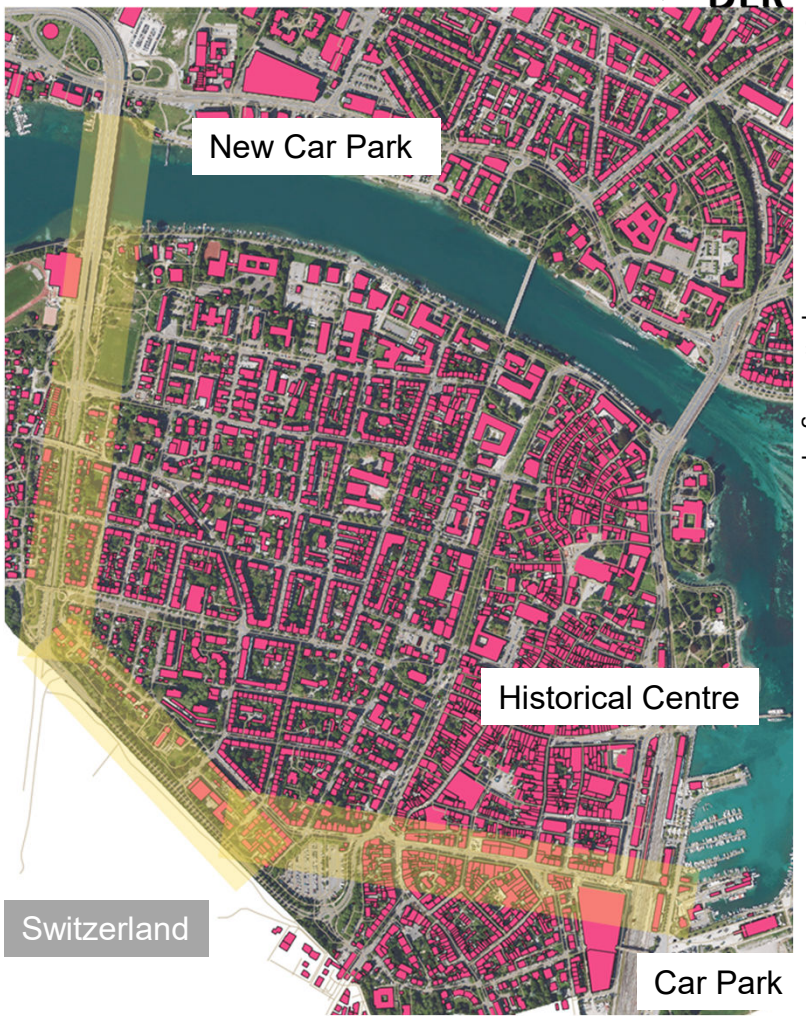
Motivation – Travel time based CO2-emission estimation

- The historical centre of Konstanz is frequently visited by tourists from Switzerland.
- The objective is to reduce private motorised traffic in the city centre and CO2 emissions.
- Measure: A new car park north of the Rhine
- Challenge: The journey time from the new car park to the historical centre is relatively long (shuttle, walk).
- The traffic management is intended to motivate commuters to use the new car park.
- Idea to Increase acceptance:
  Providing information on current CO2 emissions
- CO2 emissions are to be estimated based on travel time.
- A sensor concept and a model are to be developed for the estimation.
- Addition: Monitoring of cross-border traffic on the Europastraße.



Own Illustration based on: https://www.geoportal-bw.de

AP 3: Technical principles for recording the environmental situation

Regulatory framework in Germany:

AIR QUALITY (Health) 🏭

- 2025 - Constanz met EU limits (EU 2008/50/EC) for the first time:
  No NO_2emissions above the annual average limit of 40 µg/m³
  No PM2.5/PM10 above the annual average limit of 50 µg/m³.
- From 2030: Stricter EU limits: NO_2: 20 µg/m³ (instead of 40 µg/m³), $PM_{2,5}$: 10 µg/m³ (instead of 25 µg/m³)
- Current Deficits:
  - 44% of measuring stations do not yet meet the NO_2 target of 20 µg/m³;
  - 4% fail to meet the $PM_{2.5}$ target of 10 µg/m³

CLIMATE PROTECTION (CO_2) 🌎

- EU FLEET LIMITS: 95g CO_2/km (from 2025), -55% CO_2 (2030 vs. 2021)
- GERMAN KSG: Transport: 85 million tonnes of CO_2 (2030)
- ETS 2 (from 2027): a new CO_2 pricing system for road transport

