Fraunhofer FOKUS

EAI SimuTools 2023

Spatio-Temporal Speed Metrics for Traffic State Estimation on Complex Urban Roads

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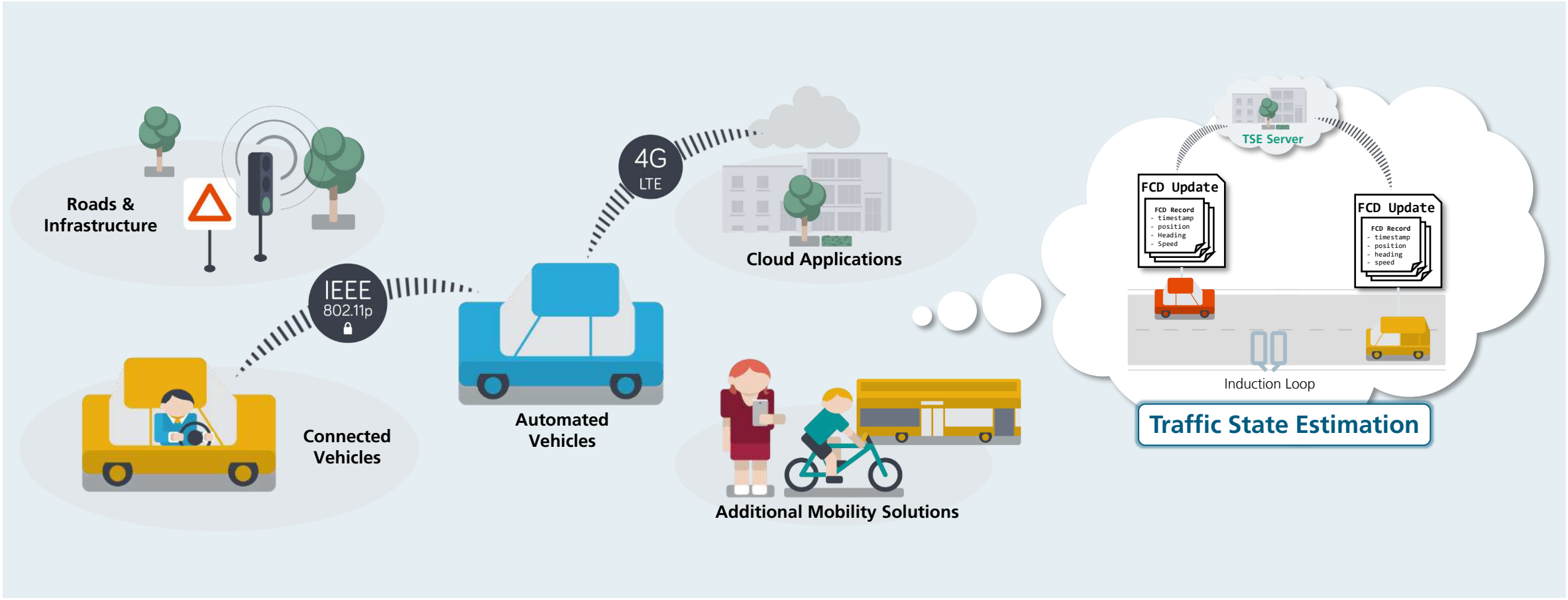
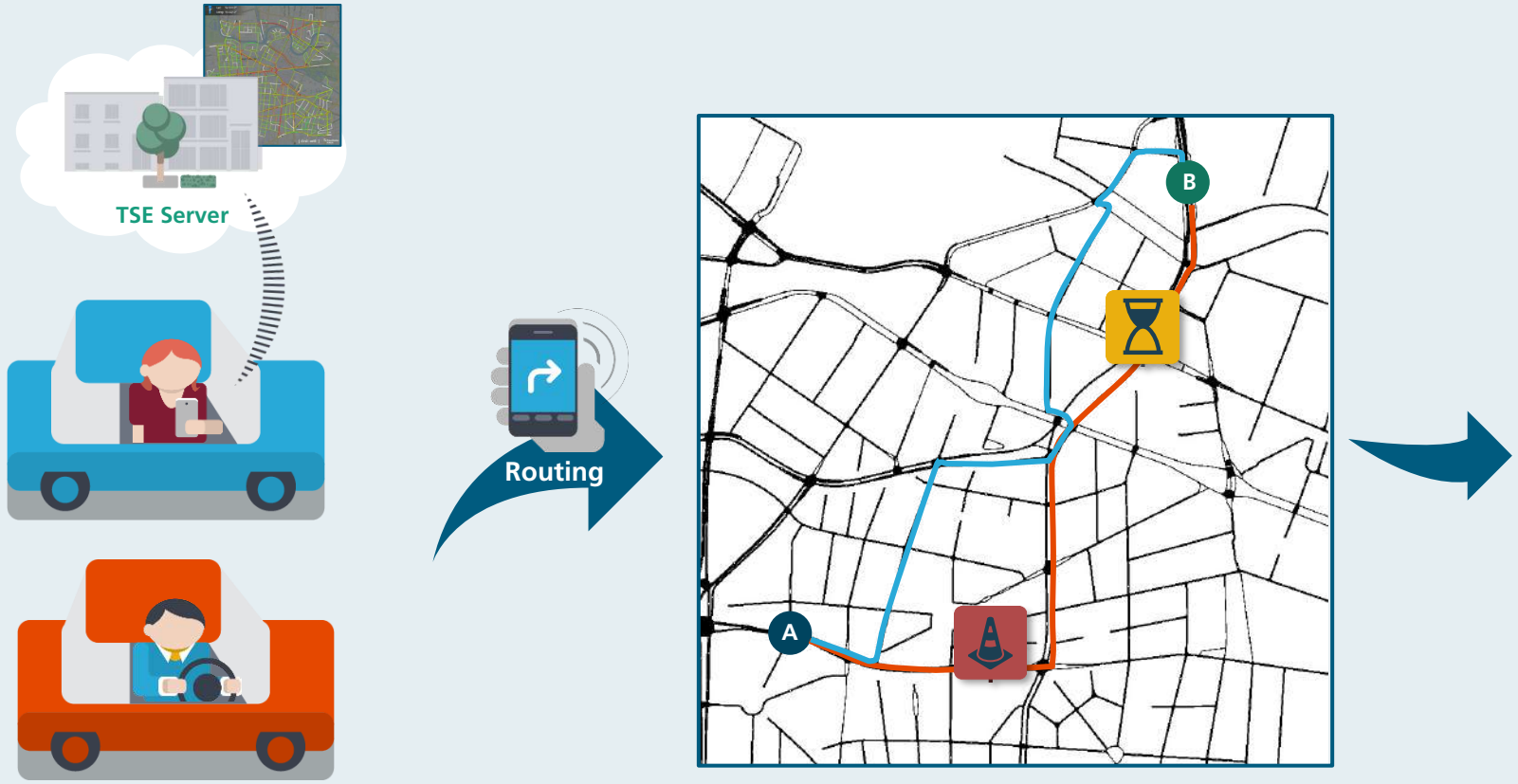
Daimler Center for Automotive IT Innovations



