Optimization-based methods for large-scale urban traffic control

Işık İlber Sırmatel

Department of EE Engineering
Faculty of Engineering
Trakya University

24.12.2025

Why do we need traffic control?

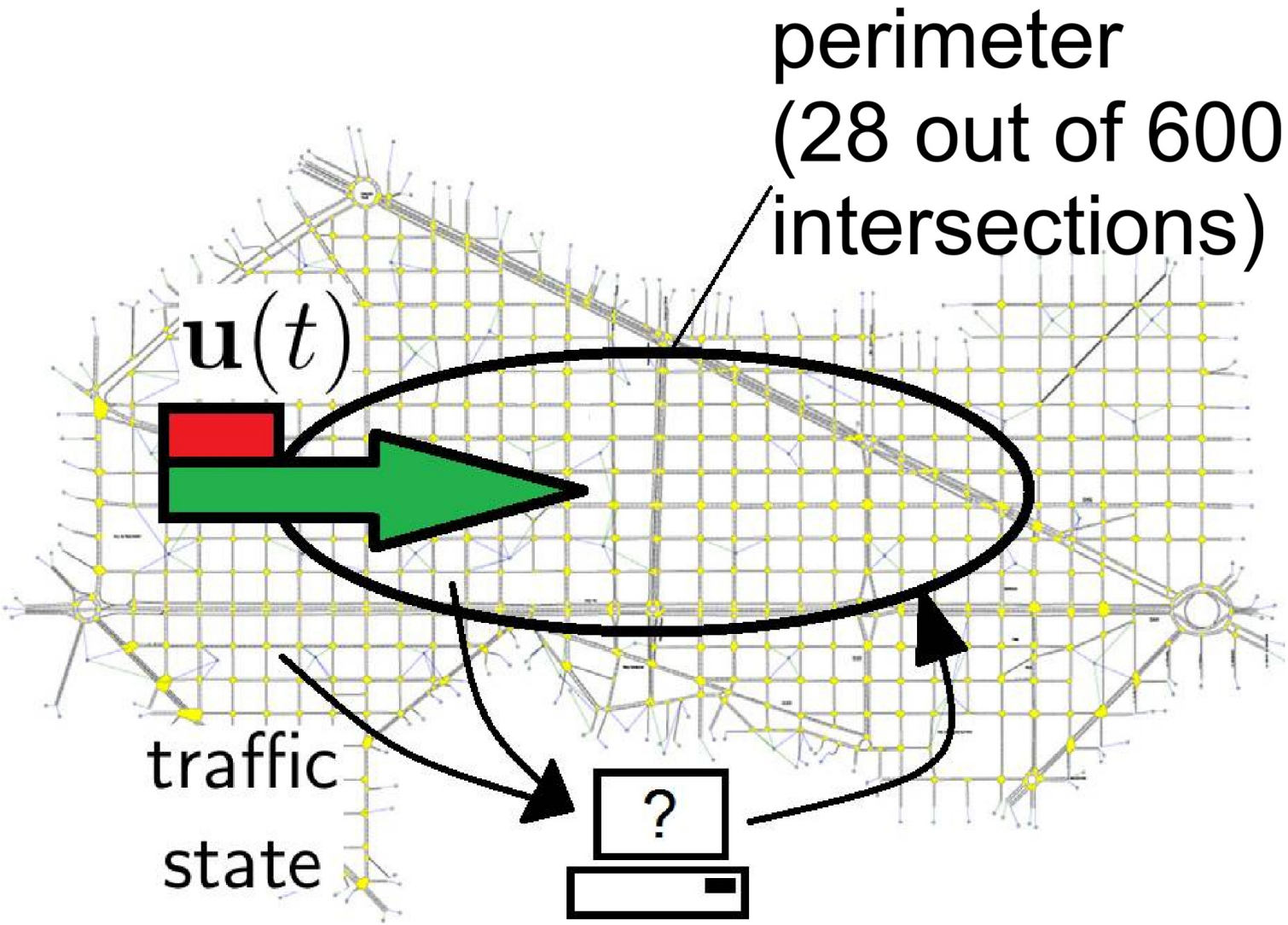
Los Angeles, 1941

Los Angeles, 2013

Large-scale urban traffic control

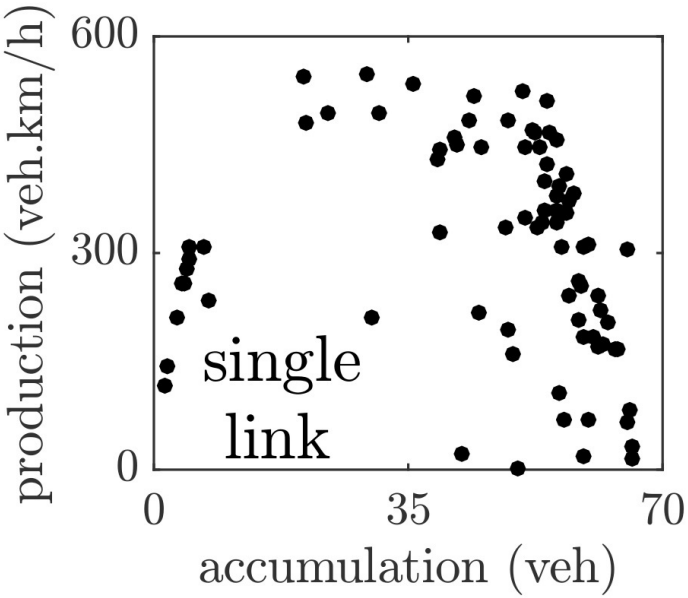
12 km^2, $\sim$600 intersections, $\sim$1500 links