Many cities see further needs for action

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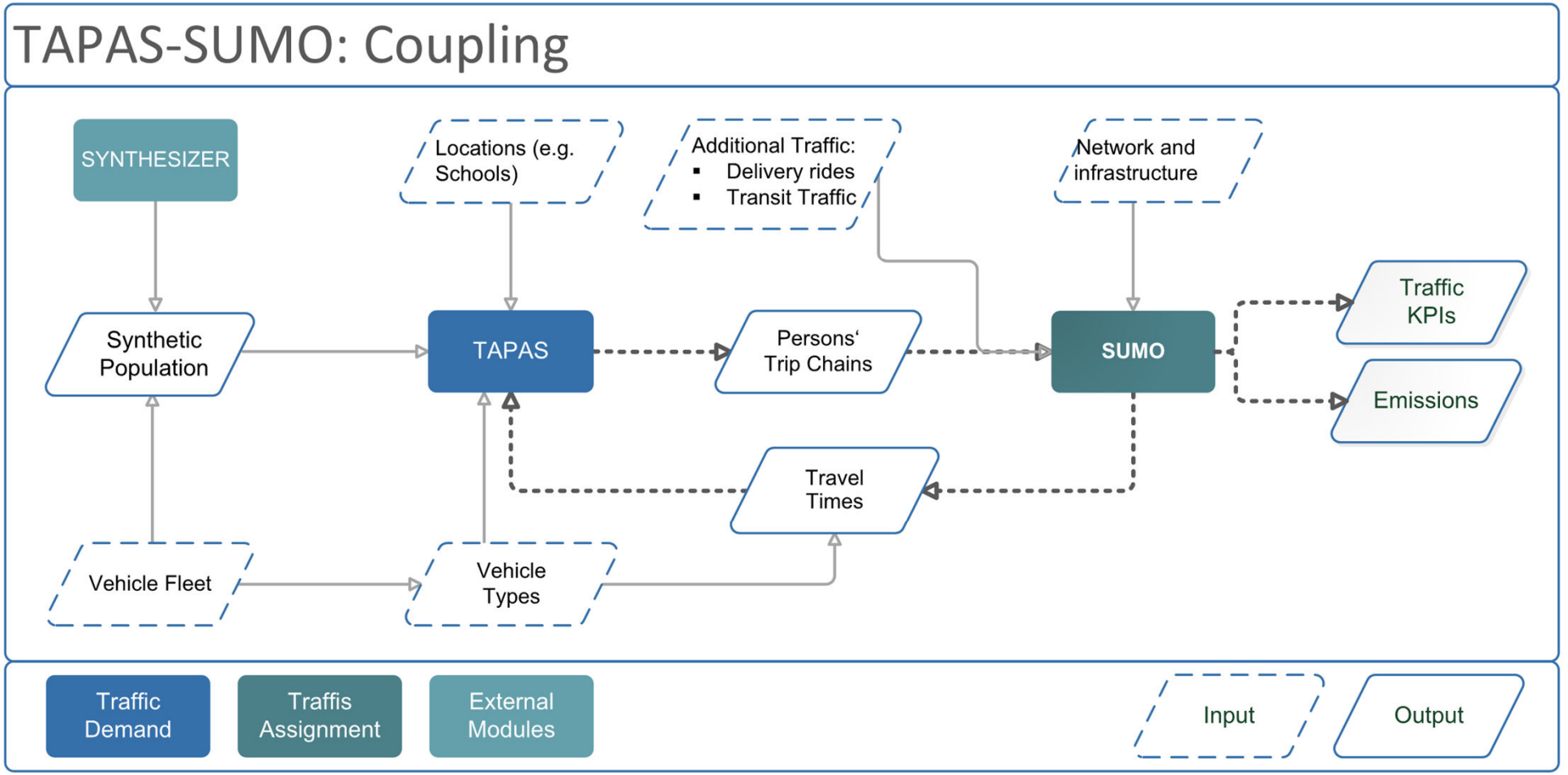
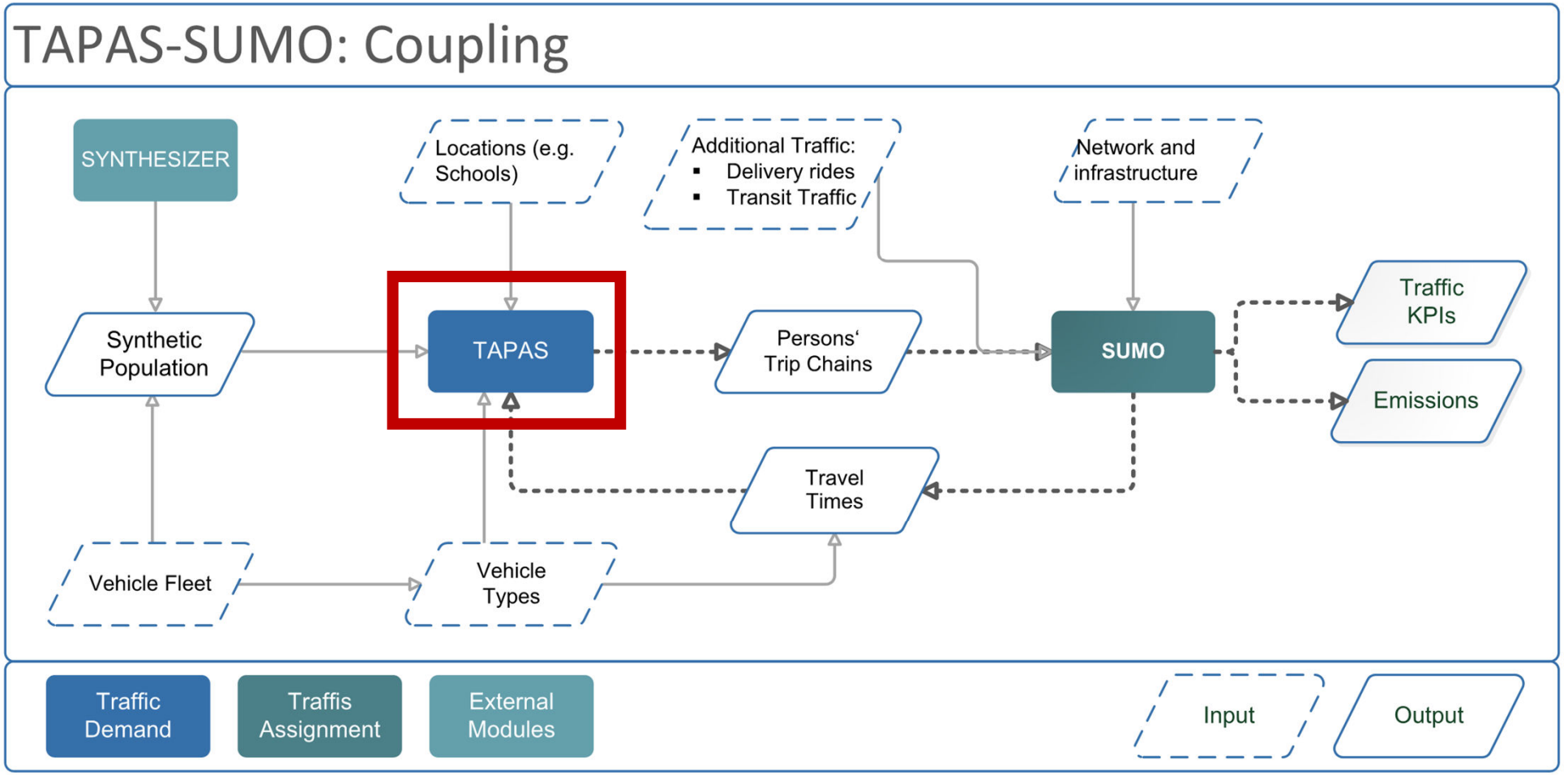
Simulation Laboratory