Motivation: Traffic State Estimation

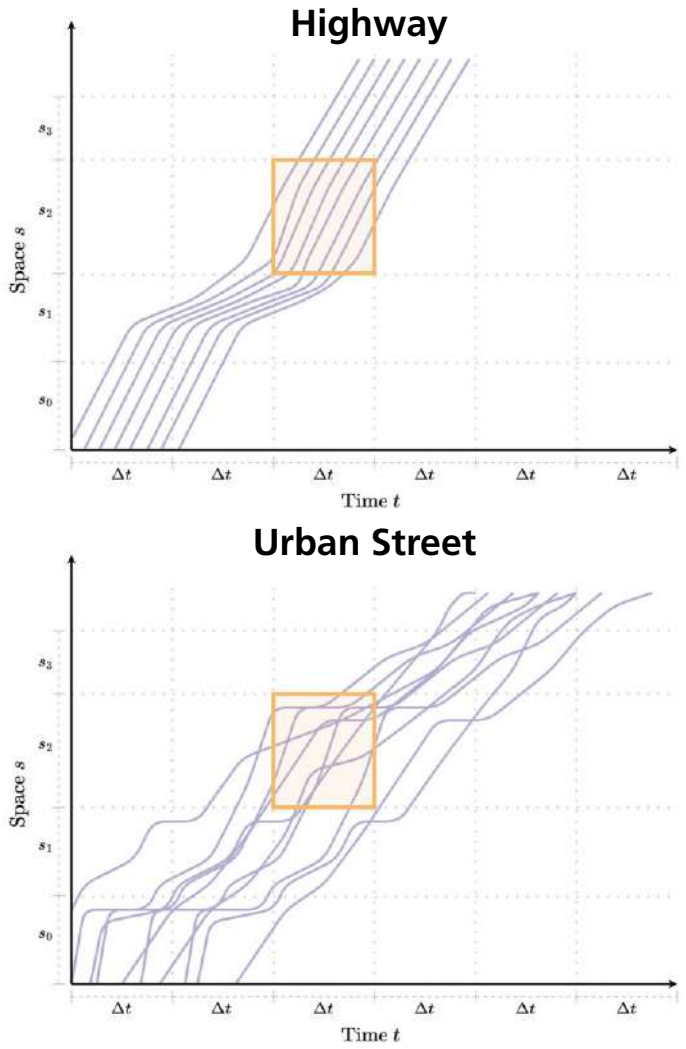


- Real-Time **Traffic State Estimation** enables smart circumnavigation
- Relief strain on bottlenecks
- Reduces Travel Times, Emissions, Fuel Consumption
- Safety critical applications exist

Traffic Dynamics (Mean Speed Estimation)

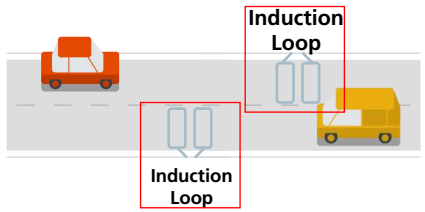
- Space-Time Diagrams to understand spatio-temporal relations on road segments[12]
- Average speed for single vehicle:
  - $\bar{v} = \frac{\Delta s}{\Delta t}$
- Aggregation over space and time required:
  - $V = \frac{1}{n}\sum_{i=0}^{n} \bar{v_i} = \frac{1}{n}\sum_{i=0}^{n} \frac{\Delta s_i}{\Delta t_i}$
- In real-world no access to complete vehicle trajectories

