Traffic state estimation at signalized intersections based on connected vehicles

Universitätstagung Verkehrswesen 2018

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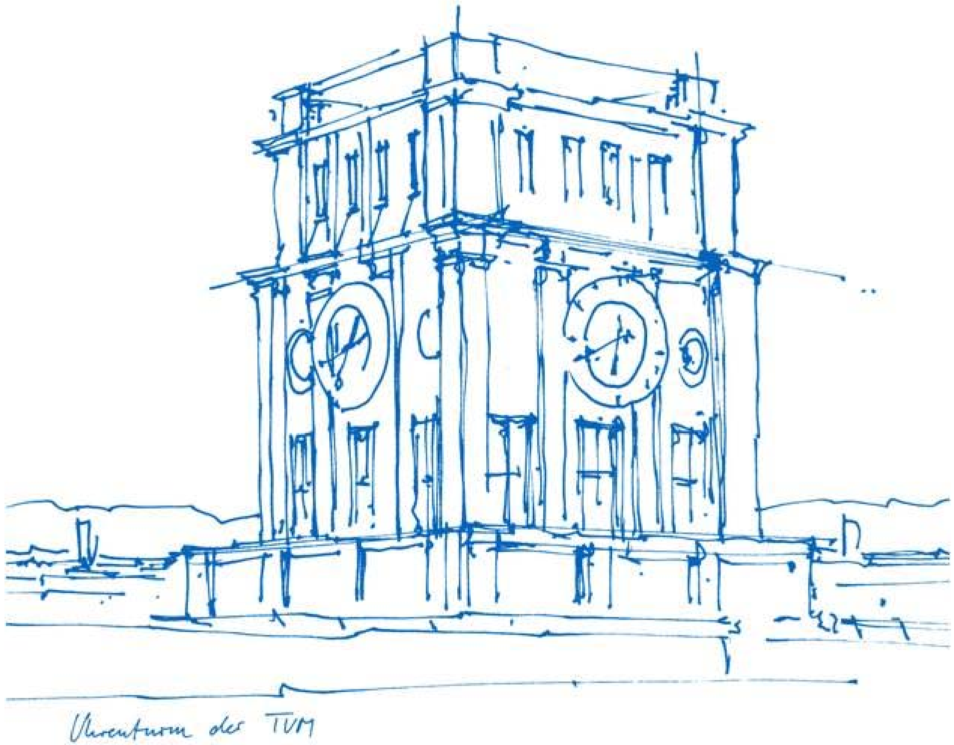

Content

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Research goal

Optimal traffic state **estimation and prediction** for traffic **signal control** by capitalizing on the new sensing and communication capabilities from **connected environments** in urban areas.

Data: Connected Environments

Measurements from new data sources:
e.g. Connected Vehicles, Cameras etc.

Extended Observer: Urban Traffic State Estimation and Prediction

Extended Traffic State Estimation and Prediction:
- Queue length
- Arrivals
- Departures
- Turnings

Controller: Urban Traffic Control

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Methodology

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Extended Observer based on (Extended) Kalman Filter

Measurement: z_k

$\hat{x}_k^{predicted}$ (*a priori state estimate*)

Time Update ("Predict")

Measurement Update ("Correct")

$\hat{x}_k^{corrected}$ (*a posteriori state estimate*)

State vector:

$$\vec{x}_k = \begin{bmatrix} x_k^{queue\ length} \\ x_k^{arrival\ rate} \\ x_k^{departure\ rate} \\ x_k^{turning\ rate} \end{bmatrix}$$

Measurement vector:

$$\vec{z}_k = \begin{bmatrix} z_k^{queue\ length\_V2X} \\ z_k^{arrival\ rate\_loop} \\ z_k^{departure\ rate\_camera} \\ z_k^{turning\ rate\_rawFCD} \end{bmatrix}$$

e.g.: $\boxed{x_k^{queue\ length} = x_{k-1}^{queue\ length} + arrivals - departures}$

e.g.: $\boxed{x_k^{turning\ rate} = a_{k-1}^{turning\ rate} \times x_{k-1}^{turning\ rate}}$ $a_{k-1}^{turning}$: changes every time step according to the historical profile.