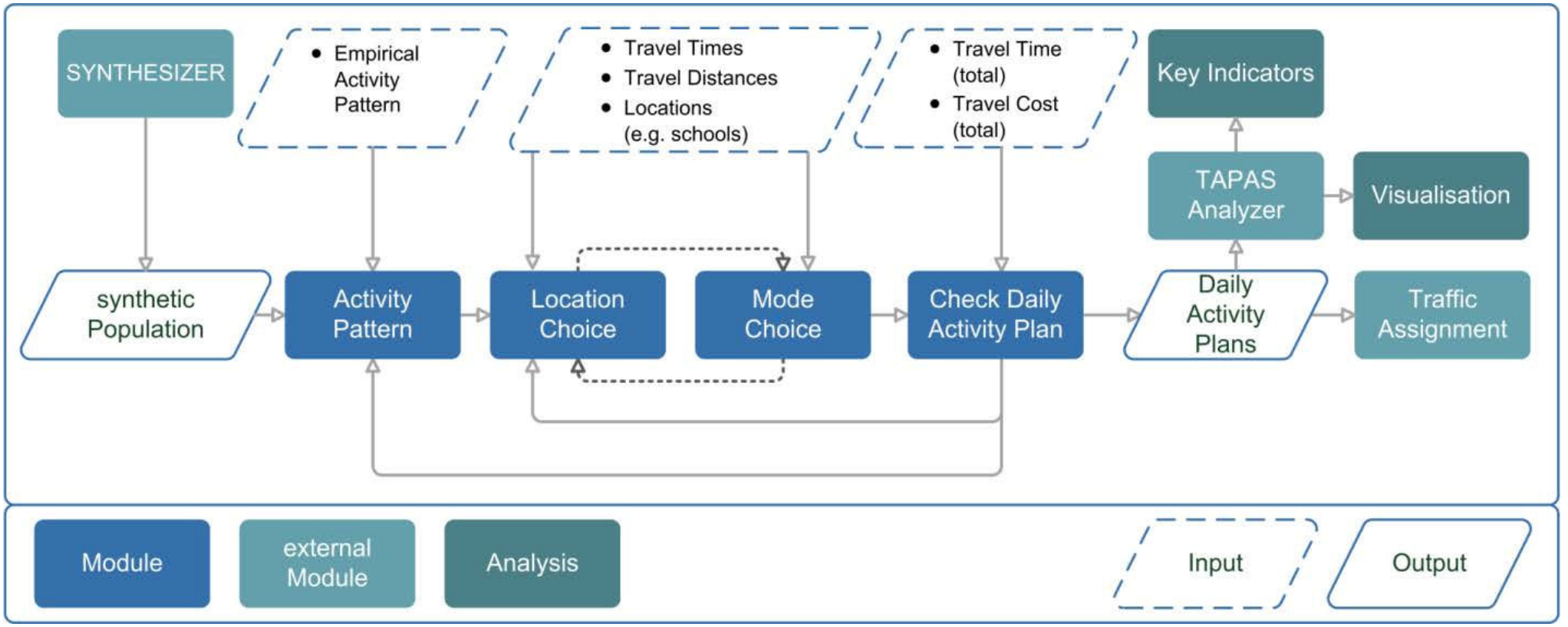
Own Illustration

Simulation Laboratory



Own Illustration

Simulation Laboratory - TAPAS 1/2



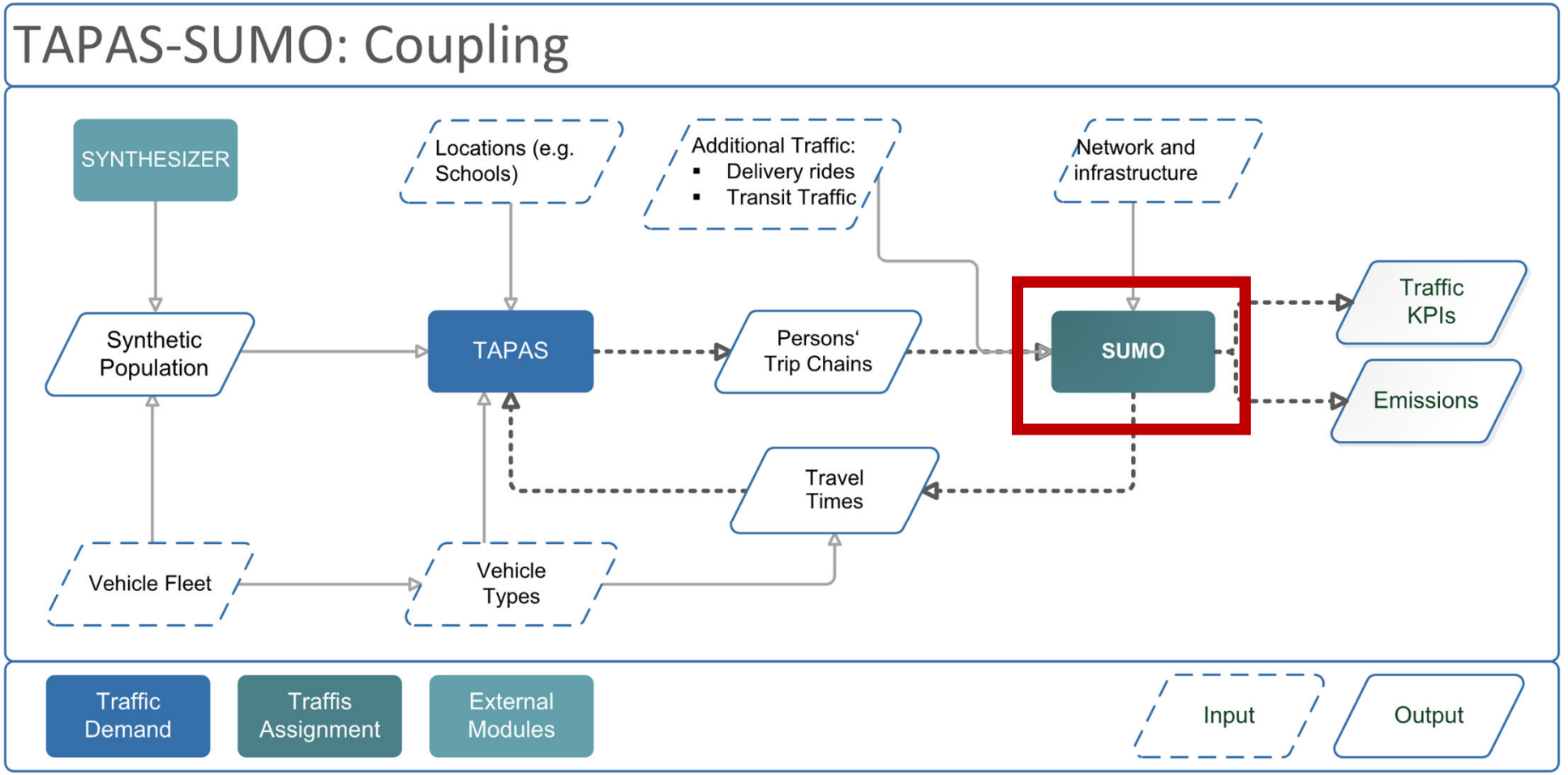
Own Illustration

Simulation Laboratory - TAPAS 2/2

- TAPAS is an agent-based demand model
- What does "agent-based" mean?
  - Each individual person is represented separately
  - Has characteristics such as age, gender, employment status (including schoolchildren and
    university students), driving licence, public transport pass, etc.
  - Belongs to a group of people
  - Selects their daily schedule according to templates that suit this group
- Special feature: Grouping by households
  - Certain mobility options (e.g. a car) can be used by different people throughout the day.
    different people
  - Ownership and use are mapped across the household
- Result of a simulation: Travel chains of individual persons on an average weekday

Own Illustration

Simulation Laboratory

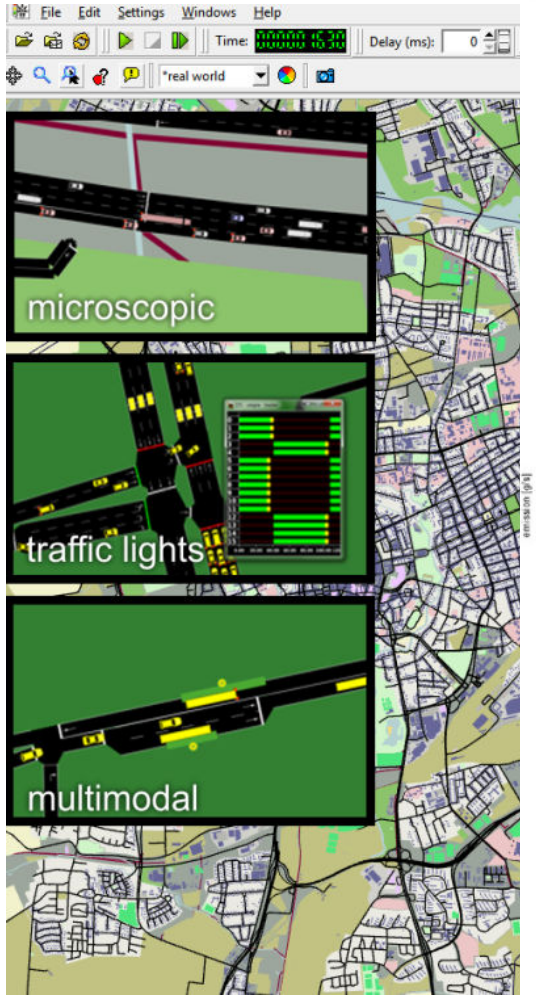


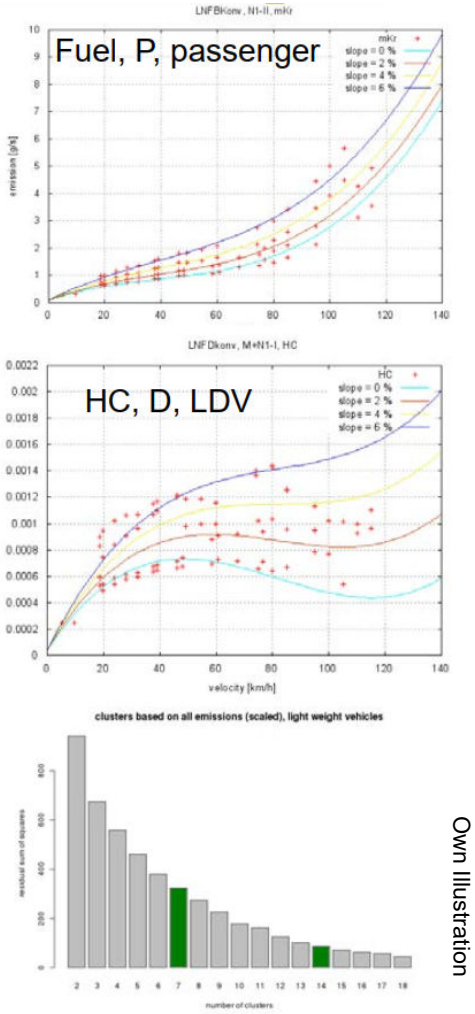
Own Illustration

Simulation Laboratory - Sumo 1/3

Overview

- Microscopic and easily parameterisable
- Covering the entire vehicle fleet
- Classification according to EURO standards
- CO, CO2, NOx, PMx, HC, and consumption
- Emission calculation for all vehicles in each simulation step
- Standard models integrated (HBEFA 2.1, 3.1, PHEMlight)
- Pre-calculated model parameters are stored as clustered hydrographs in SUMO for fast calculation