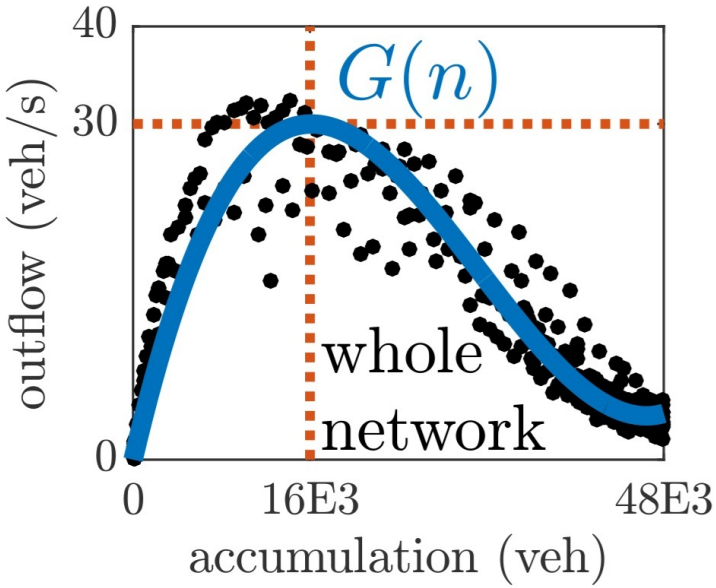
Traffic control with perimeter actuation

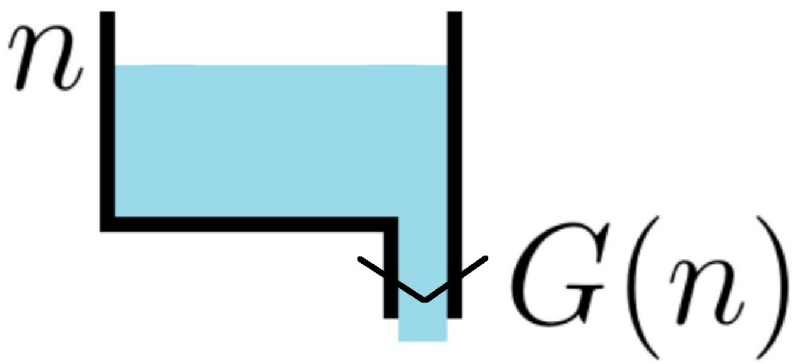


example: $\mathbf{u}(t) = 0.8 \rightarrow$ traffic light cycle 80% green

Macroscopic fundamental diagram (MFD)[1]

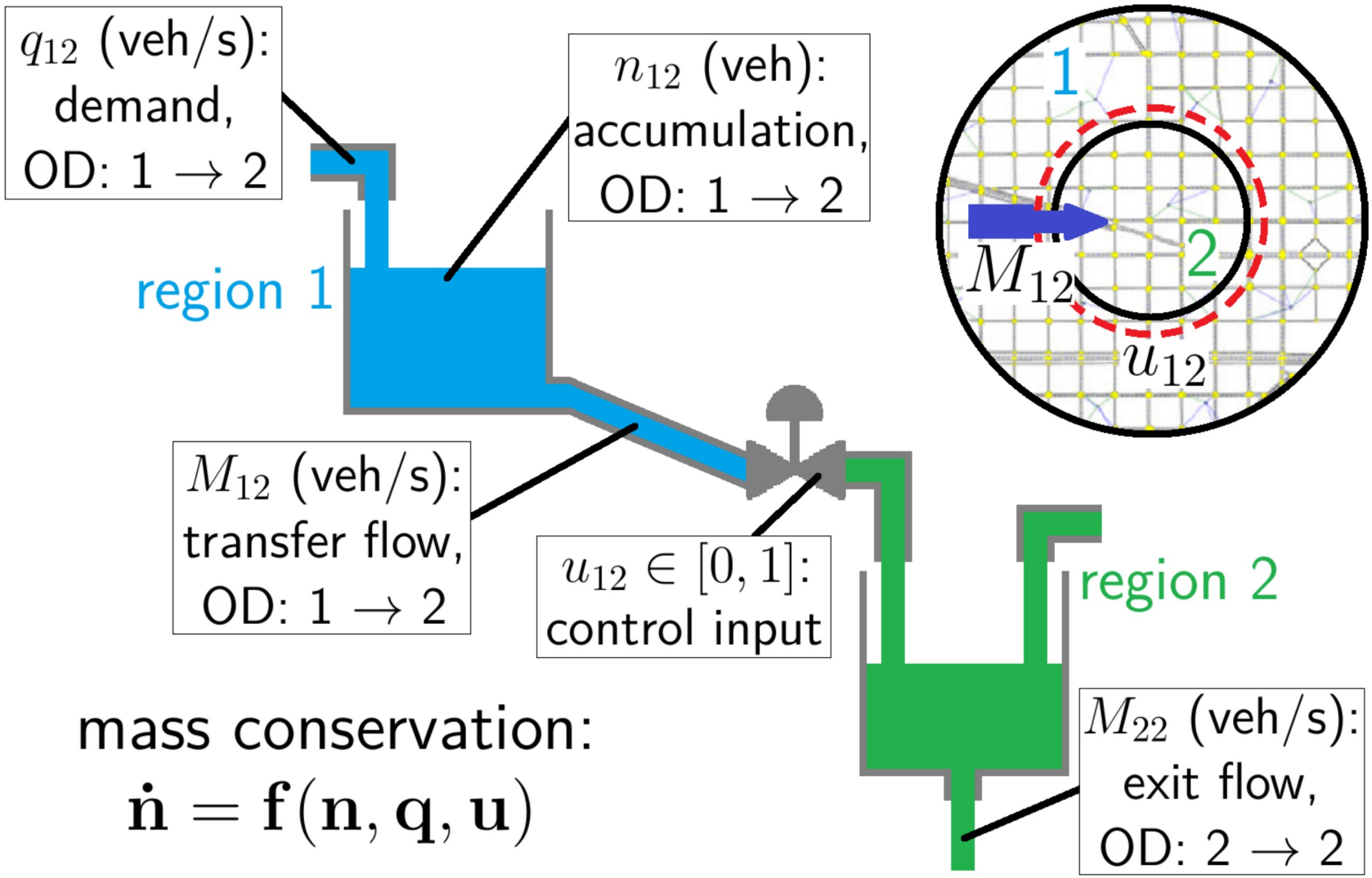






[1] Nikolas Geroliminis and Carlos F Daganzo. *Transportation Research Part B: Methodological* 42.9 (2008), pp. 759–770.