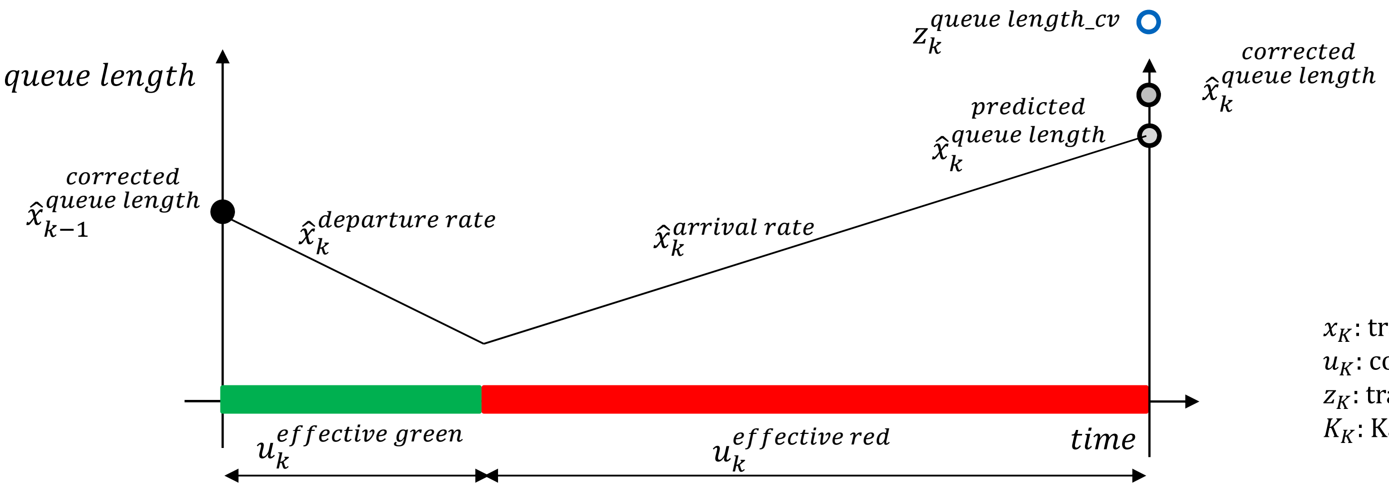
Filter step ("Predict" and "Correct")

$$\hat{x}_k^{predicted\ queue\ length} = \hat{x}_{k-1}^{corrected\ queue\ length} - (\hat{x}_k^{departure\ rate} \times u_k^{effective\ green}) + (\hat{x}_k^{arrival\ rate} \times u_k^{effective\ red})$$

Time Update ("Predict")

$$\hat{x}_k^{corrected\ queue\ length} = \hat{x}_k^{predicted\ queue\ length} + K_k \times (z_k^{queue\ length\_cv} - \hat{x}_k^{predicted\ queue\ length})$$

Measurement Update ("Correct")

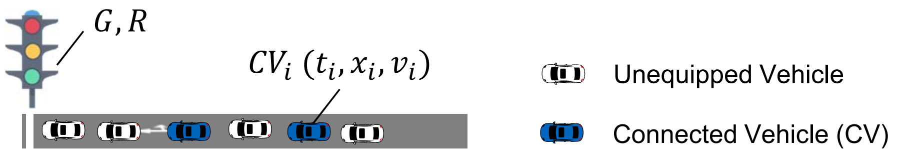


x_K: traffic states (queue length, arrival rate, departure rate)
u_K: control input (signal timings)
z_K: traffic measurements (from Connected Vehicles)
K_K: Kalman gain

Measurement Update ("Correct")

Input needed from Connected Vehicles and signal control:

- timestamp (t_i)
- position (x_i)
- speed (v_i)
- last cycle red duration (R)
- last cycle green duration (G)



Intermediate parameters for the calculation of $\vec{z}_k$:

- time joining the queue ($t_{joining\_queue}$)
- time crossing the stopline ($t_{crossing\_stopline}$)
- position in the queue (l)
- number of CVs in the queue (m)

Measurement vector: $\vec{z}_k = [z_k^{*queue\ length\_cv}, z_k^{*arrival\ rate\_cv}, z_k^{departure\ rate\_cv}]^T$

*Comert, G. (2016). Queue length estimation from probe vehicles at isolated intersections: Estimator for primary parameters. European Journal of Operational Research 252, 502-521.

