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Network inefficiency – empirical findings for six European cities

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CIVIL & ENVIRONMENTAL ENGINEERING
UNIVERSITY OF MICHIGAN

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Network inefficiency – empirical findings for six European cities

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Agenda

Network inefficiency
- Definition
- Impact factors
- Measurement

→

Methods and analysis concept
- MFD
- Excess delays
- Estimation techniques

→

Data
- Data sources
- Data types

→

Results
- Network loading
- Multimodality
- Traffic control

→

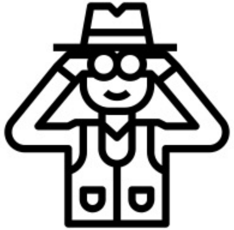
Conclusion
- Summary
- Outlook

Network inefficiency

What is network inefficiency?

Problem:

- Planning often assumes stationary and homogenous traffic conditions
- Capacities of urban road facilities are overestimated



Observations:

- Empirical data indicate reduced performance and inefficient use of infrastructure
- Reasons are complex traffic dynamics, multimodal vehicle interactions, traffic control strategies

Complex traffic dynamics

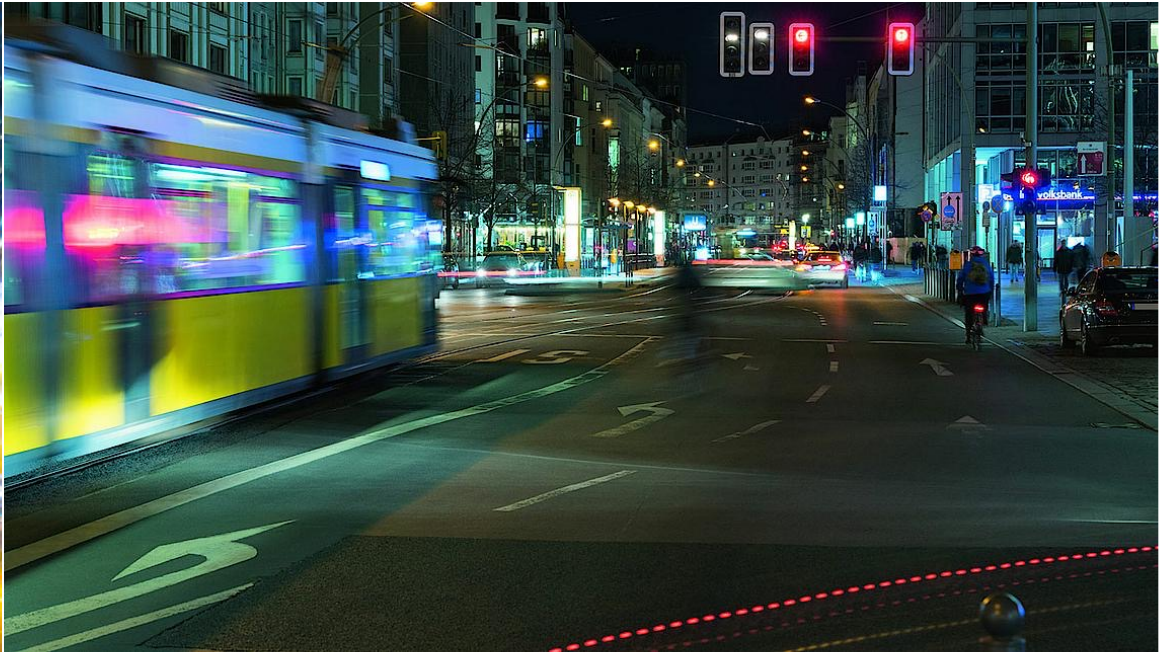
Source: http://www.reluctantchauffeur.com/2013/07/interesting-traffic-dynamics-and-tips.html

Multi-modal vehicle interactions

Source: https://ingenuity.siemens.com/2020/12/web-summit-2020-the-future-of-urban-mobility-will-be-multimodal-shared-and-sustainable/

Traffic control strategies

Source: https://trlsoftware.com/products/traffic-control/scoot/



Source: https://www.yunextraffic.com/global/en/portfolio/traffic-management/centrals/tools-for-urban-traffic-control

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How can we measure network inefficiency?