Dynamics of a two region system[2]



[2]Nikolas Geroliminis, Jack Haddad, and Mohsen Ramezani. *IEEE Transactions on Intelligent Transportation Systems* 14.1 (2013), pp. 348–359.

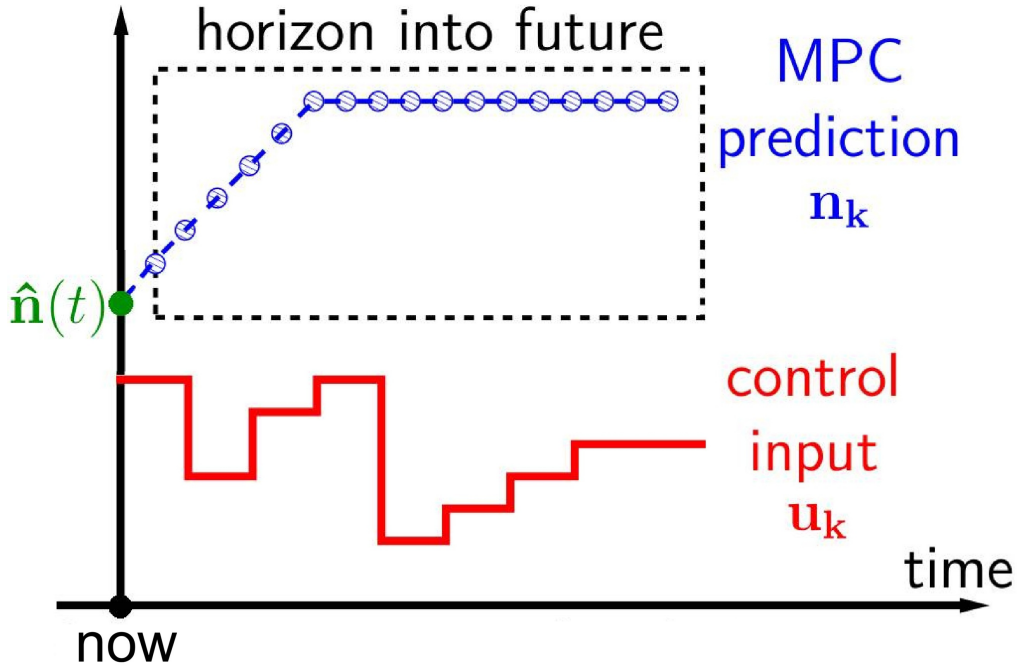
MFD-based control literature

approaches	related works (nonexhaustive)
optimal control	Daganzo 2007
multivariable PID	Keyvan-Ekbatani 2012, Aboudolas 2013, Kouvelas 2017
model predictive control (MPC)	Geroliminis 2013, Hajiahmadi 2013 Zhou 2017, Ni 2019
reinforcement learning	Zhou 2021, Jiang 2023, Li 2024, Yu 2025

some unexplored directions:

- joint state estimation and control
- integrating perimeter and routing actuation
- control under uncertainty

MPC with perimeter actuation[3]



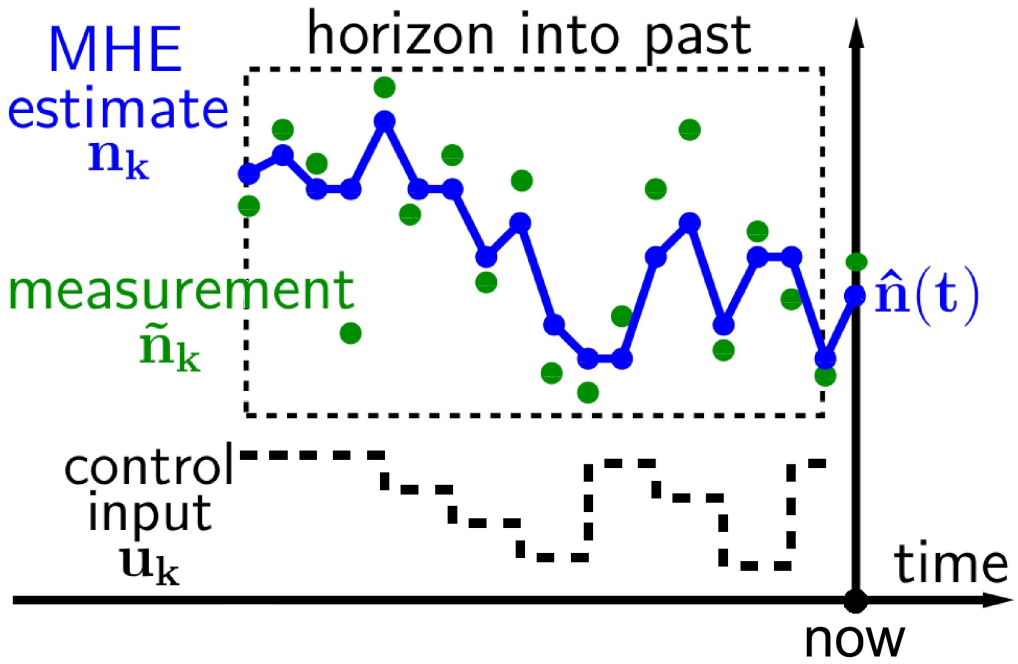
minimize (input) total time spent

subject to current measurement, constraints

MFD-based model $(\dot{\mathbf{n}} = \mathbf{f}(\mathbf{n}, \mathbf{q}, \mathbf{u}))$

[3] Nikolas Geroliminis, Jack Haddad, and Mohsen Ramezani. *IEEE Transactions on Intelligent Transportation Systems* 14.1 (2013), pp. 348–359.