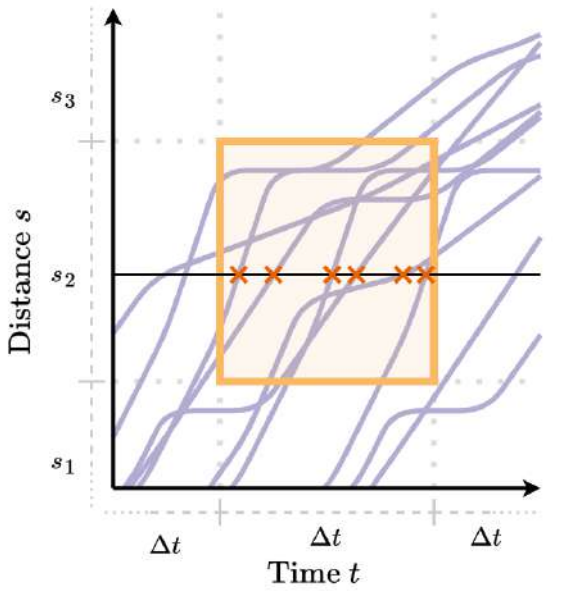
➢ Estimations on Highways simpler than on Urban Streets



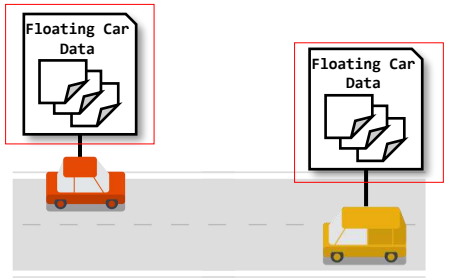
[12] Treiber, M., Kesting, A.: Traffic flow dynamics. Traffic Flow Dynamics: Data,Models and Simulation, Springer-Verlag Berlin Heidelberg pp. 983–1000 (2013)

Sensor Technologies

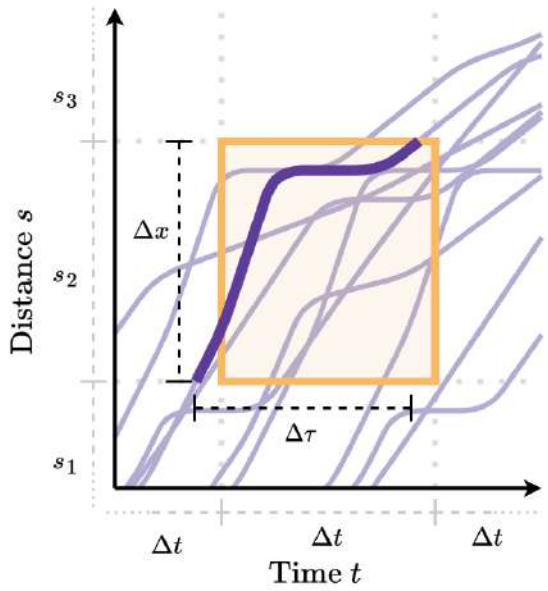




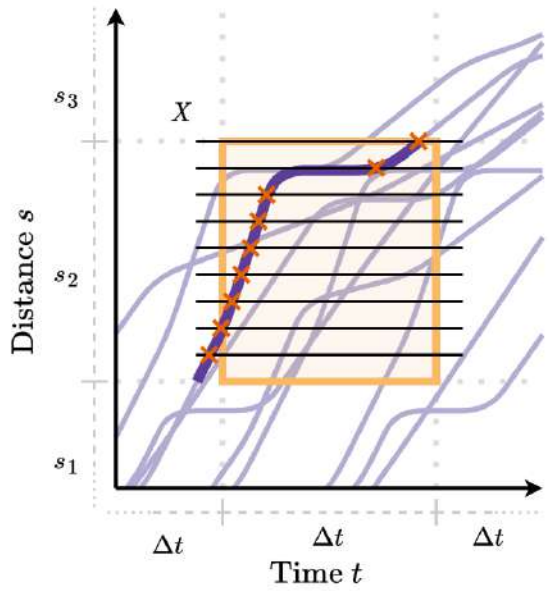
Time Mean Speed & Space Mean Speed



➔ Curve-fitted



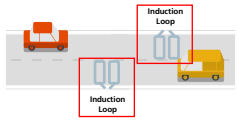
Temporal Mean Speed[14]