New concept:

- Excess delays in the macroscopic fundamental diagram (MFD)
- Idealized MFD: Perfect fit of supply and demand
- Observed MFD: Interaction of existing supply and demand
- Excess delays: Difference of both, come *on top* of delays already quantified in idealized MFD

Advantages:

- Quantification of *additional* effects of network loading, multimodality, and signal control

➡ *Aim:* Explorative quantification of the effects of the network loading, multimodality, signal control on network inefficiency by exploiting different types of data sources

Methods and analysis concept

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MFD

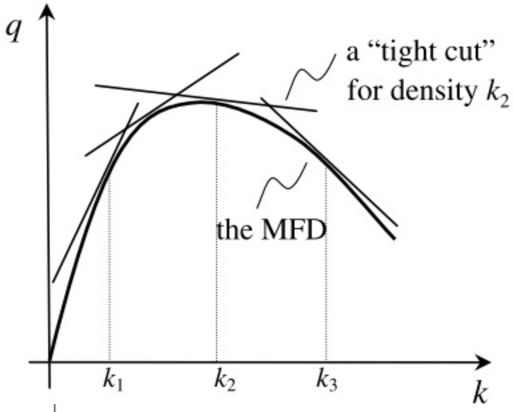
Concept:

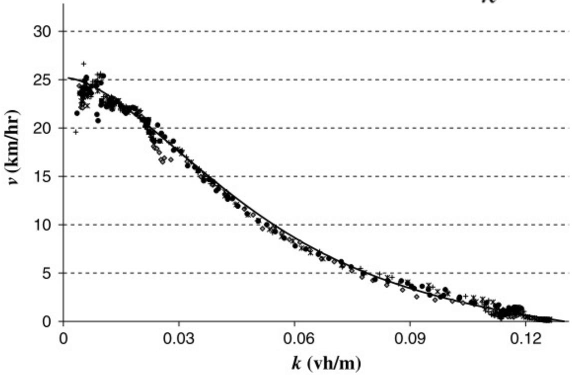
- Relation between network-wide average flow (production) and density (accumulation)
- Robust, reproducible, low-scatter when homogeneous densities
- Exists in contiguous urban areas of ~ 5-10km^2

$$\mathrm{v} = \frac{\Pi}{N} = \frac{q}{k}$$

Applications:

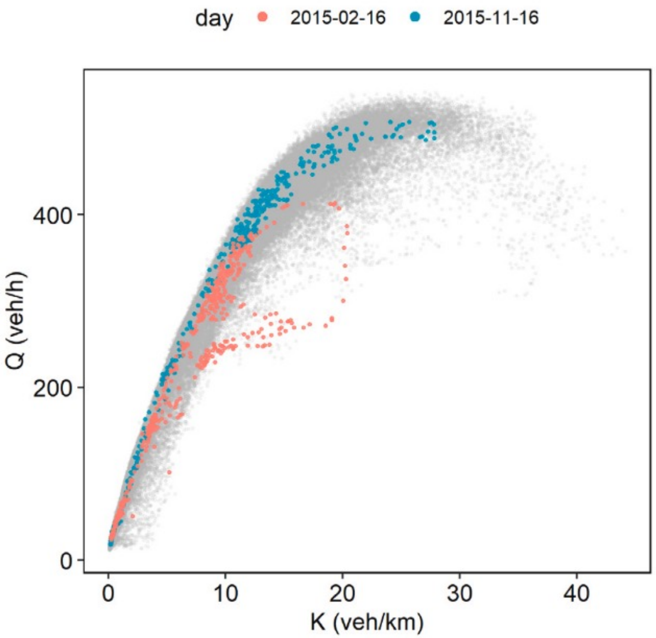
- Region-based traffic flow modeling
- Planning, pricing, control
- Traffic analysis





Daganzo, C.F., Geroliminis, N. (2008).

MFD: Scatter is real



Ambühl, L., Loder, A., Leclercq, L., & Menendez, M. (2021).

Network inefficiency and the MFD

Network loading processes and hysteresis:

- Temporal: Onset and offset of congestion
- Spatial: Heterogeneous density distribution

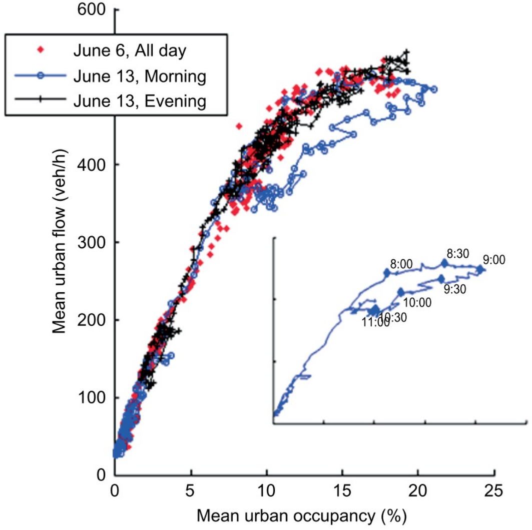
Multimodal vehicle interactions:

- Cars, buses and bicycles
- Limited space

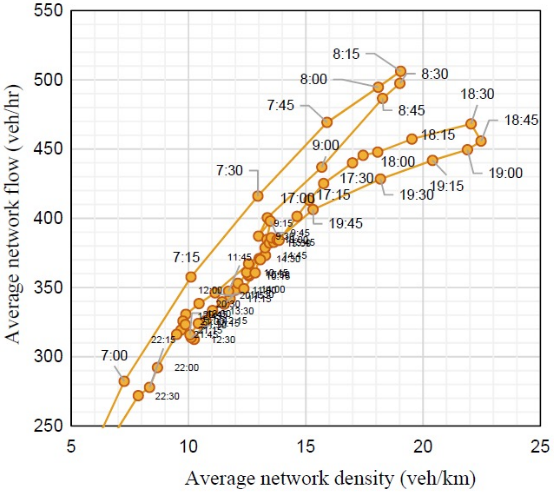
Traffic signal control:

- Effects of dynamic traffic management schemes

Network loading

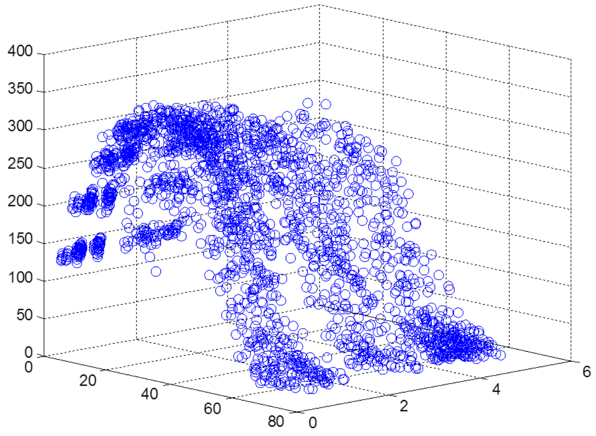


Buisson, C., & Ladier, C. (2009).

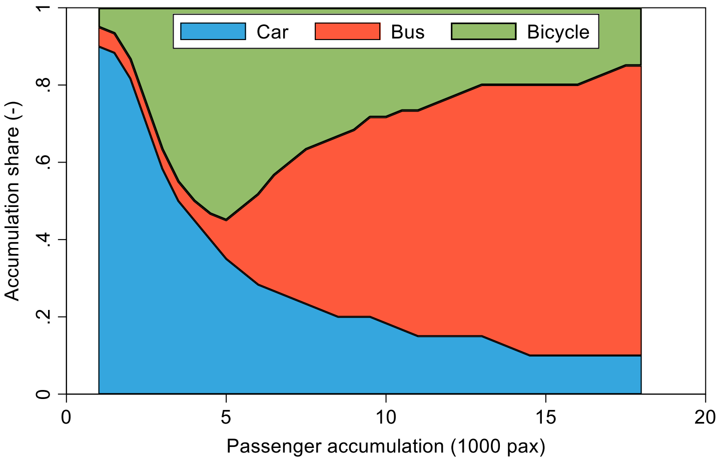


Shim, J., Yeo, J., Lee, S., Hamdar, S. H., & Jang, K. (2019).

Multi-modal vehicle interactions



Ortigosa, J., Menendez, M., Zheng, N. & Geroliminis, N. (2015).



Loder, A., Dakic, I., Bressan, L., Ambühl, L., Bliemer, M. C., Menendez, M., & Axhausen, K. W. (2019); Loder, A., Bressan, L., Wierbos, M. J., Becker, H., Emmonds, A., Obee, M., ... & Axhausen, K. W. (2019).