Moving horizon estimation (MHE)[4]



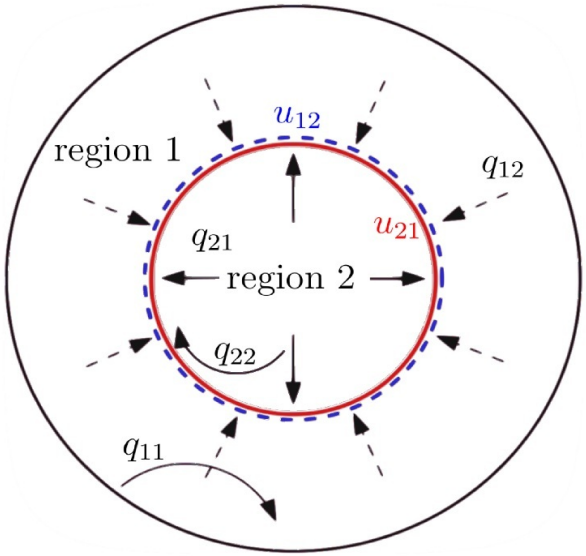
minimize process noise — tradeoff (process vs. meas. noise)

subject to — past measurements, constraints

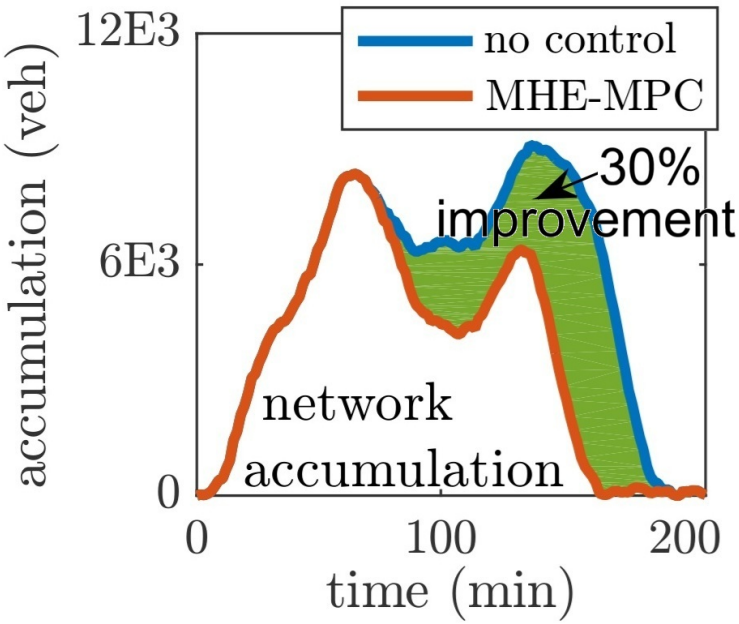
MFD-based model $(\dot{\mathbf{n}} = \mathbf{f}(\mathbf{n}, \mathbf{q}, \mathbf{u}))$

[4] Isik Ilber Sirmatel and Nikolas Geroliminis. *IEEE Transactions on Intelligent Transportation Systems* 21.12 (2019), pp. 4983–4994.

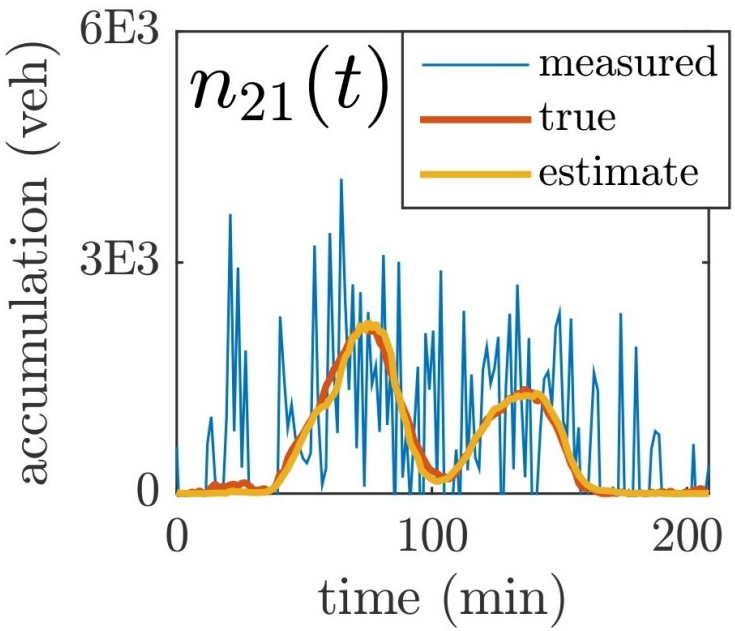
Simulation results (macroscopic)