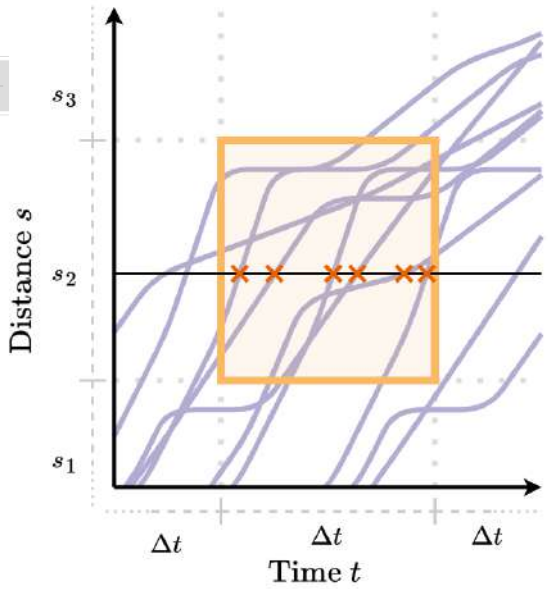


Spatial Mean Speed[14]

[14] Yoon, J., Noble, B., Liu, M.: Surface street traffic estimation. In: Proceedings of the 5th international conference on Mobile systems, applications and services. pp.220–232 (2007)

Sensor Technologies



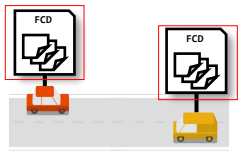


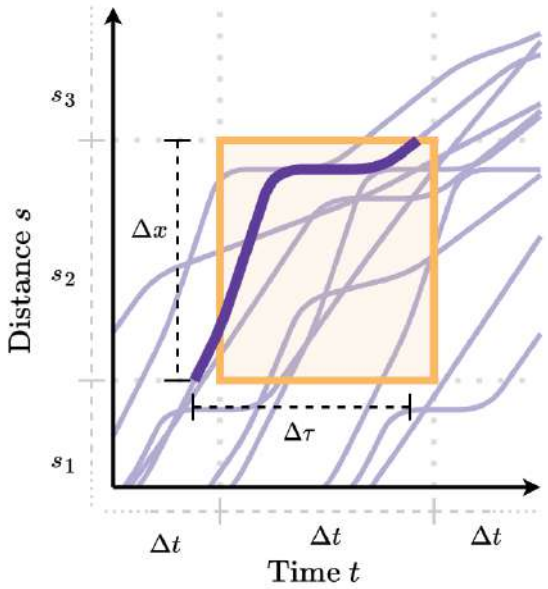
Time Mean Speed

$$V_{TMS} = \frac{1}{n}\sum_{\alpha=1}^{n} v_\alpha$$

Space Mean Speed

$$V_{SMS} = \frac{n}{\sum_{\alpha=1}^{n} v_\alpha}$$

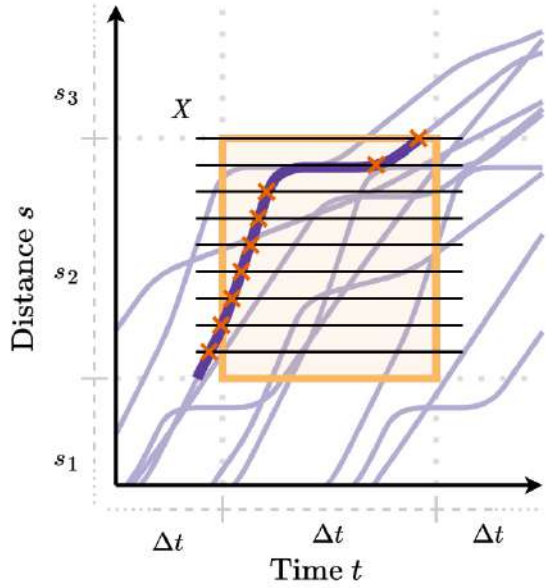




Temporal Mean Speed

$$v_{\text{temporal}} = \bar{v} = \frac{\Delta x}{\Delta \tau}$$

$$\rightarrow V_{\text{temporal}} = \frac{1}{n}\sum_{\alpha=1}^{n} v_{\text{temporal}}(\alpha)$$