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Contributions

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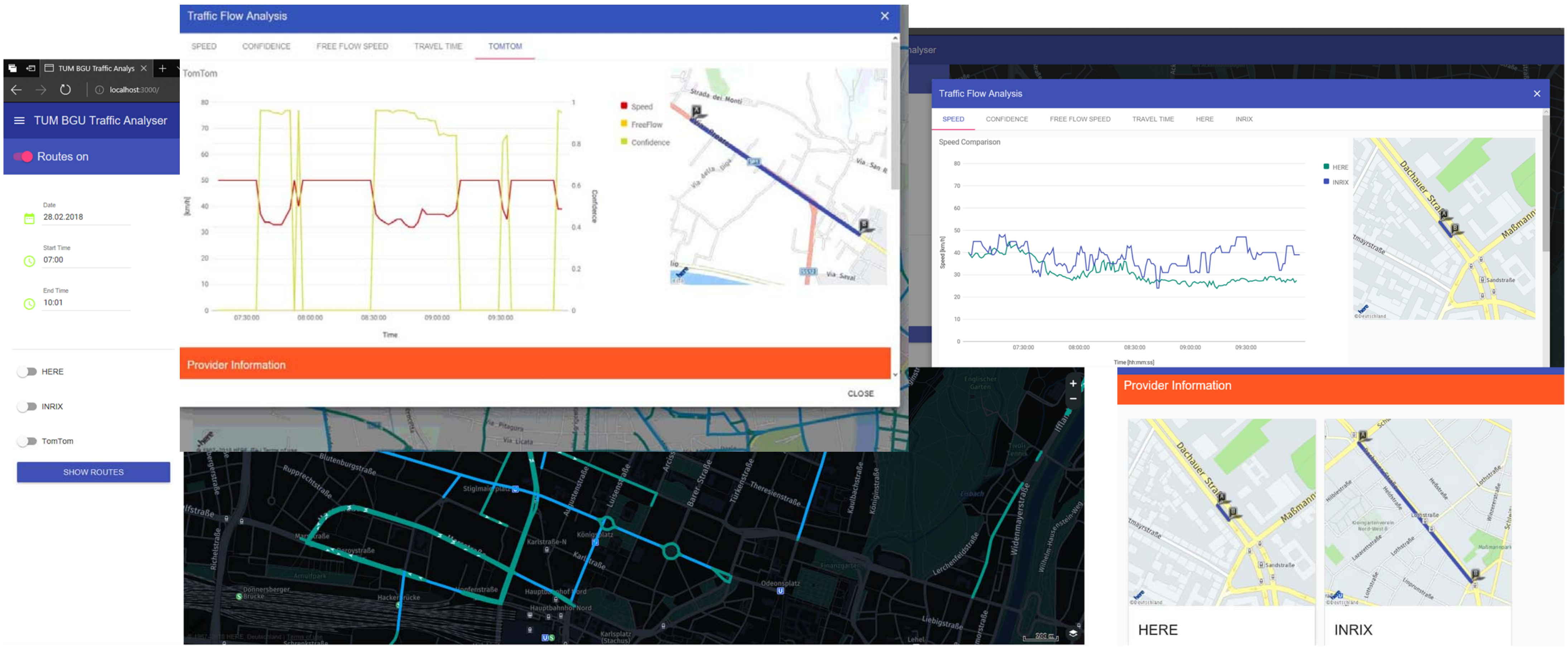
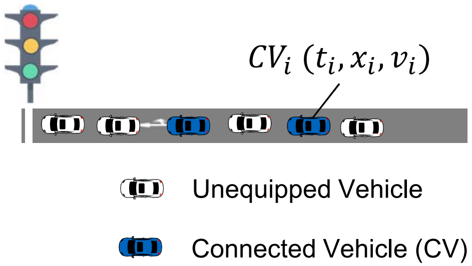
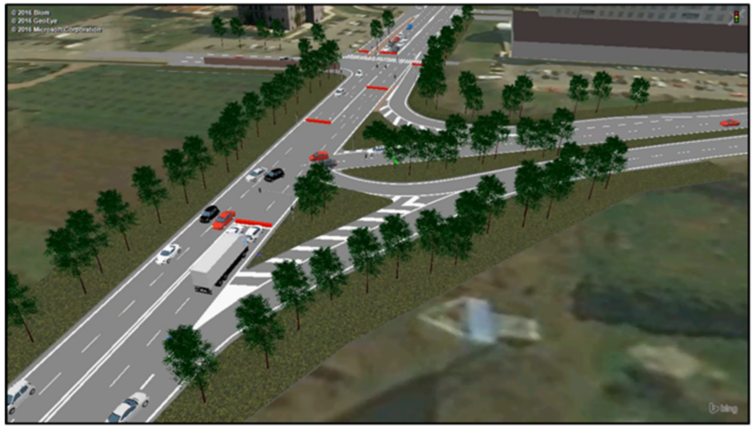
Potential of new data