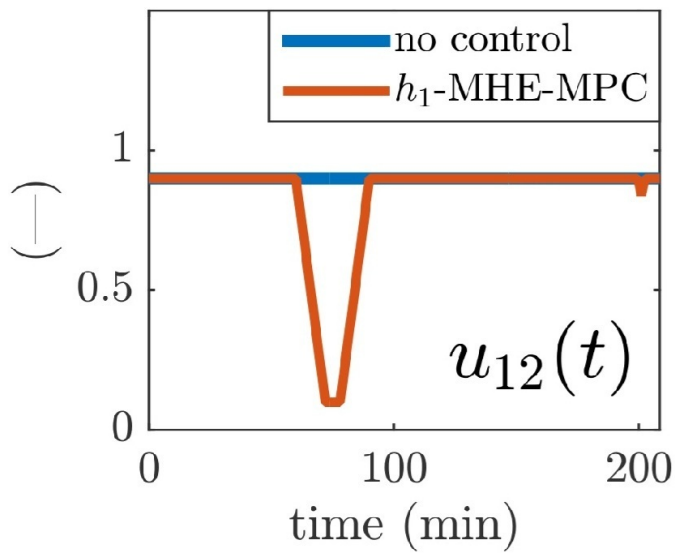


control performance

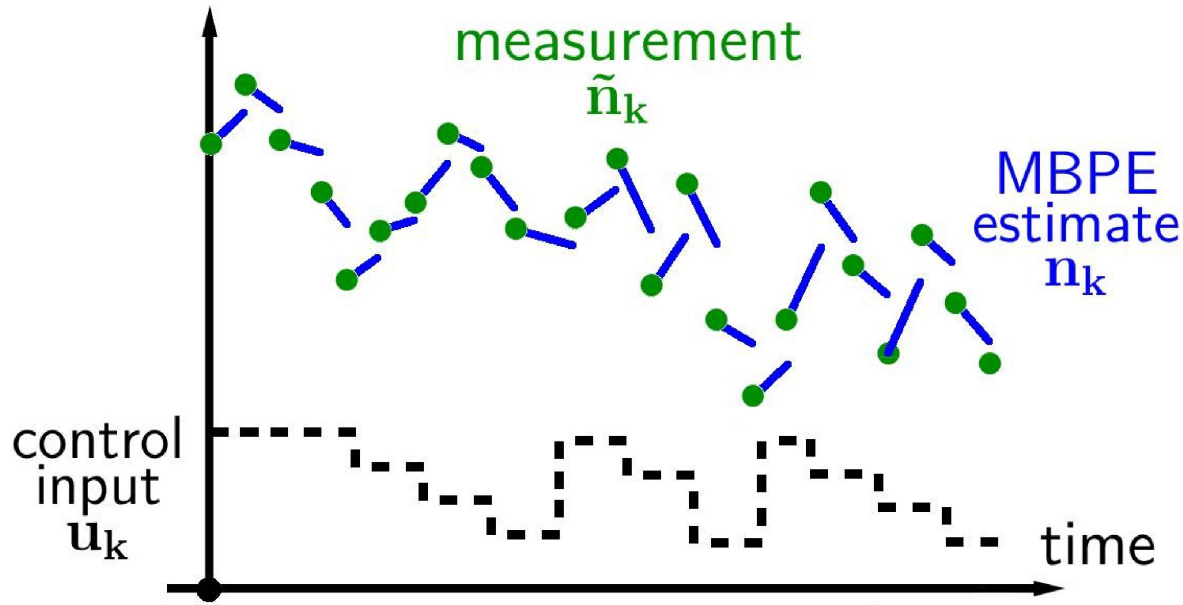


estimation performance





Model-based parameter estimation[5]



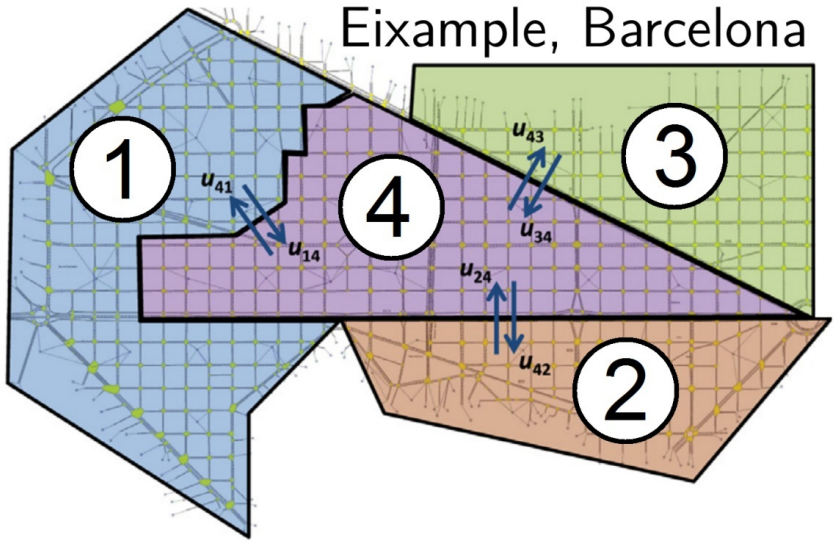
minimize parameters — tradeoff (process vs. meas. noise)

subject to — recorded measurements, constraints

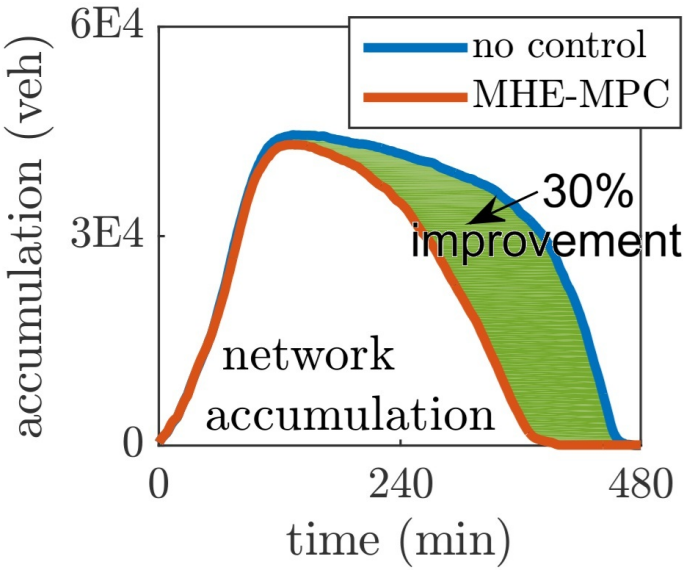
MFD-based model $(\dot{\mathbf{n}} = \mathbf{f}(\mathbf{n}, \mathbf{q}, \mathbf{u}))$

[5] Isik Ilber Sirmatel and Nikolas Geroliminis. *2020 European Control Conference (ECC)*. IEEE. 2020, pp. 408–413.