Spatial Mean Speed

$$v_{\text{spatial}} = \frac{1}{X}\sum_{x=1}^{X} v(x)$$

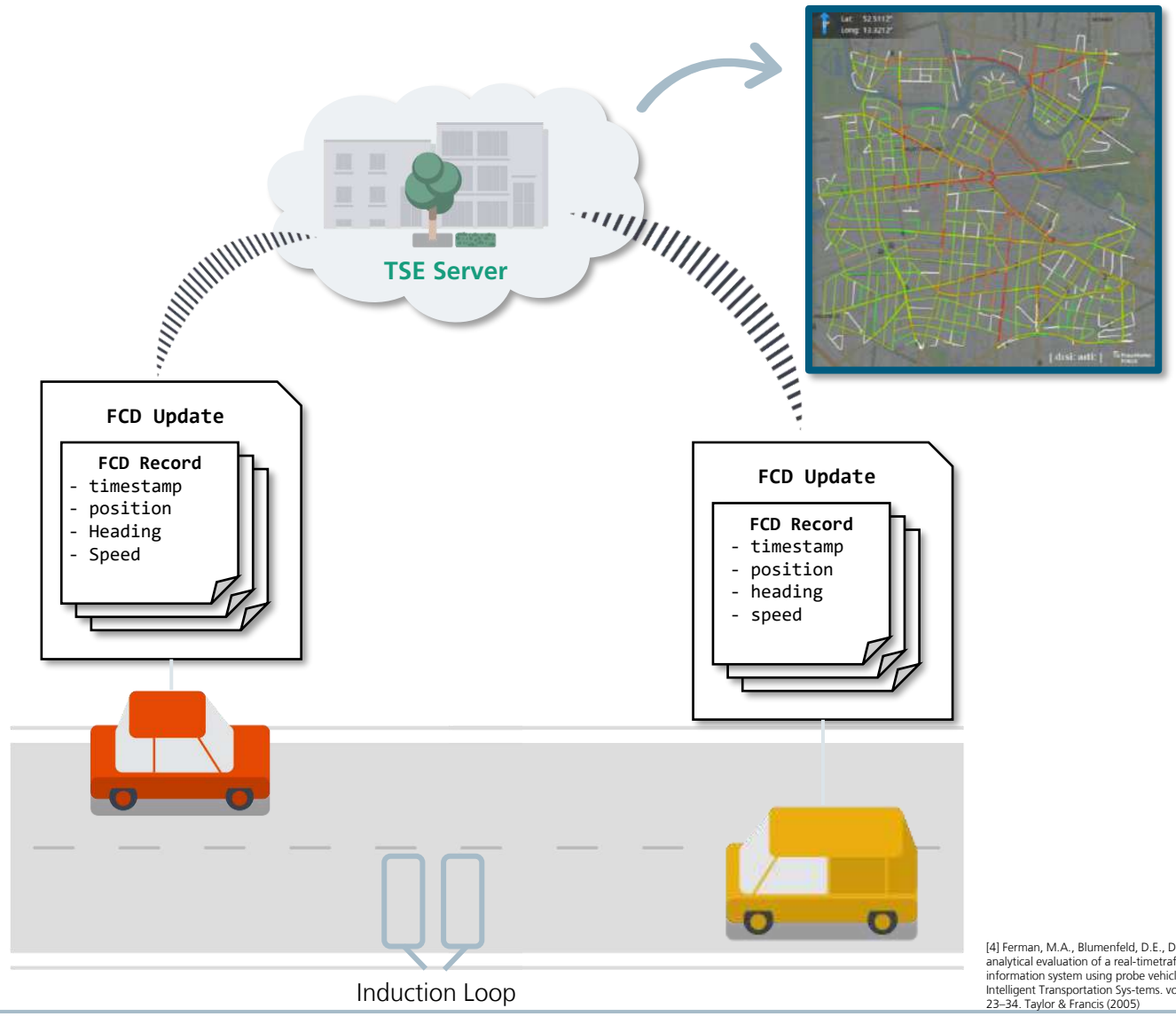
$$\rightarrow V_{\text{spatial}} = \frac{1}{n}\sum_{\alpha=1}^{n} v_{\text{spatial}}(\alpha)$$

Traffic State Estimation System

- Reconstruction of the traffic state (≙ *realizable* mean speed) based on incomplete **sensor data**
  - **Induction Loops**
    - precise measurements
    - costly, limited observation
  - **Floating Car Data (FCD)**
    - commonly used and complete insight
    - require 5-15% market penetration on highways[4]

➢ Different sensor modalities imply different ways of metric calculation

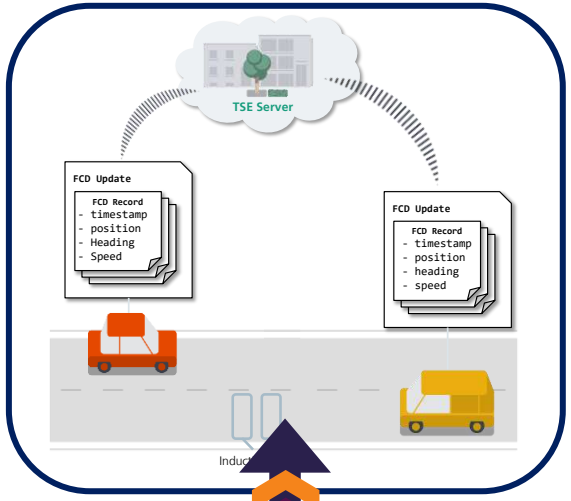
https://github.com/mosaic-addons/traffic-state-estimation



[4] Ferman, M.A., Blumenfeld, D.E., Dai, X.: An analytical evaluation of a real-timetraffic information system using probe vehicles. In: Intelligent Transportation Sys-tems. vol. 9, pp. 23–34. Taylor & Francis (2005)

ECLIPSE MOSAIC[9]