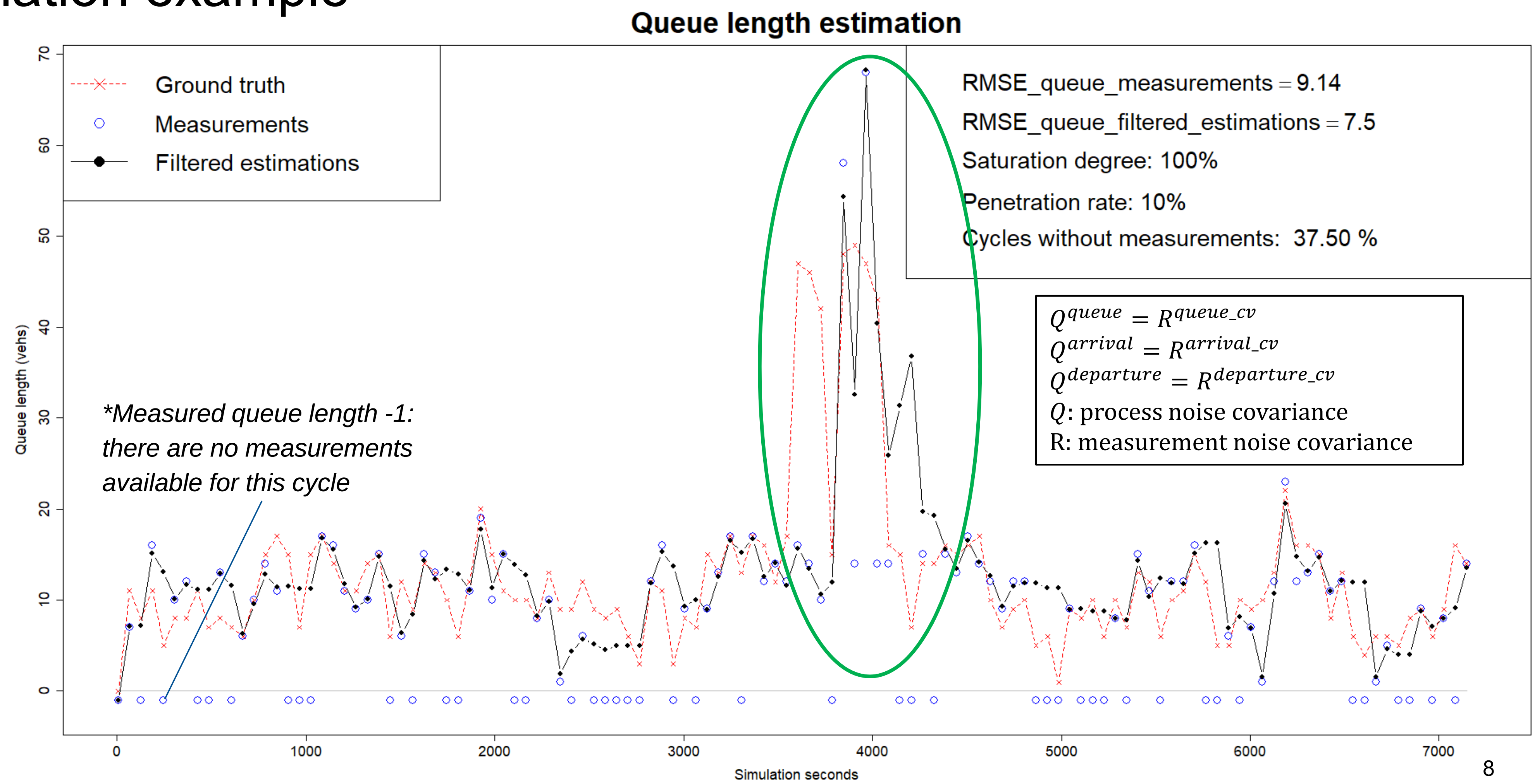
Simulations with **limited and imperfect** measurements