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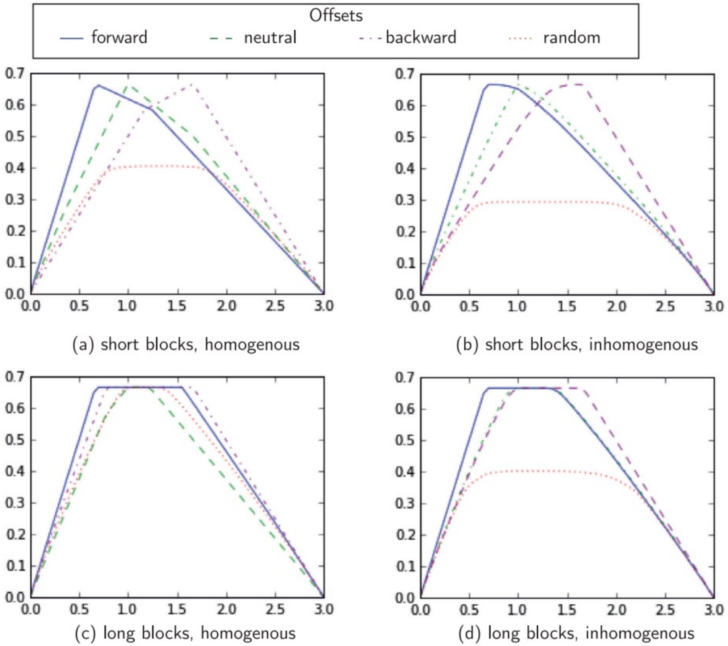
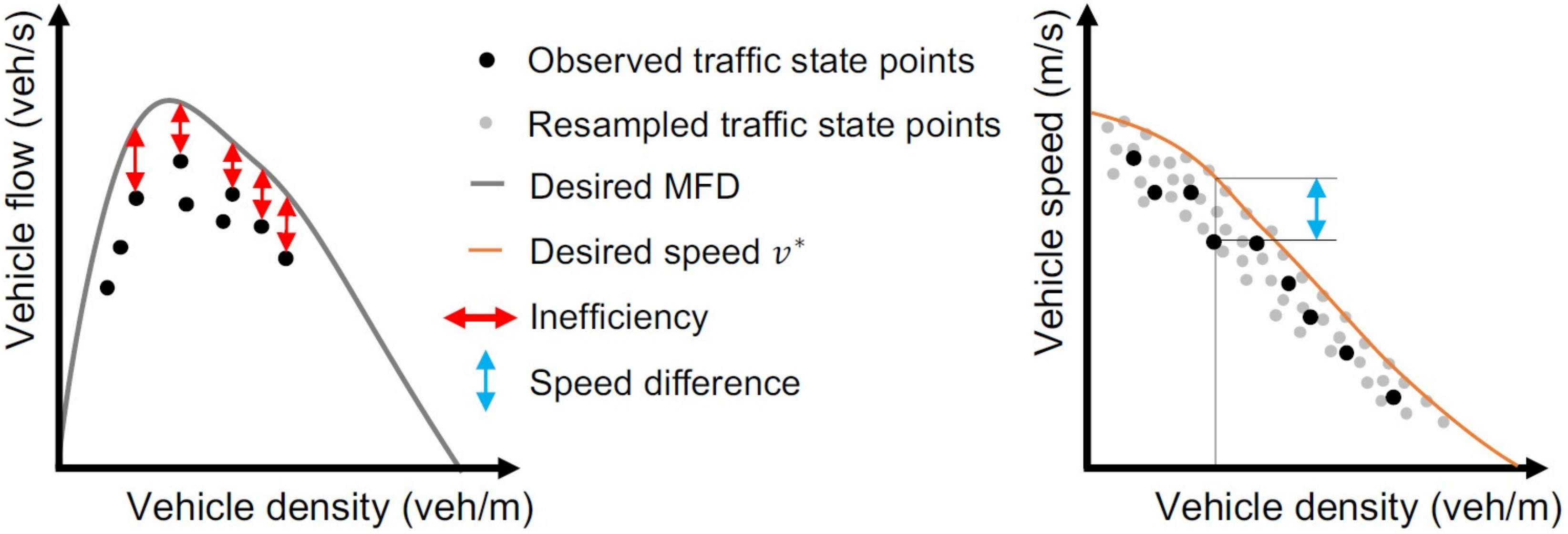
Traffic signal control



Daganzo, C. F., & Lehe, L. J. (2016)

Network inefficiency and the MFD



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Network inefficiency and the MFD

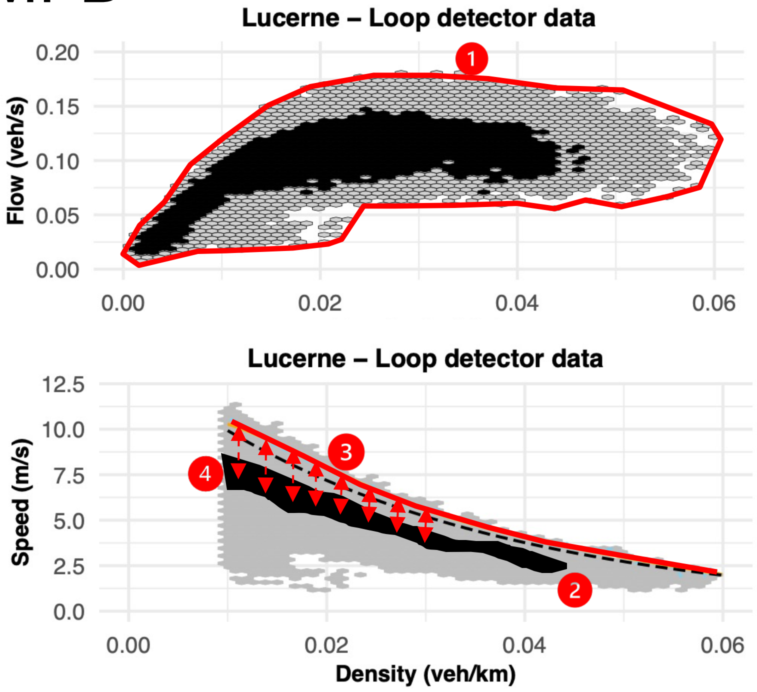
1. Estimate the *resampled* MFD

2. Estimate the observed *speed* MFD

3. Estimate the *desired speed* MFD (upper bound)

4. Estimate *excess delays*

5. Analyze excess delays as a proxy for *network inefficiency*



Estimation of the desired speed MFD

Investigation three different fitting methods:

- Ambühl et al. (2020): Functional form of the MFD
- 99th percentile of the speed distribution at density bins
- Underwood (1961): Exponential function: $v^*(k) = \exp(\log(c_0) + \log(c_1 * k)$

Data

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Data origins: Six European cities

Diverse set of cities

Large differences in:
- Surface areas
- Population size
- Network size
- Traffic densities
- Average speeds
- Measurement technologies

Source: https://www.freeworldmaps.net/printable/europe/

Data types: Drone data

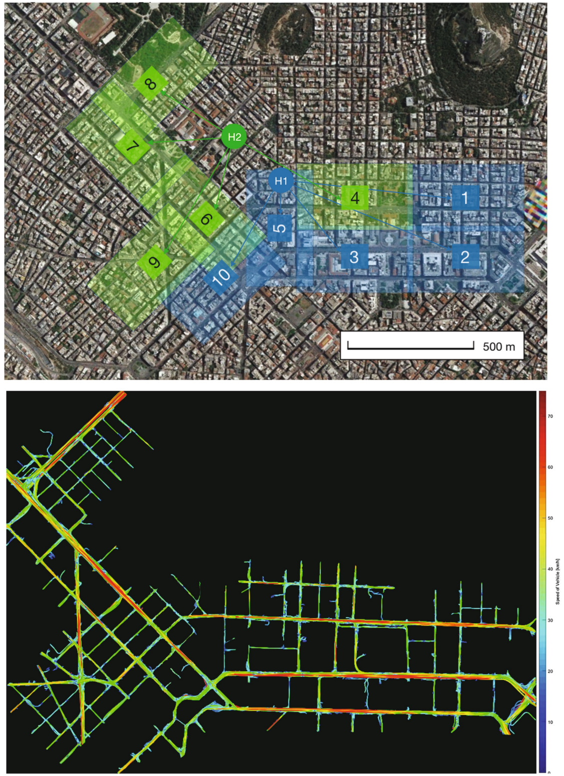
pNEUMA dataset of Athens (Barmpounakis &Geroliminis, 2020)

Characteristics:

- Four weekdays, only morning hours
- Ten drones
- Coordinates with time stamps for car, bus, taxi, large & medium vehicles, motorcycles
- 2-min aggregation interval
- Extensive pre-processing needed

Purpose:

- Other type of data collection, data set includes multimodal traffic (not only cars)



(Barmpounakis & Geroliminis, 2020)

Data types: Loop detector data

Characteristics:

- Part of the UTD19 data set (more than 30 cities) (Loder, Ambühl, Menendez, and Axhausen, 2020)
- Occupancy (time fraction occupying detector) and traffic counts (no. of vehicles passing) from stationary loop detectors in city areas
- 5-min and 1-hour aggregation intervals

Purpose:

- Large-scale data (large time windows up to 365 days)
- Large network sizes (up to 160 km^2)
- More cities for comparison
- Different types of biases

Source: https://www.linkedin.com/pulse/20141005200312-83983163-traffic-signals-part-6-vehicle-detection/

Data types: Simulation data

Characteristics:

- Microscopic SUMO simulation of Innsbruck
- Based on OSM network
- Random demand ODs, trapezoidal loading curve
- 4 hours of simulation (i.e. rush hour)
- 5-min aggregation period

Purpose:

- Measure impact of signal control on network inefficiency
- Variation in fixed-time signal control characteristics

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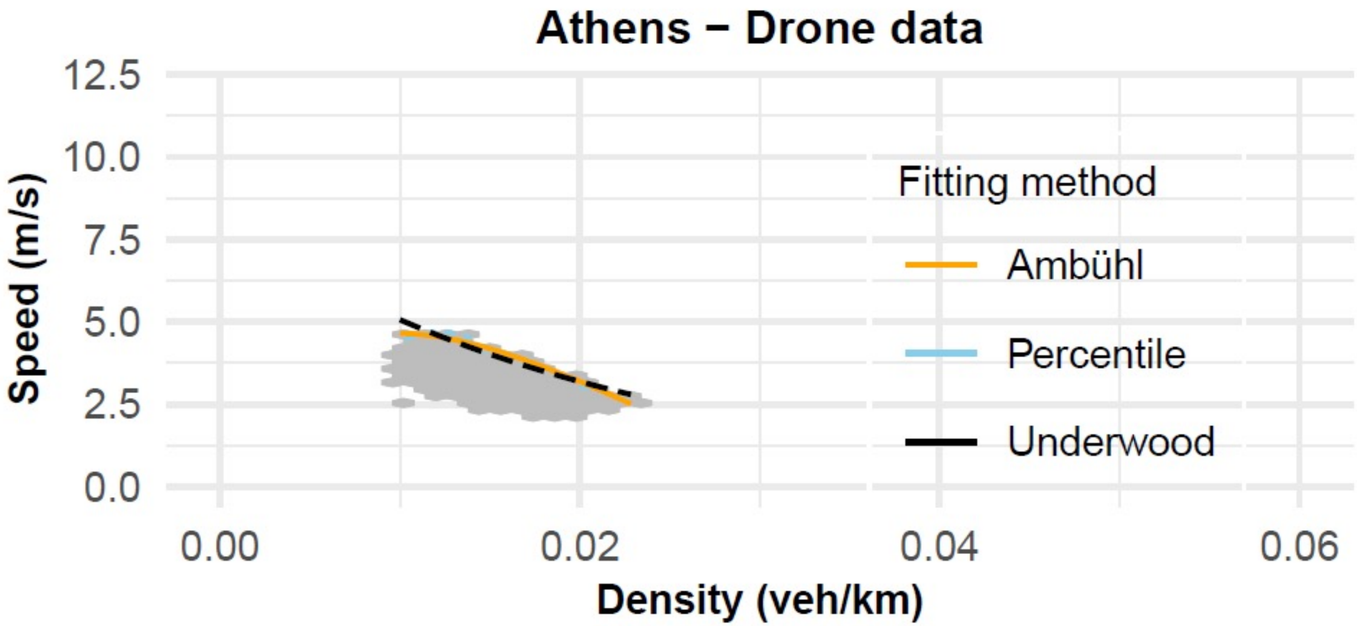
Data summary