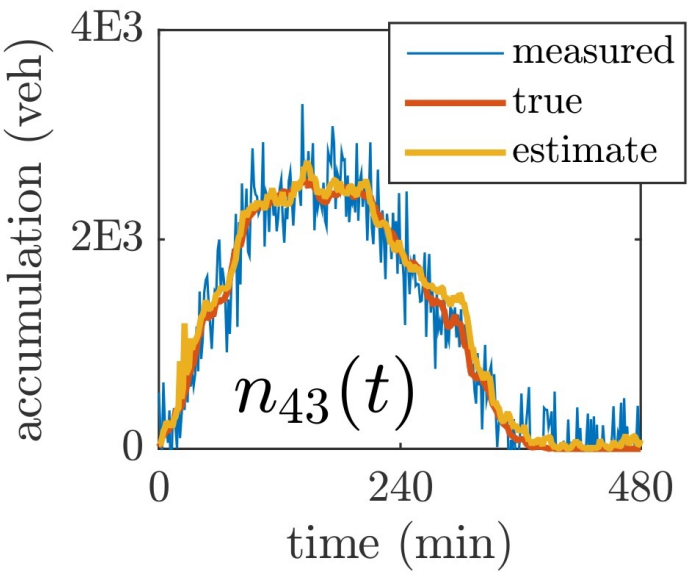
Simulation results (microscopic)

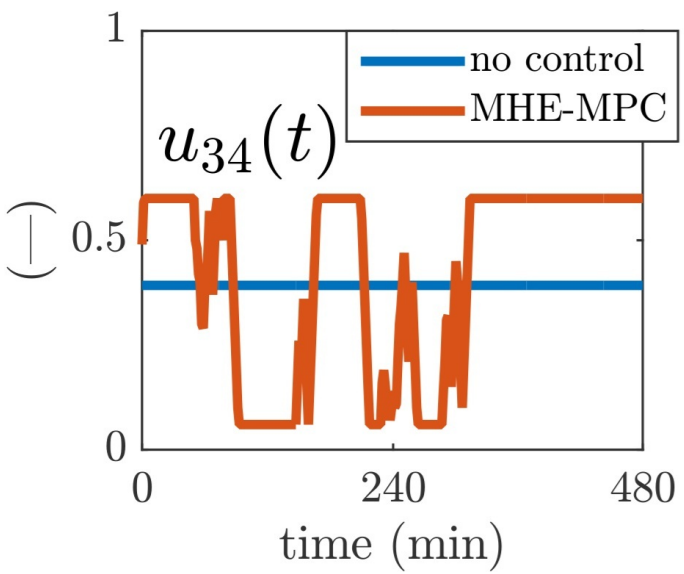


control performance

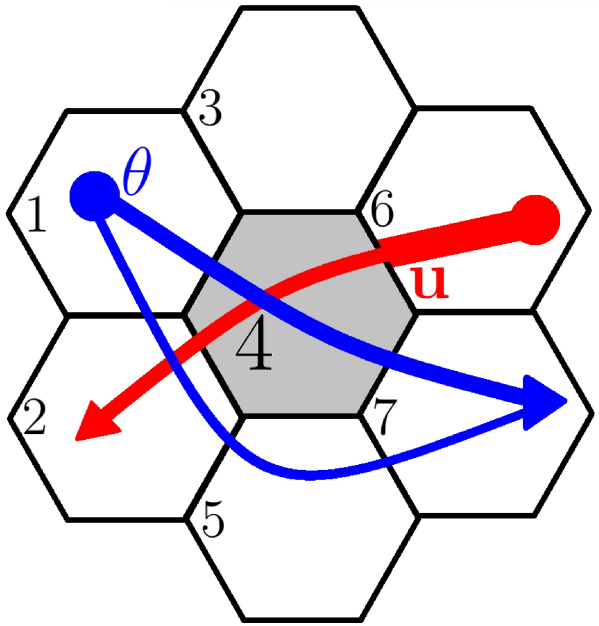


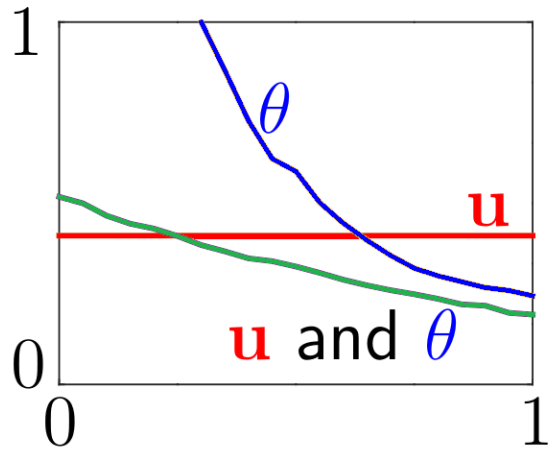
estimation performance





Perimeter and routing actuation MPC[6]