- Demonstrate the **working principles** of the developed Extended Observer
- Demonstrate the **potential and limitations** of the developed Extended Observer

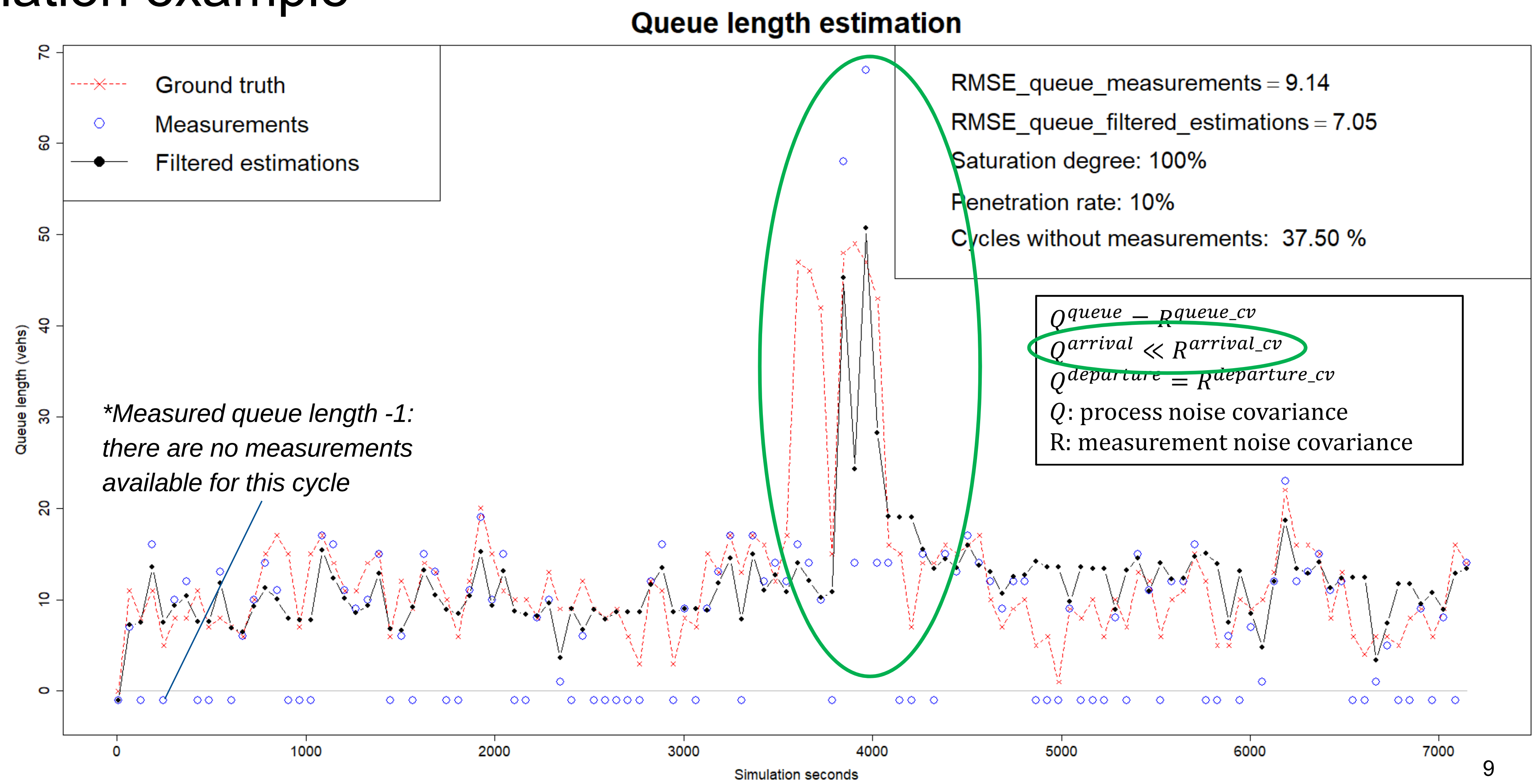