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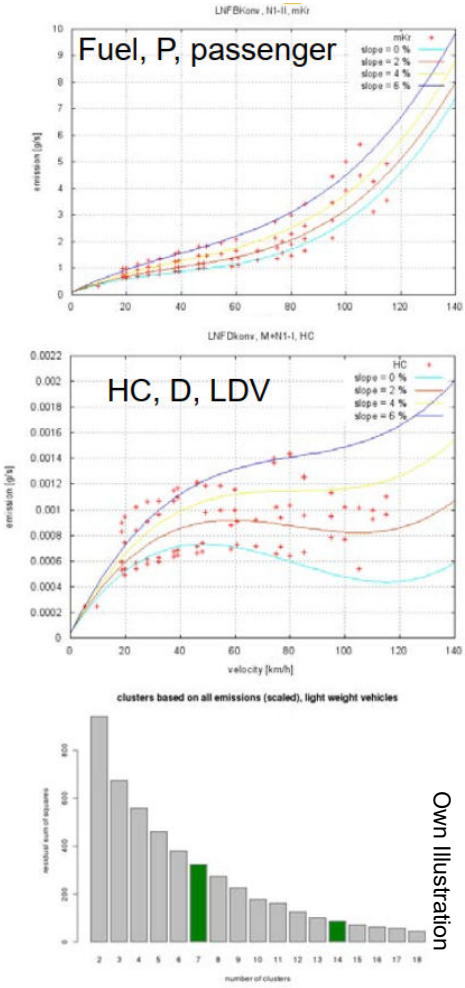
Simulation Laboratory - Sumo 2/3

Emission

Requirement	HBEFA 2.1-based	HBEFA 3.1-based	PHEMlight
No. of emission classes	56*2(+1)	45(+1)	112(+1)
coverage	no modern (Euro 6) and seldom classes	Major passenger, heavy duty, and bus classes	almost complete
Euro-Norms	-	x	x
Covers chosen polutants	x	x	x
Uses speed	x	x	x
Uses acceleration	x	x	x
Uses slope	-	-	x
Needs further attributes	-	-	- (are included)
Step-size resolution	x	x	x
Easy parameterization	x	x	x



Own Illustration

Simulation Laboratory - Sumo 3/3

- Simulation of vehicle classes according to HBEFA4.2:

1. Breakdown into cars, minibuses, lorries, buses and motorcycles based on the average of city centre detectors K07 and K11
2. Distribution by emission classes according to HBEFA4.2 Fleet mix (2022)
   7 passenger cars, 5 minibuses, 3 lorries, 3 buses, 2 motorcycles
3. Combination with different driver types
   5 passenger cars, 3 minibuses, 3 lorries, 1 bus, 1 motorbike
4. Powertrain Type based on statistic data for Constanz

https://sumo.dlr.de/docs/Models/Emissions/HBEFA4-based.html

Vehicle type	SUMO emission class	Fleet share 2022	scale 100%	City detector KN07 & KN11	Result %
Passenger				85.35	
	PC_petrol_Euro-4	18.60	26.41		22.54
	PC_petrol_Euro-6ab	14.34	20.36		17.38
	PC_petrol_Euro-5	13.64	19.37		16.53
	PC_petrol_Euro-6d-temp	7.16	10.16		8.67
	PC_petrol_Euro-6d	6.28	8.92		7.61
	PC_diesel_Euro-6ab	6.24	8.85		7.56
	PC_diesel_Euro-5	4.18	5.93		5.06
Light vehicle				5.15	
	LCV_diesel_N1-III_Euro-6ab	21.96	31.79		1.64
	LCV_diesel_N1-III_Euro-5	20.04	29.00		1.49
	LCV_diesel_N1-III_Euro-4	11.87	17.19		0.89%
	LCV diesel N1-III Euro 6d	7.81	11.30		0.58
	LCV_diesel_N1-III_Euro-6d-temp	7.41	10.72		0.55
City bus				1.50	
	UBus_Artic_gt18t_Euro-VI_A-C	29.20	52.72		0.79
	UBus_Artic_gt18t_Euro-V_SCR_(DPF)	15.18	27.41		0.41
	UBus_Artic_gt18t_Euro VI_D-E	11.00	19.86		0.30
Motorbike				4.00	
	MC_4S_gt250cc_preEuro	15.43	53.06		2.12
	MC_4S_gt250cc_Euro-3	13.65	46.94		1.88
Heavy goods				4.00	
	TT_AT_gt34-40t_Euro-VI_A-C	21.58	51.81		2.07
	TT_AT_gt34-40t_Euro-VI_D-E	14.99	35.99		1.44
	RT_le7.5t_Euro-VI_A-C	5.08	12.20		0.49