Data set	Athens	Innsbruck	London	Lucerne	Paris	Zurich
Population size (mil.)	0.664	0.131	8.961	0.082	2.161	0.403
Network size (km^2)	1.3	33	160	5	24	15
Detection method	drone	simulation	loop det.	loop det.	loop det.	loop det.
Time window	4 days	4 hours	22 days	365 days	335 days	365 days
Aggregation interval (seconds)*	120	300	300	300	3600	300
No. of subsamples*	100	100	20	100	20	100
Fraction size *	0.25	0.25	0.2	0.25	0.2	0.25

Results

Results: v* fitting method



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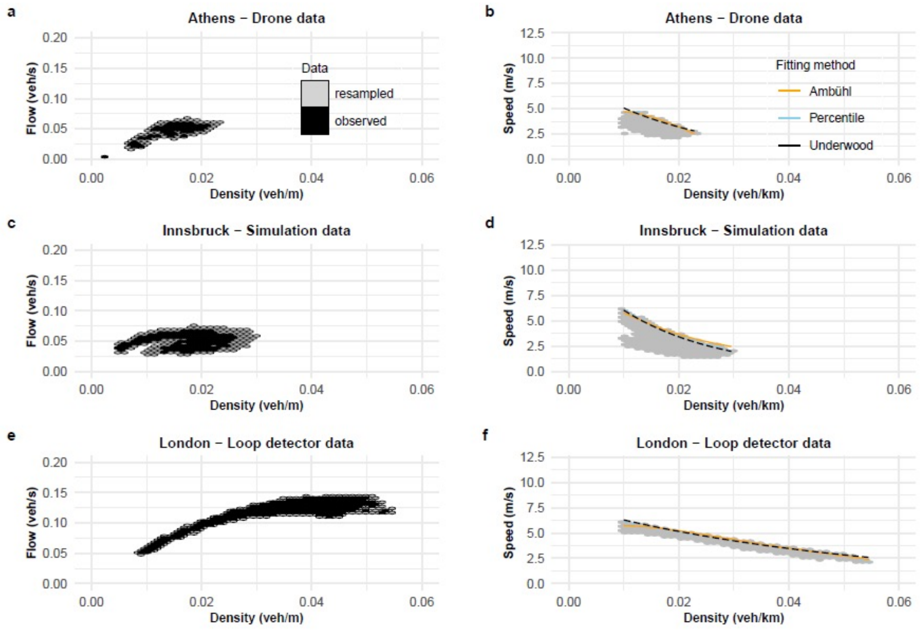
Results: network loading