https://eclipse.dev/mosaic/



Communication

ns-3 SNS

OMNeT++ Cell

Vehicles & Traffic

SUMO CARLA

Phabmacs

Eclipse MOSAIC Simulation RTI

Federation Management

Time Management

Interaction Management

Applications

Application Simulator

Couple your Own

Evaluation Tools

File Output

Statistics Output

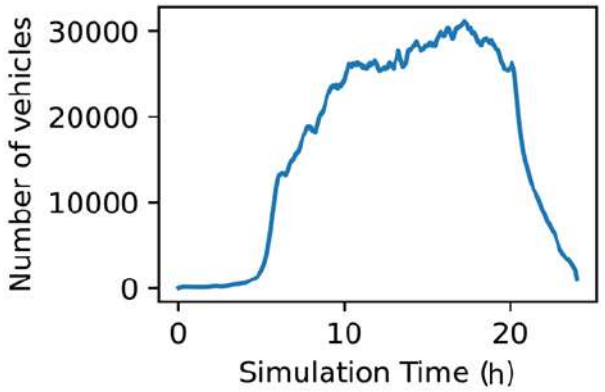
2D/3D-Visualization

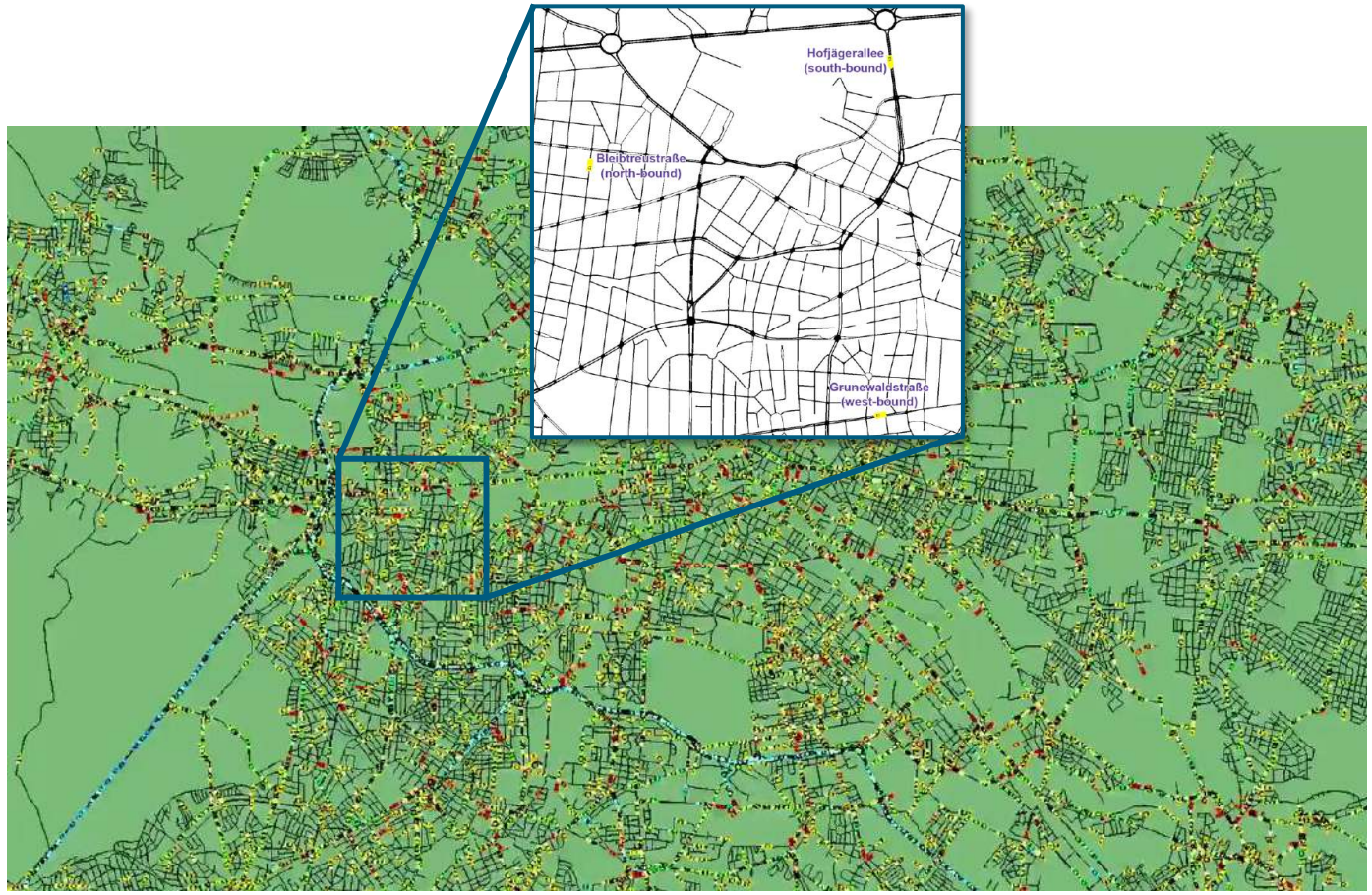
[9] K. Schrab, M. Neubauer, R. Protzmann, I. Radusch, S. Manganiaris, P. Lytrivis, A. J. Amditis: "Modeling an ITS Management Solution for Mixed Highway Traffic with Eclipse MOSAIC." IEEE Transactions on Intelligent Transportation Systems, Volume 24, Issue 6, pp. 6575-6585, June 2023. DOI: 10.1109/TITS.2022.3204174

Evaluation Scenario

Berlin **S**UMO **T**raffic (**BeST**) Scenario[10]