Simulation example



Simulation example



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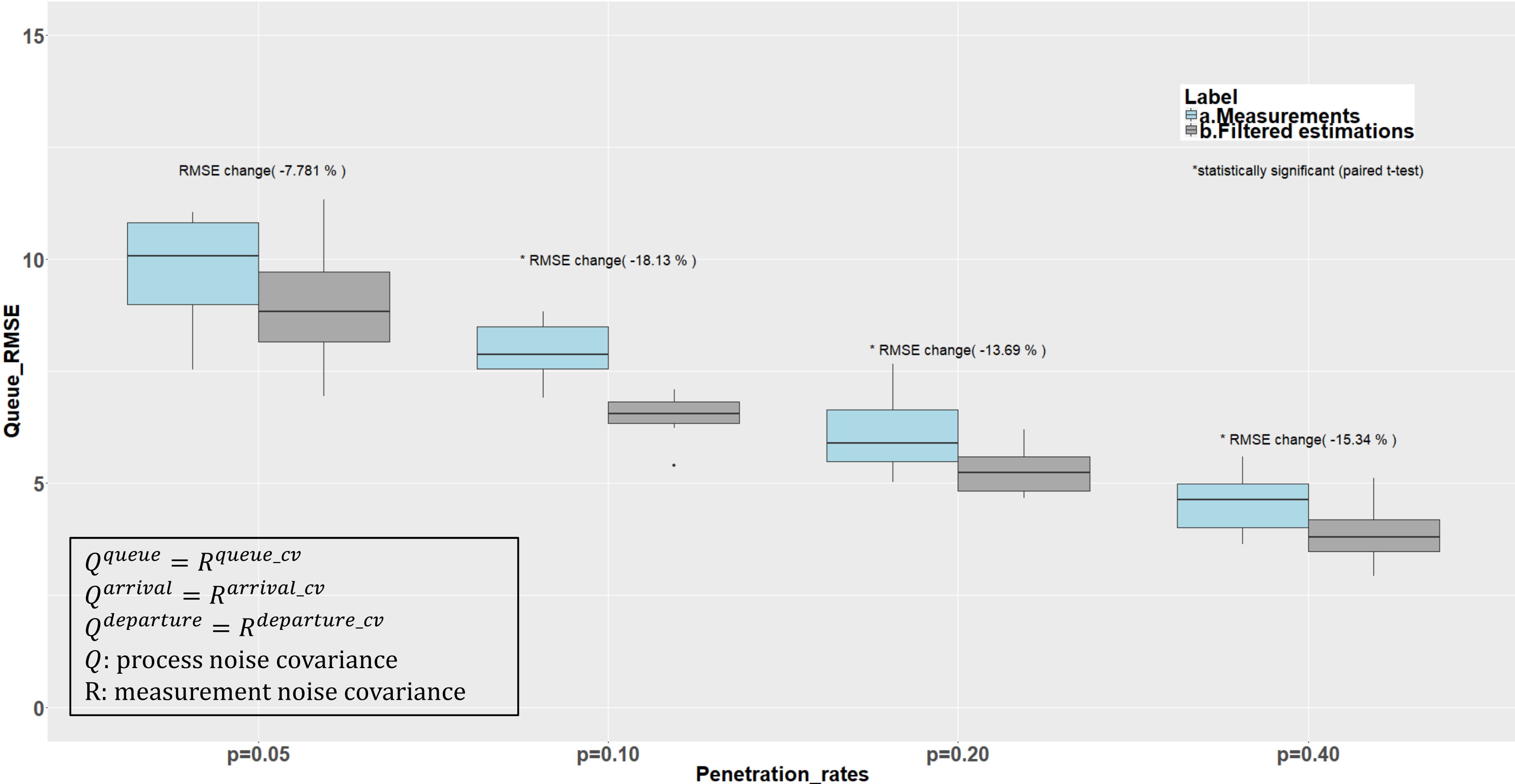
Preliminary simulations results