x-axis: driver compliance

y-axis: total time spent

$$\underset{\text{inputs}}{\text{minimize}} \quad \text{total time spent}$$

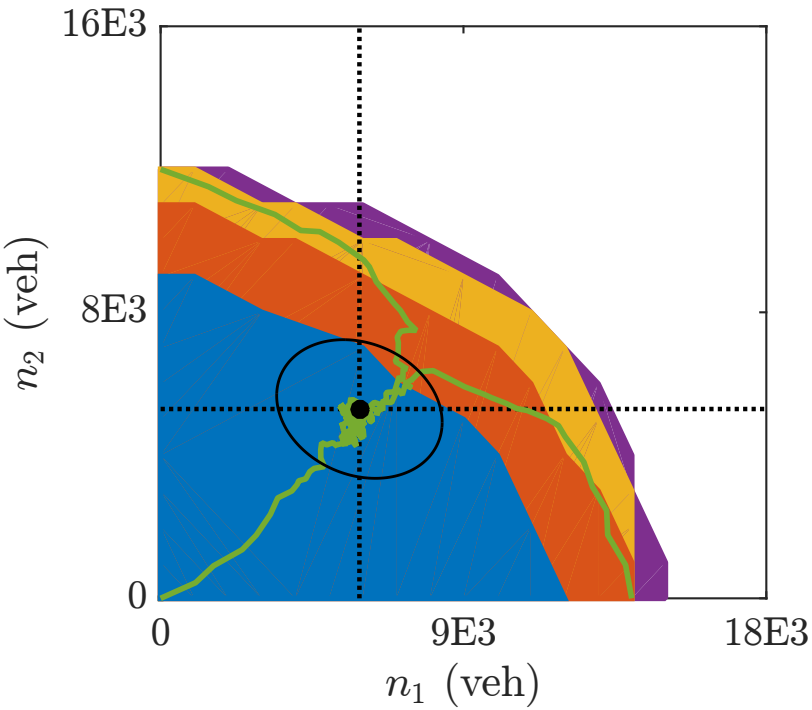
subject to measurement, input constraints

dynamical model $(\dot{\mathbf{n}} = \mathbf{f}(\mathbf{n}, \mathbf{q}, \mathbf{u}, \theta))$

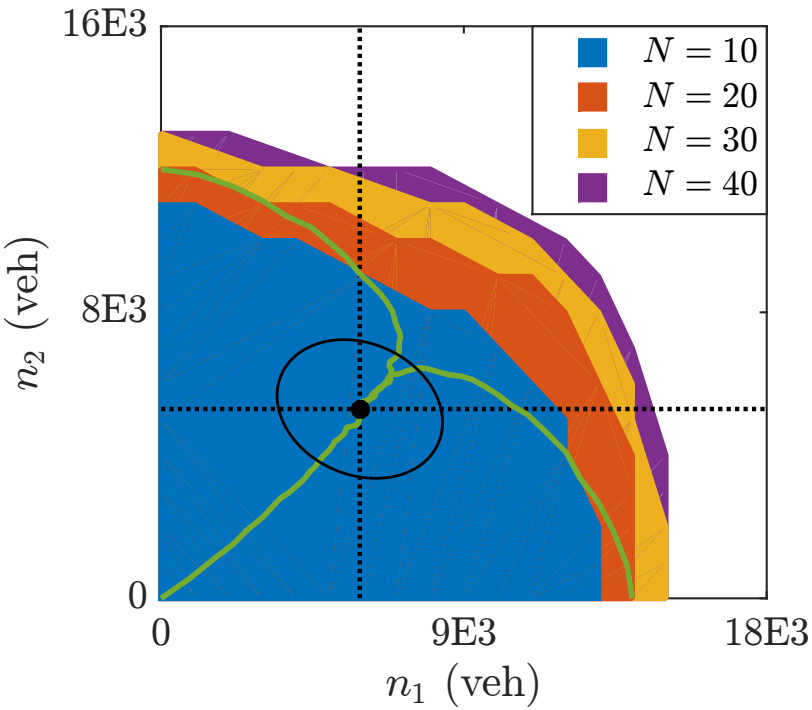
[6] Isik Ilber Sirmatel and Nikolas Geroliminis. *IEEE Transactions on Intelligent Transportation Systems* 19.4 (2018), pp. 1112–1121.

Stability of MPC for MFD systems[7]

domain of attraction (regulatory MPC)