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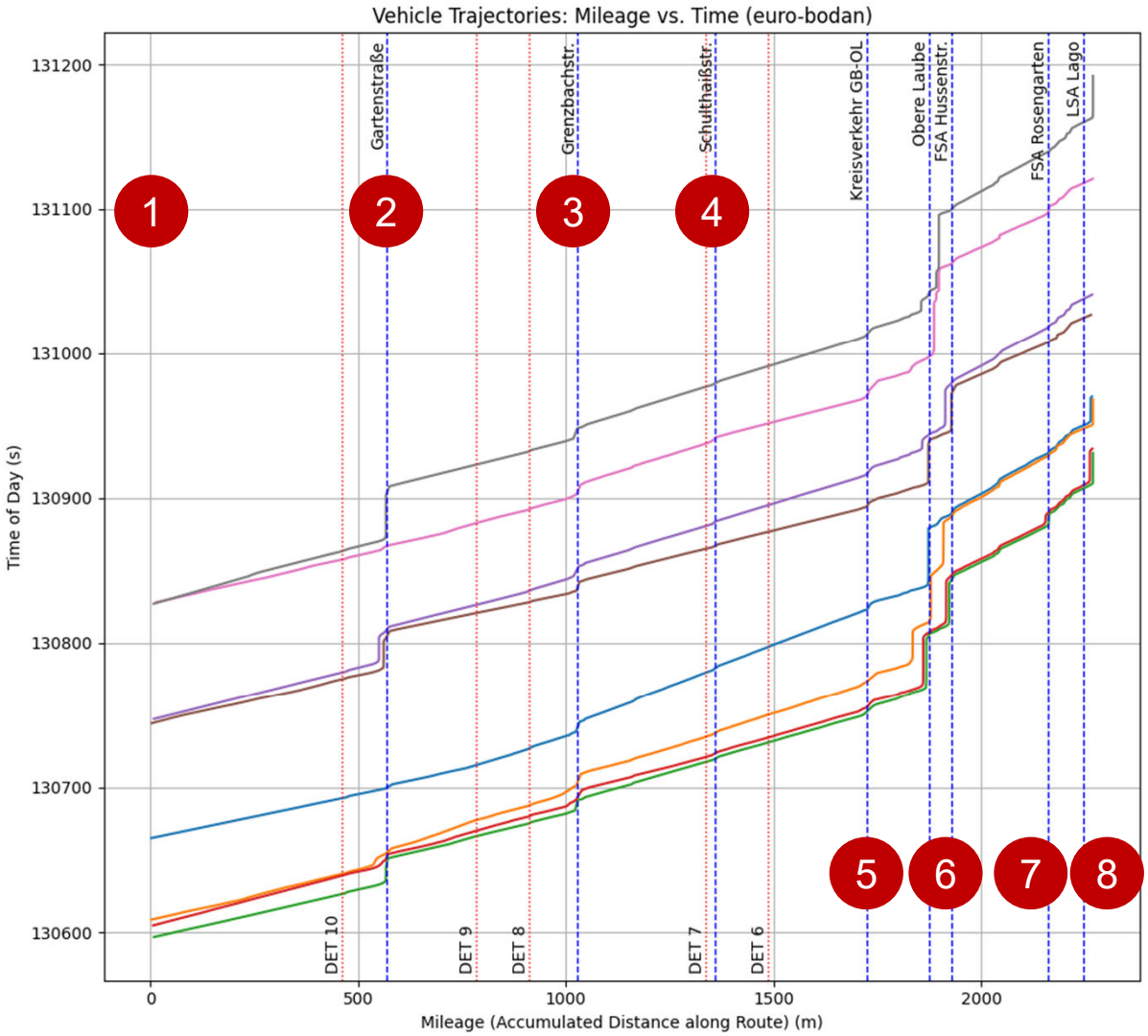
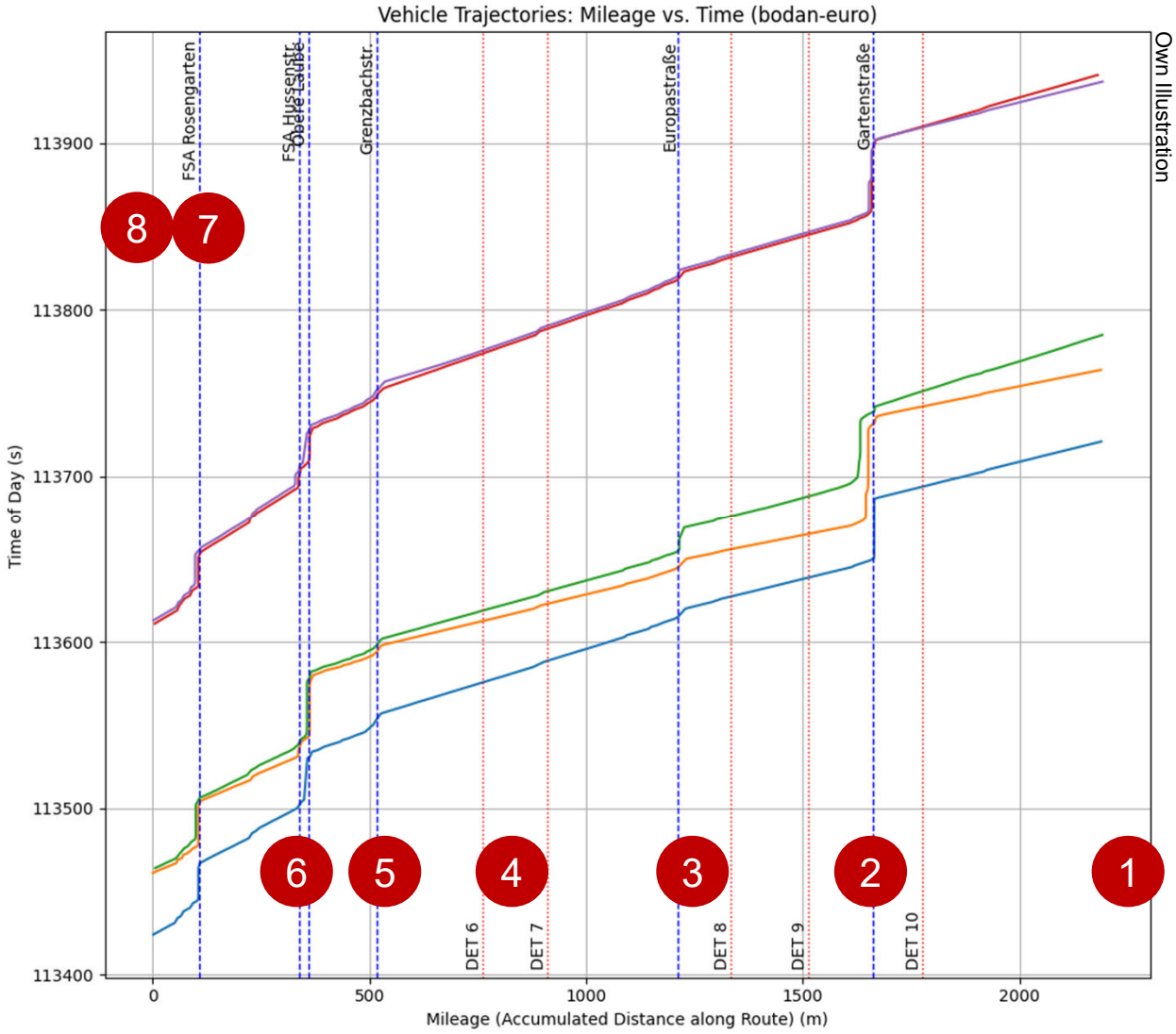
Simulation laboratory