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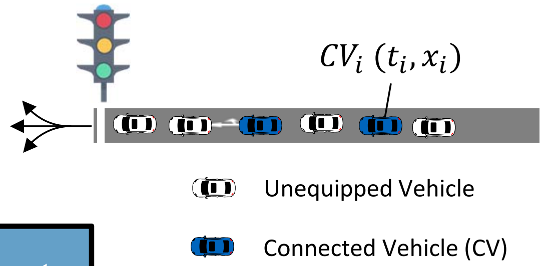
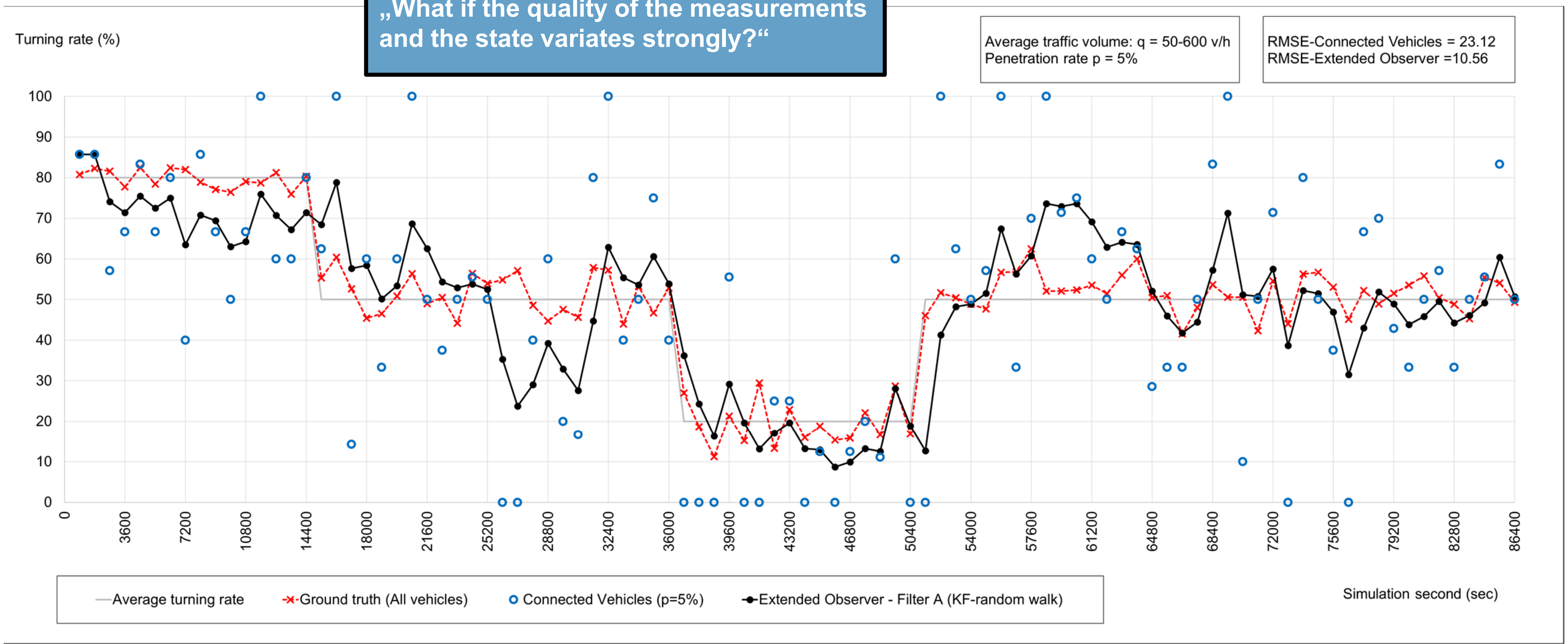
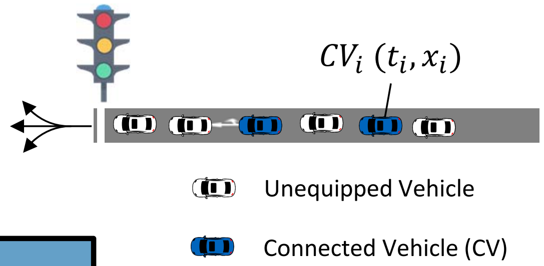
Simulation example