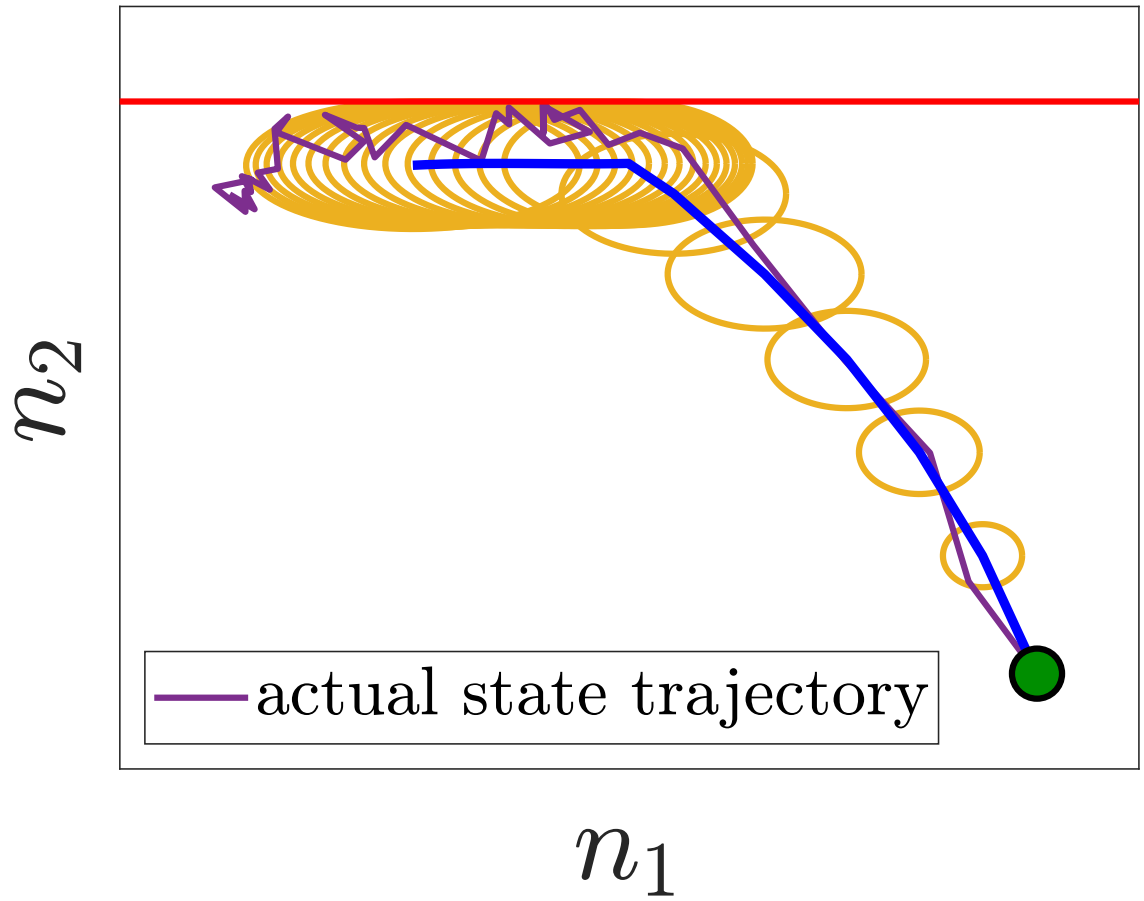


domain of attraction (regulatory MPC+MHE)



[7] Isik Ilber Sirmatel and Nikolas Geroliminis. *Control Engineering Practice* 109 (2021), p. 104750.

Robust nonlinear MPC (ongoing work)



minimize (input) nominal tracking cost

subject to current measurement, robustified constraints

MFD-based uncertain model, tube dynamics

Conclusion

contributions:

- MBPE, MHE, and MPC with MFDs
- perimeter and routing actuation

results:

- MHE-MPC $\rightarrow$ control under noise
- routing $\rightarrow$ control under low compliance

ongoing work:

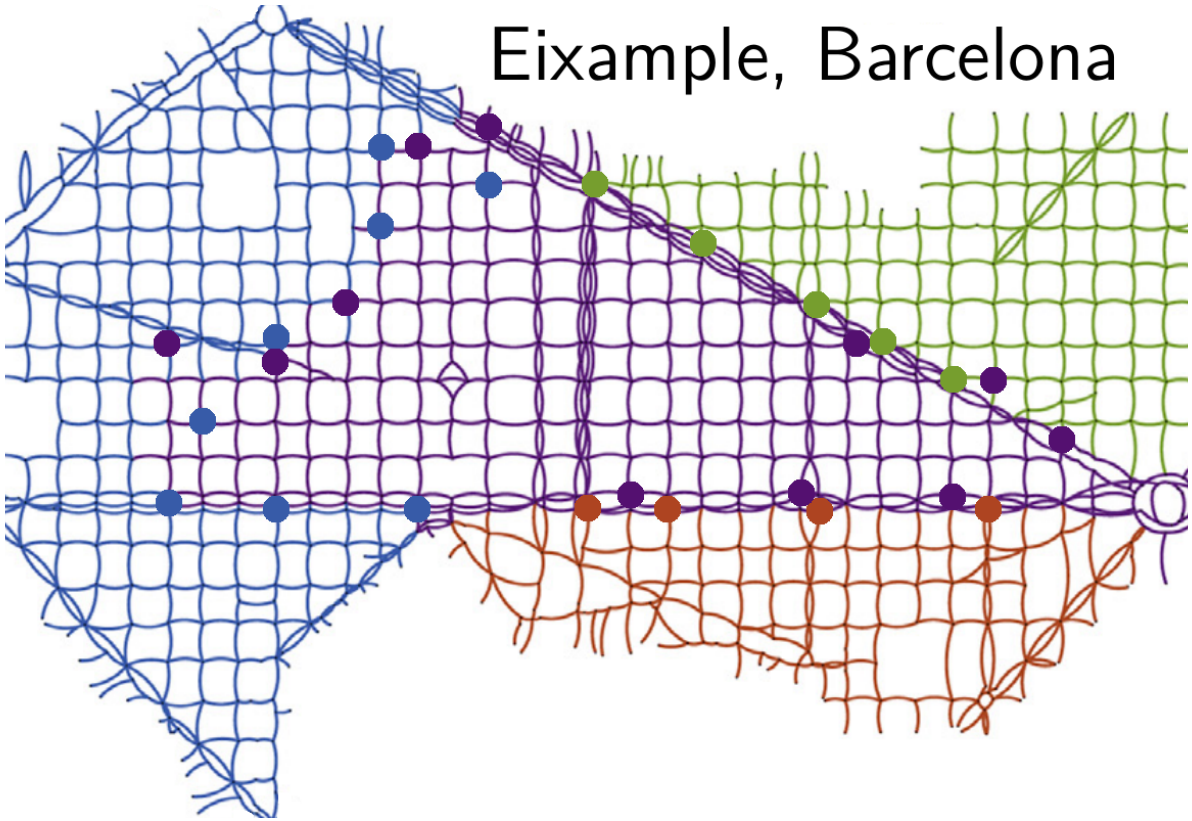
- parameter estimation and model validation
- robust nonlinear MPC $\rightarrow$ safe recovery

future work:

- modeling and control in mixed traffic
- hierarchical and distributed control

Discussion

sirmatel.github.io/seminar.pdf



12 km^2, $\sim$600 intersections, $\sim$1500 links

(28 controlled intersections shown as dots)