Own Illustration based on Apple Maps

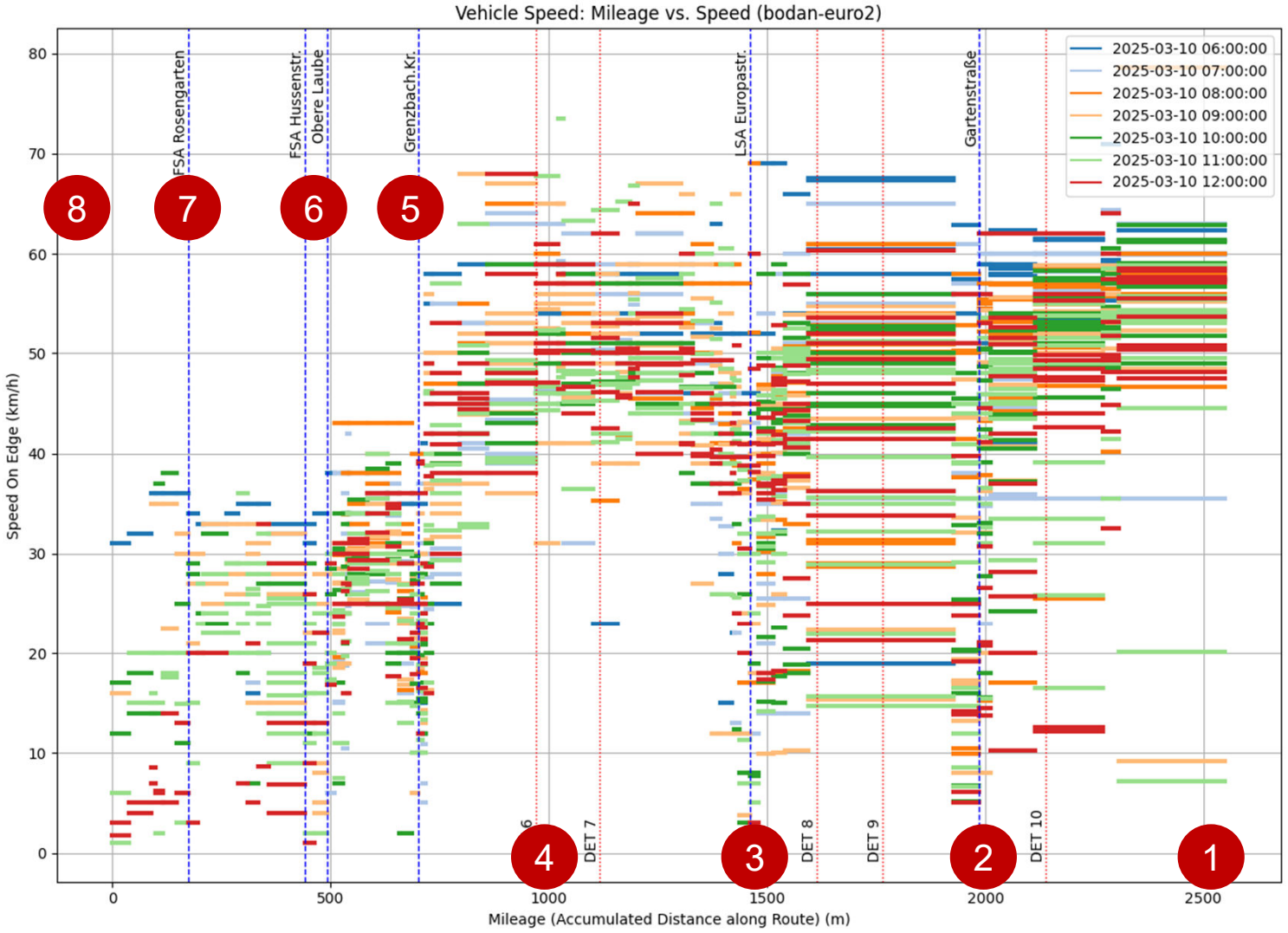
Simulation laboratory

Own Illustration based on Apple Maps



Own Illustration

Simulation lab – FCD from HERE



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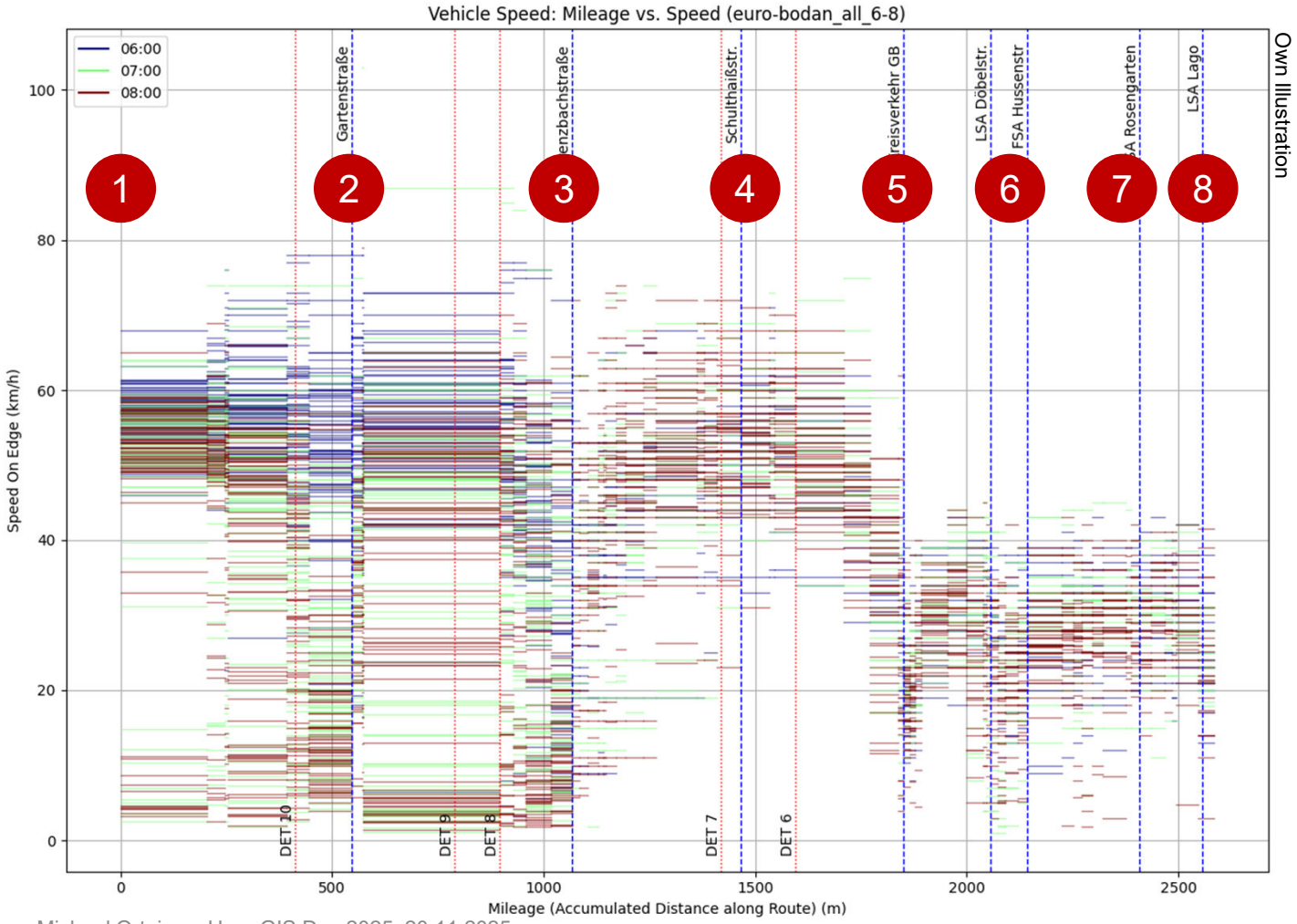