„What if the quality of the measurements and the state variates strongly?“



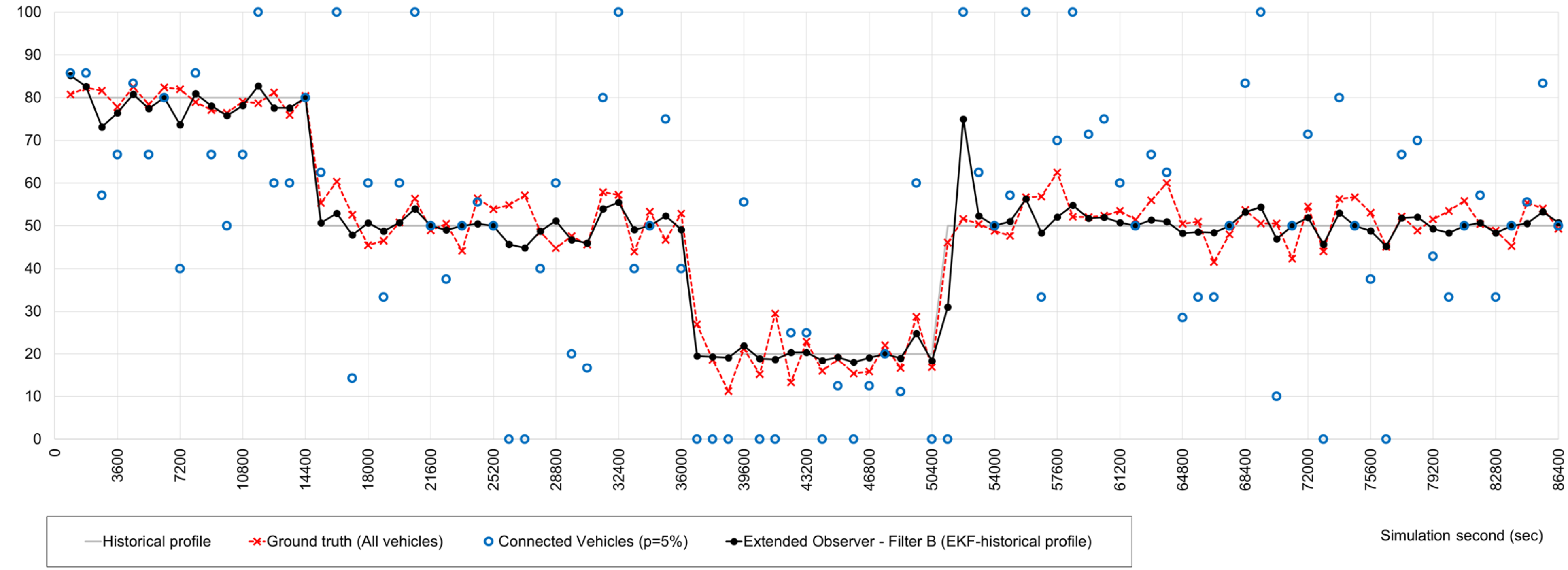
Simulation example



„What if there is a specific historical profile that we want to trust more than the measurements?“

Average traffic volume: q = 50-600 v/h
Penetration rate p = 5%

RMSE-Connected Vehicles = 23.12
RMSE-Extended Observer = 5.22



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Conclusions

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Extended Observer (based on Extended Kalman Filter):

- Utilizes **imperfect measurements** from low number Connected Vehicles (**low penetration rates**)
- Provides **improved estimation** in comparison to relying solely on the measurements
- Provides an **intuitive way for tuning** the filter (“should I trust the measurements or the model more?”)

But:

- **Tuning (Q, R)** is very critical in Kalman filtering
- **Biased measurements** or **biased model** can lead to reduced performance

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Outlook

Outlook

- Compare with estimation from **loop** detectors
- Test different **data availability** combinations
- Evaluate the **impact** on signal control
- Derive **requirements** for connected environments
- Add another layer: “**Continuous**” filter (every 3 seconds)

„*Science fiction is sexier than science facts*“
(Dr. S. Shladover, UC Berkeley,
MFTS 2018, Ispra, 11.06.2018)

Thank you for your attention