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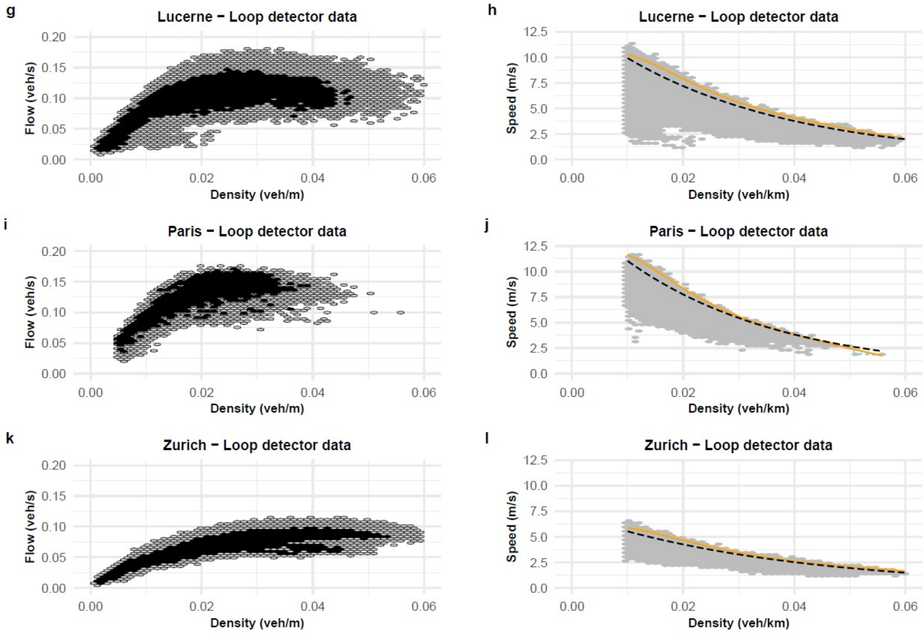
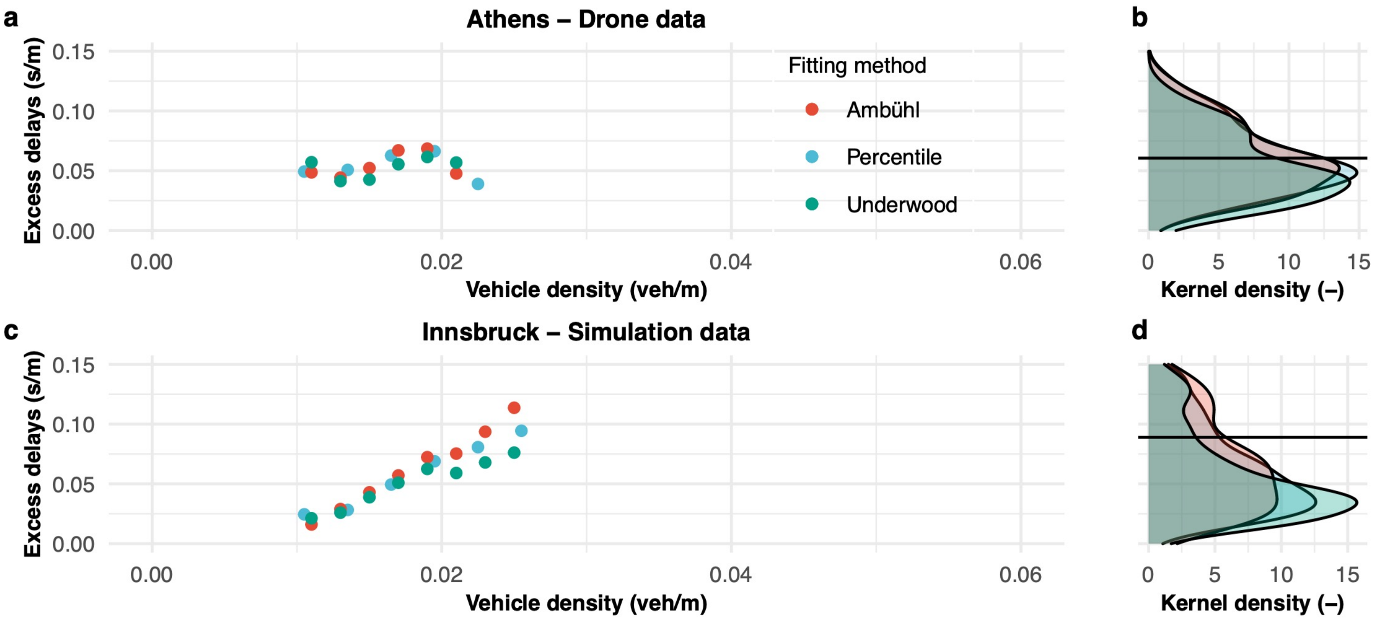
Results: network loading