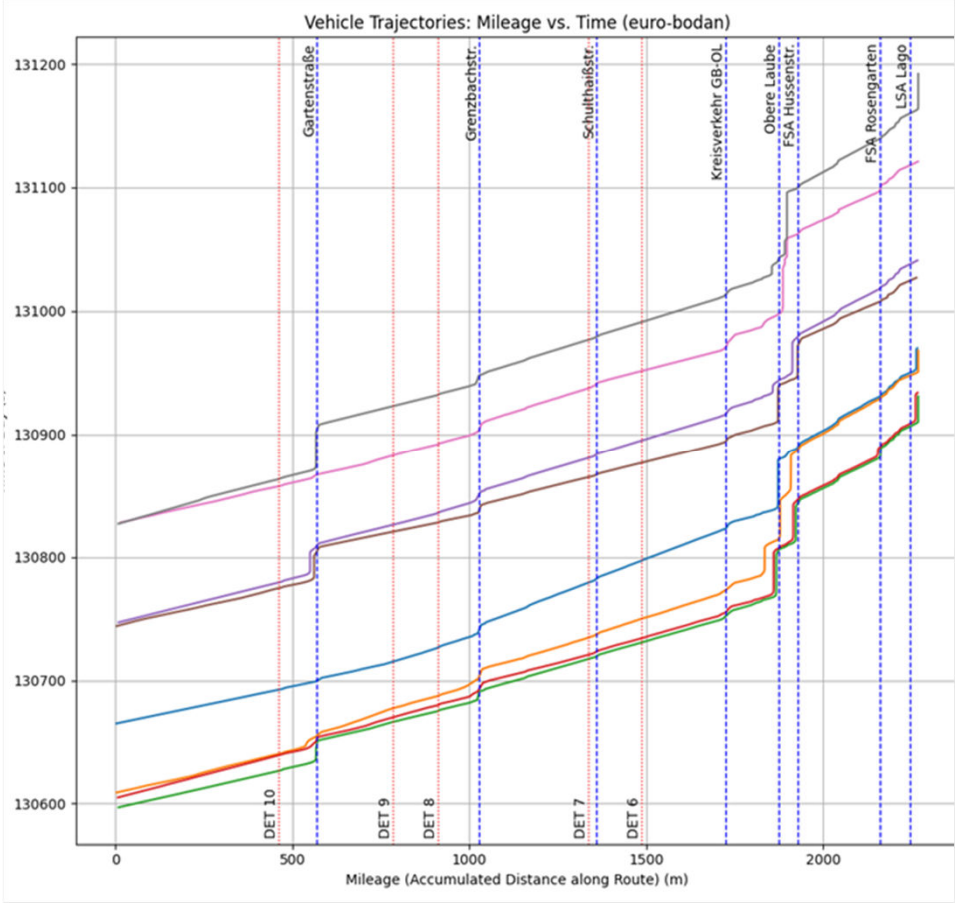
Own Illustration

Own Illustration based on Apple Maps

Simulation laboratory & FCD – traffic flow

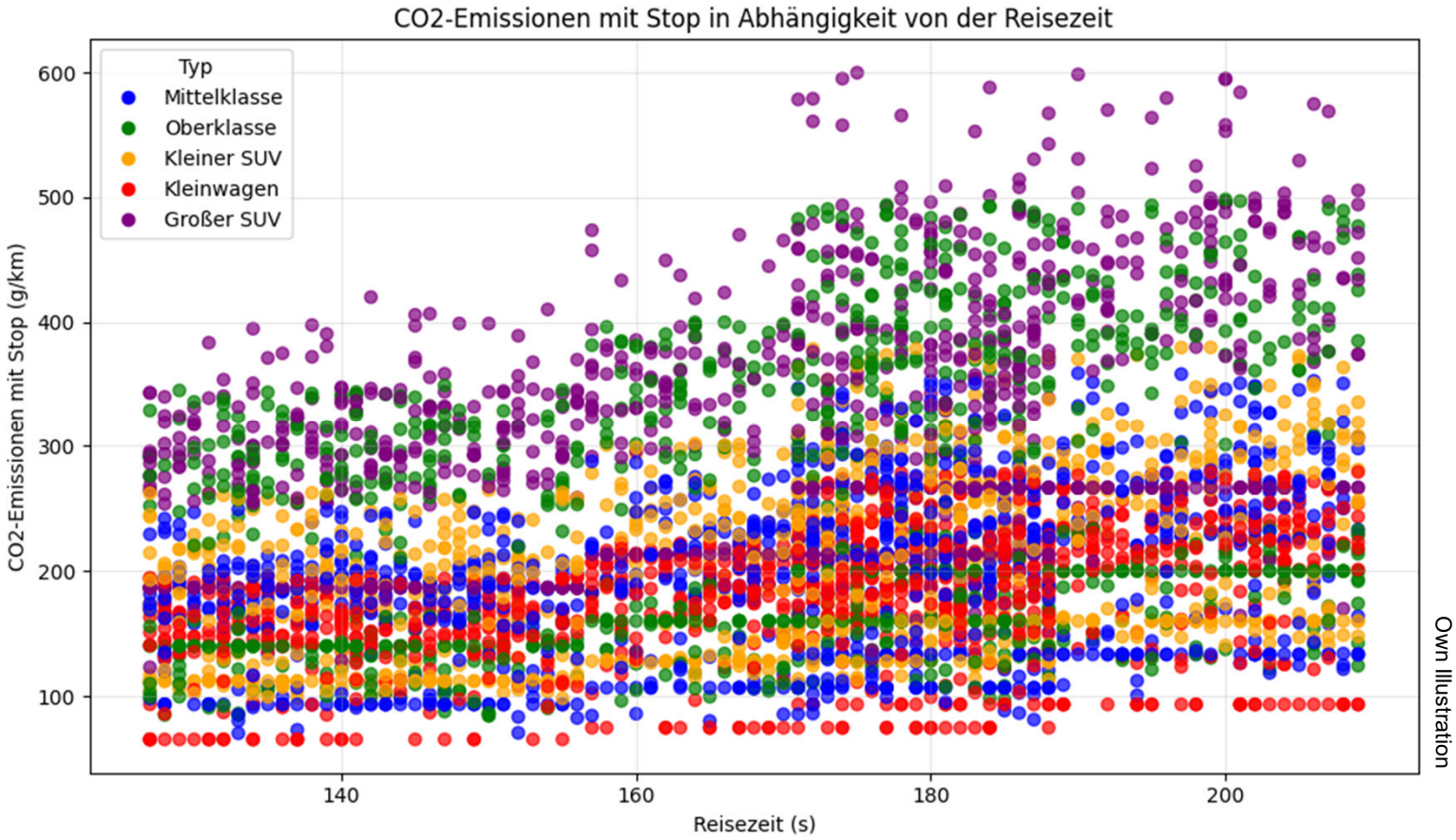
- Traffic flow along the route is significantly influenced by start and stop processes.
- Travel times provide a good initial indication of traffic flow, but do not reflect it completely.
- The undisturbed driving speed (30-60 km/h) in urban areas has only a very minor impact on emissions (which tend to be higher at lower speeds).
- Vehicle type (size) and drive type have a significant impact on emissions, leading to large variations.
- A good emissions estimate must take infrastructure conditions into account.
- Traffic load influences the overall balance.

Requirements for detection
Trajectory, vehicle data, traffic volume, data protection



Own Illustration

CO2 emissions with stops at travel times by vehicle class



Own Illustration

Context model with a simple neural network

	Feature				Static Assessment		
	Typ	Powertrain Type	Travel Time	Number Stops	MAE g CO_2 / km	MSE (g CO_2 / km)^2	R^2
Szenario 1	x	x	x	x	19	664	0,93
Szenario 2	x	x	x		24	1065	0,88
Szenario 3	x	x		x	20	675	0,93
Szenario 4	x			x	61	5550	0,39

Metrik	Value	Description
Mean Absolute Error (MAE)	19	The MAE indicates the average absolute error between the predicted and actual values. A value of 19 means that the predictions deviate from the actual values by an average of 19 units.
Mean Squared Error (MSE)	644	The MSE measures the average squared error between the predicted and actual values. A higher value compared to the MAE indicates that there are some larger errors in the predictions, as larger errors are weighted more heavily.
R^2 Score (R-Square)	0.93	The R^2 score indicates how well the model explains the variance of the dependent variable. A value of 0.93 means that the model explains 93% of the variance in the data, which indicates that the model fits the data very well.

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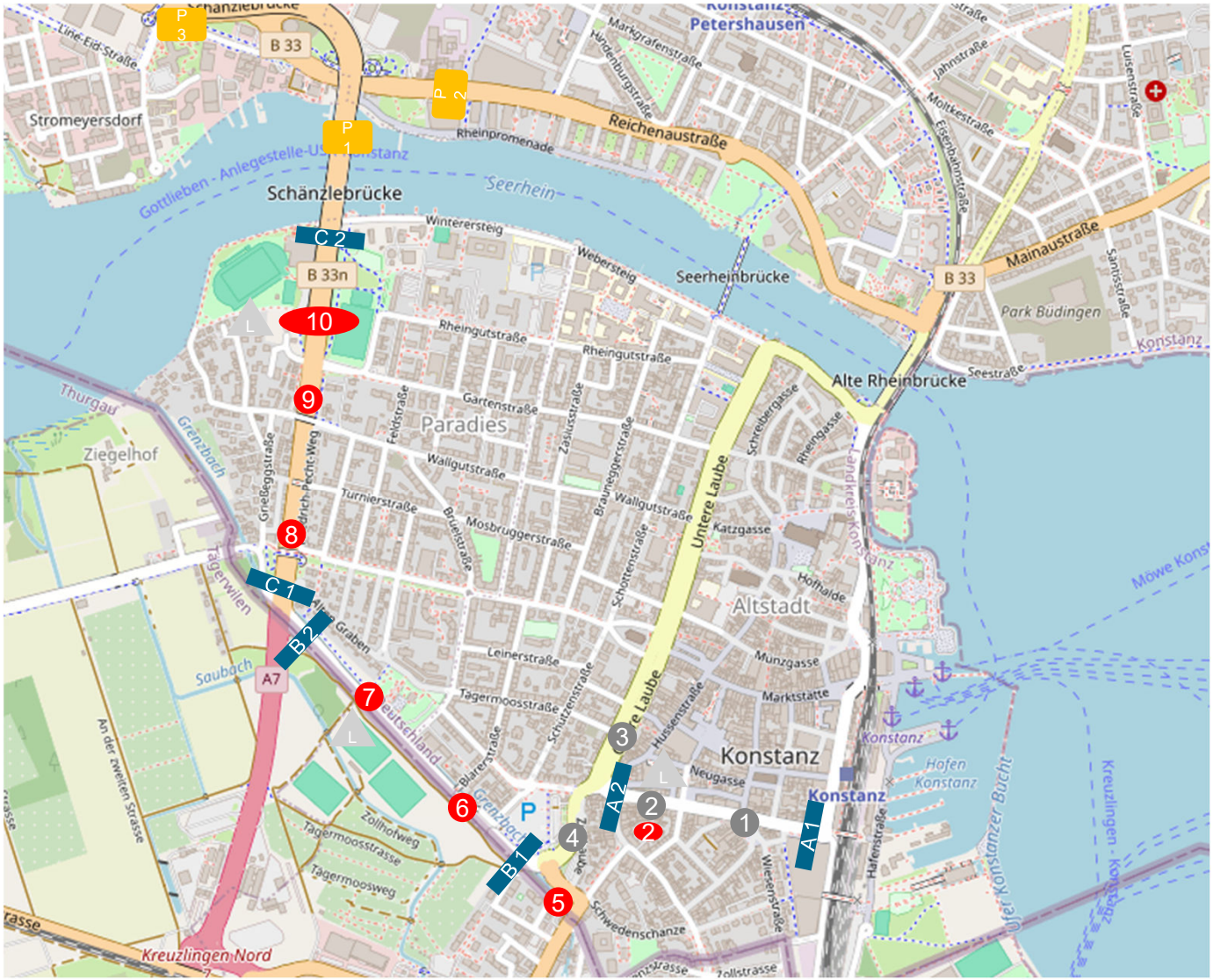
Suitability of detection methods