- 800 km² area
- 24h time frame
- **2 248 952** individual trips





https://github.com/mosaic-addons/best-scenario

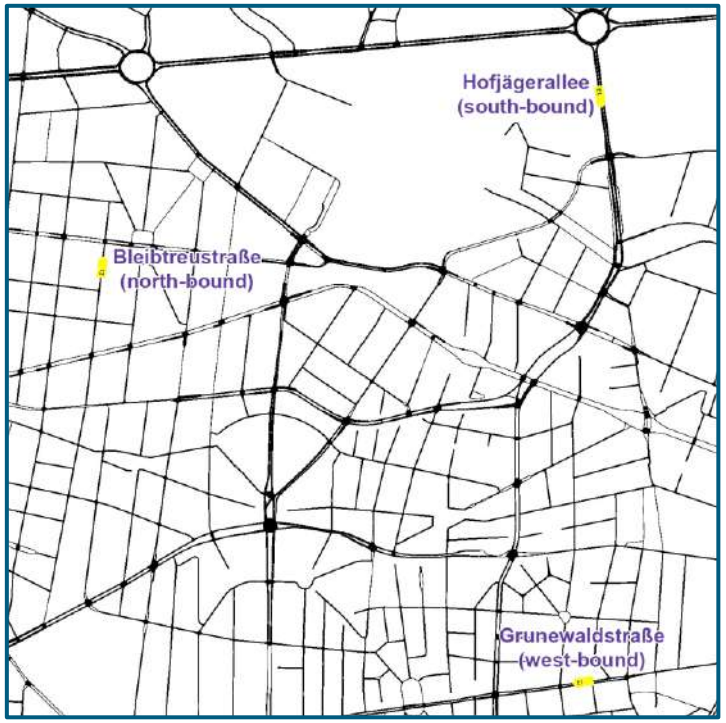
[10] Schrab, K., Protzmann, R., & Radusch, I. (2022, August). A Large-Scale Traffic Scenario of Berlin for Evaluating Smart Mobility Applications. In Conference on Sustainable Urban Mobility (pp. 276-287). Cham: Springer Nature Switzerland.

Evaluation Setup

- Coupled Simulators:
  - **Traffic:** Eclipse SUMO
  - **Applications:** MOSAIC Application & Mapping
  - **Communication**: MOSAIC Cell Simulator

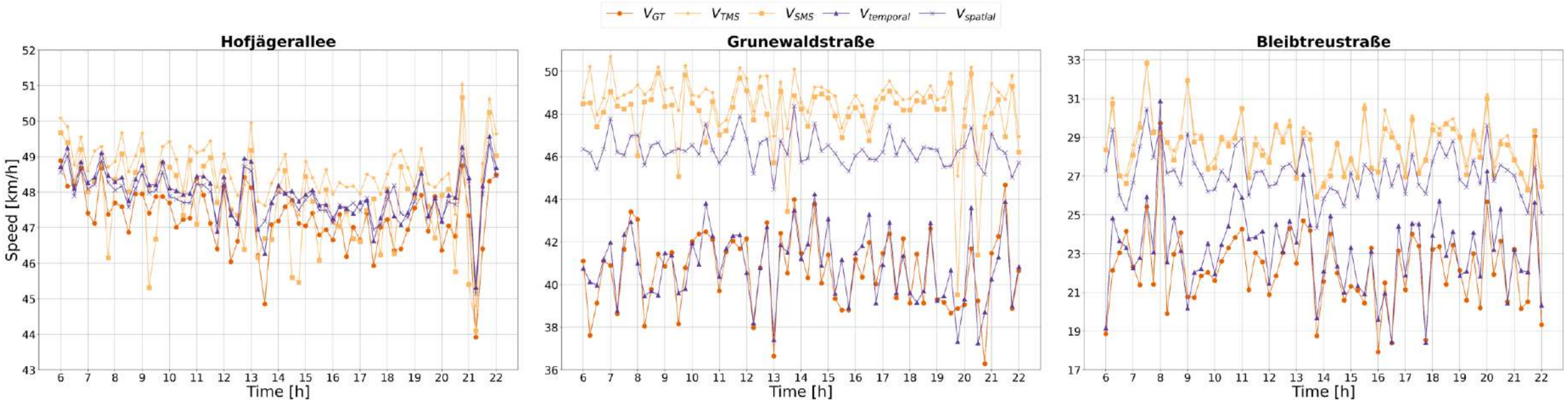
- Charlottenburg Configuration for BeST Scenario
  - 24h of extracted traffic
  - Separate demand configuration with ~200.000 individual trips

- Measurements:
  - Setup Induction Loops on all lanes at marked road segments
  - Equip all vehicles with FCD Applications
  - Measure ground truth using SUMO



Street	Length	#Lanes	Speed Limit	Signalized End
Hofjägerallee	399.96m	3	$50\frac{km}{h}$	no
Grunewaldstraße	185.37m	2	$50\frac{km}{h}$	yes
Bleibtreustraße	182.34m	1	$30\frac{km}{h}$	yes

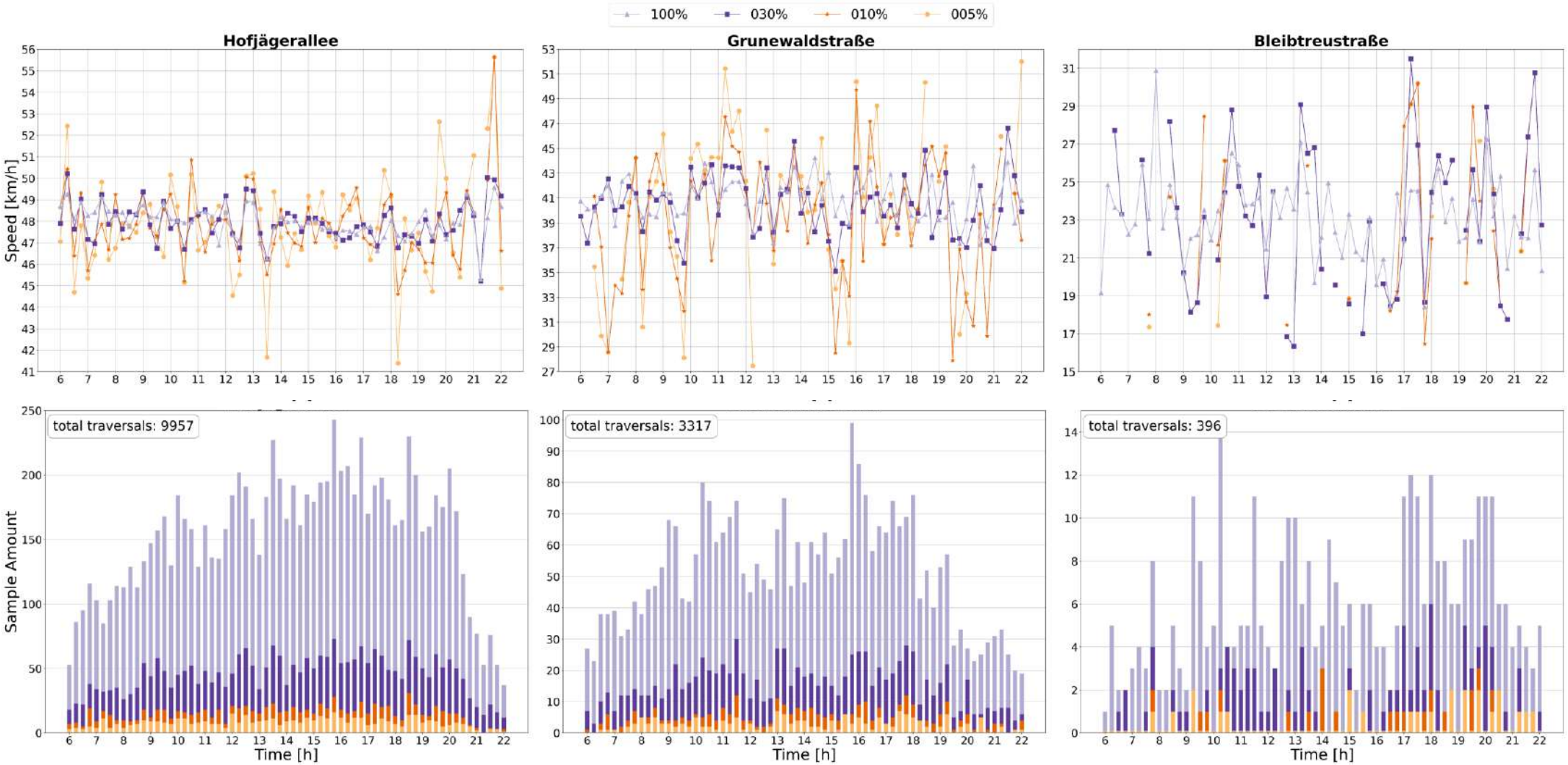
Evaluation



- All Mean Speeds reflect ground truth well due to highway-like characteristics
- Time and Space Mean Speed fail to capture the ground truth properly due to single point of inspection
- Spatial Mean Speed overestimates ground truth due to only small build-ups at the end of the road
- Temporal Mean Speed properly captures the ground truth

Street	$\bar{V}_{GT}$	$\bar{V}_{TMS}$	$\bar{V}_{SMS}$	$\bar{V}_{temporal}$	$\bar{V}_{spatial}$
Hofjägerallee	$47.3\frac{km}{h}$	$48.7.3\frac{km}{h}$	$47.7\frac{km}{h}$	$48.0\frac{km}{h}$	$47.9\frac{km}{h}$
Grunewaldstraße	$40.9\frac{km}{h}$	$49.0\frac{km}{h}$	$48.0\frac{km}{h}$	$40.9\frac{km}{h}$	$46.3\frac{km}{h}$
Bleibtreustraße	$22.4\frac{km}{h}$	$28.6\frac{km}{h}$	$28.4\frac{km}{h}$	$23.2\frac{km}{h}$	$27.2\frac{km}{h}$

Evaluation (Market Penetration)



Conclusion & Outlook

✓Introduction into different measures and sensor modalities for speed estimation on urban roads

✓Presented an open-source toolkit for implementing, testing, and validating TSE methods

✓Comparative study for mean speed measurements and definition of thresholds for effective FCD-based measurements on different road types

➢Test system against disruptive traffic patterns

➢Enrich Floating Car Data with additional sensor data (i.e., perception data)

➢Large scale evaluation metrics to rank TSE quality for the entirety of a city

https://eclipse.dev/mosaic/

https://github.com/mosaic-addons/traffic-state-estimation

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