	Infrared	Thermal imaging camera	Radar	Lidar	Camera	Bluetooth	FCD
Trajectory	-	-	-	-	travel time only	Travel time only	Complete
Vehicle type	Powertrain	Size Powertrain	-	Size No Powertrain	Size No Powertrain	-	-
Traffic volume	X	X	X	X	X	-	-
Data protection	Anonymous	(Anonymous)	Anonymous	Anonymous	Licence plates and faces are recorded	MAC address is recorded	Provider Anonymised



Own Illustration based on Google Maps

- Location of air sensors
- 1 2 3 4 Detectors Inventory
- 2 Supplementary LIDAR sensor technology Veh
- Measurement section Distance measurement
- 5 Traffic volume, speed **Infrared**, radar
- 6 Traffic volume, speed **Infrared**, radar
- 7 Vehicle classes, traffic volume, speed **LIDAR**, camera
- 8 Traffic volume, speed **Infrared**, radar
- 9 Traffic volume, speed – traffic light control **Infrared**, radar
- 10 Vehicle classes Traffic volume, speed **LIDAR**, camera
- P 1 Detection system Car park **Camera**

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Variant comparison Costs

Full expansion

System	Installation costs	Annual operating costs
Traffic detection	€235,000	€15,000
Environmental detection	€150,000	€22,500
Software context model	€100,000	€10,000
3 display cross-sections	€150,000	€7,500
Software service platform	€100,000	€10,000
Total	€735,000	€65,000

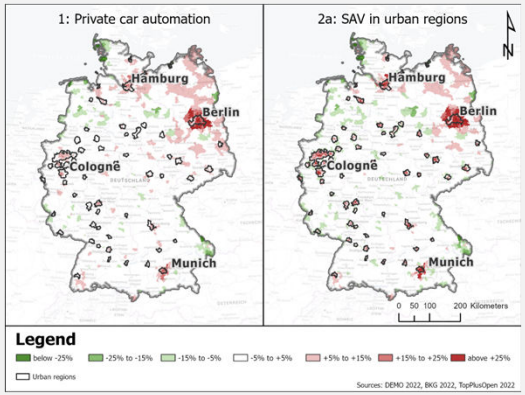
Initial solution

System	Installation costs	Operating costs/year
Traffic detection	€235,000	€15,000
Environmental detection Measurement campaigns		€35,000
Software context model	€100,000	€10,000
3 display cross-sections		- €
Software service platform	€50,000	5,000
Total	€385,000	€65,000

Car Ownership Model CHARGIN

Transformation of transport at national level

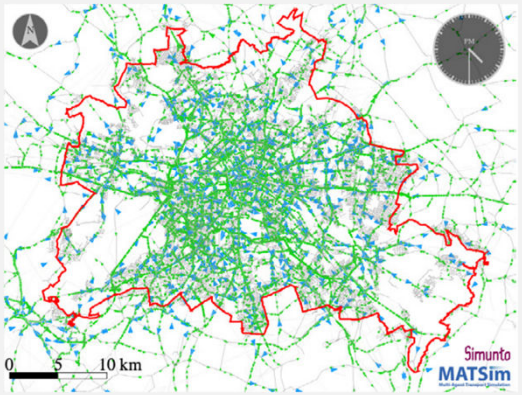
CAST & DEMO models



- Car ownership as a long-term decision that determines transport demand
- Vehicle stock and technology diffusion in annual increments (CAST model) in combination with adjusted car availability rates by region (DEMO model)

Designing public transport systems

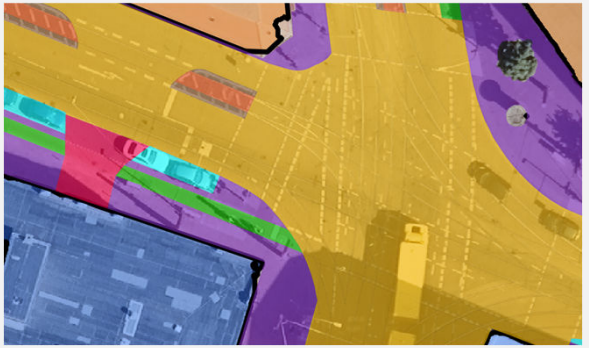
MATSim & UrMoAC models



- Potential analysis and design options for demand-responsive transport (DRT)
- Intermodal integration Feeder services
- Strategic route network planning
- Acceptance analysis and systemic evaluation

Planning charging infrastructure

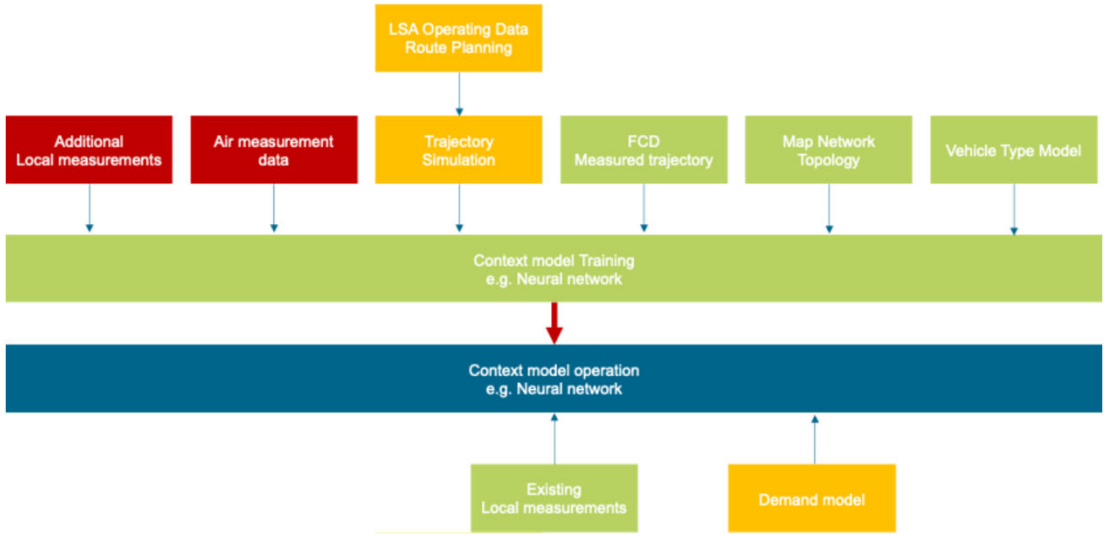
CAST & CHARGIN models



- Modelling and forecasting future charging demand (CHARGIN model) in combination with modelling the development of new registrations and vehicle stock (CAST model)

Own Illustration

Conclusion and Recommendation



Own Illustration

- Building a netwide measurement infrastructure is cost-intensive, especially for measuring emissions.
- However, existing measurement infrastructure for controlling traffic lights should be used.
- FCD provide good results for travel time and are an indicator of emission-relevant start and stop processes.
- The number of intersections along a route (from a map) can increase the accuracy of a model.
- The powertrain type (required for a sound estimate) can be provided by a statistical model.
- An AI model (neural network) can deliver sound results for traffic and mobility management.
- Model features: FCD, statistical powertrain types, network topology.

Imprint

Topic: **Estimating CO_2 emissions through Travel Time**
Date: 2025-11-20 (YYYY-MM-DD)

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Institute: Institut für Verkehrsforschung

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