Results: Density vs. excess delays



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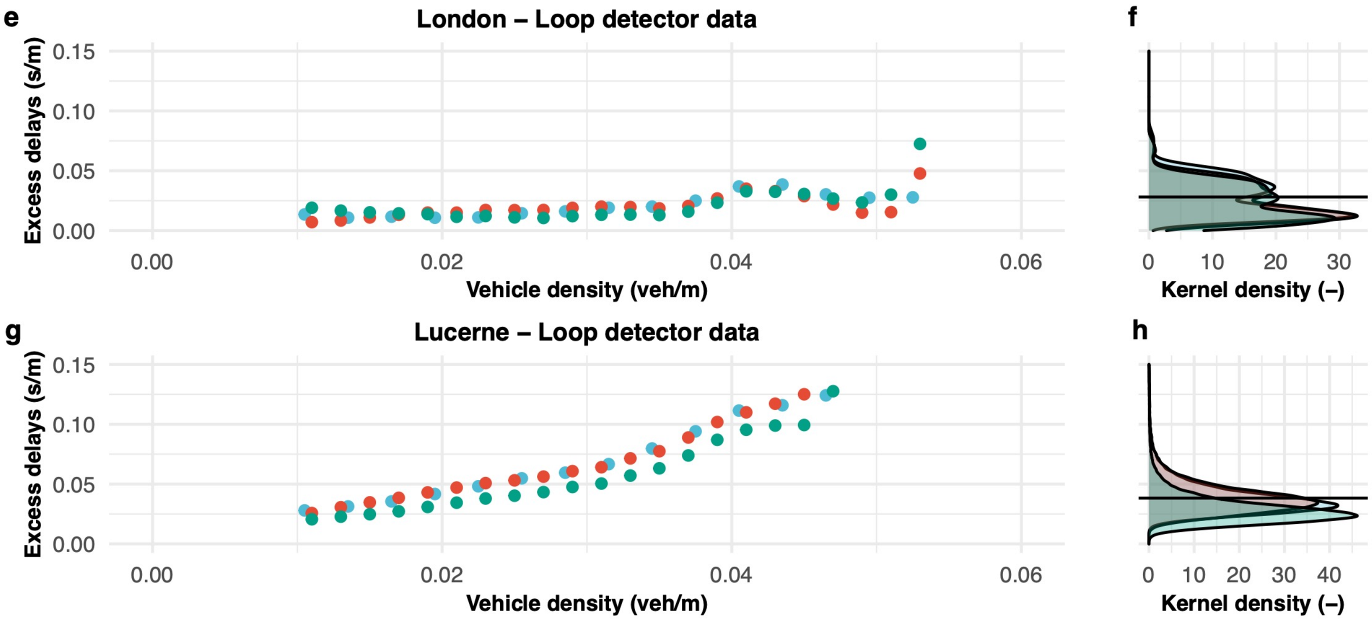

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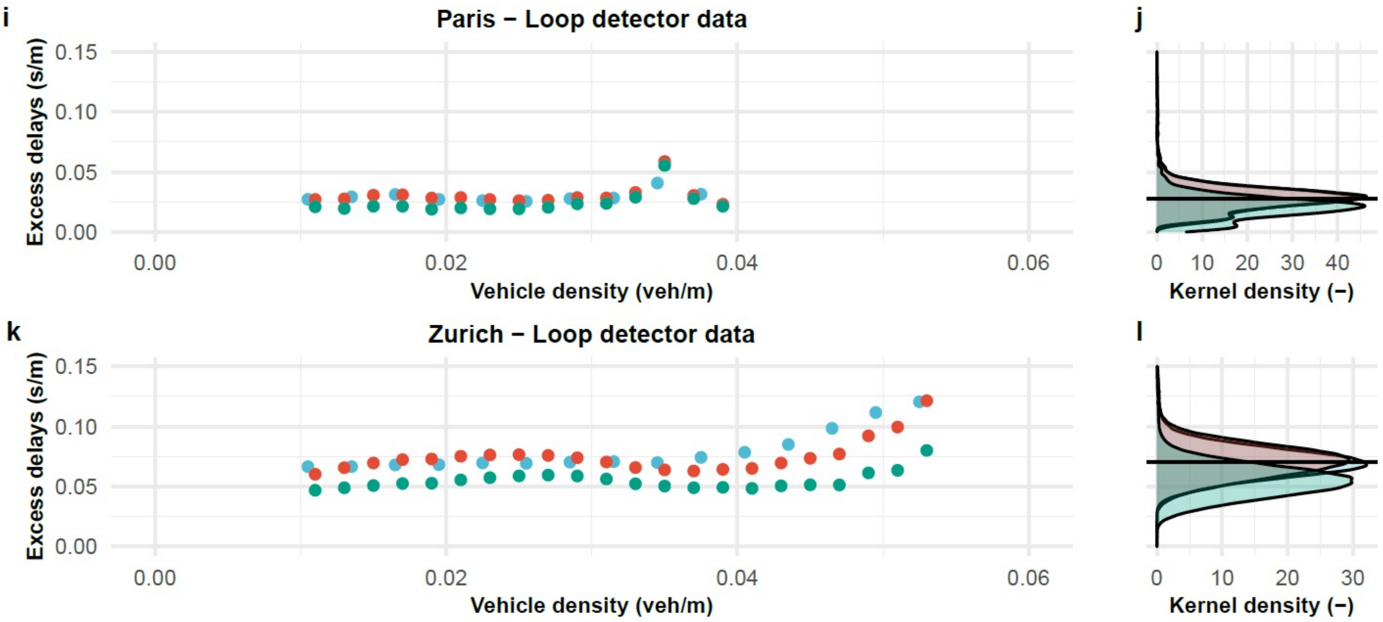

Effect of density and network loading on excess delays

Dataset	Effect of density	Effect of loading	R^2	Density range (veh/m)
Athens	2.96 ($p < 0.01$)	-0.038 ($p < 0.01$)	0.26	0.01 to 0.02
Innsbruck	3.53 ($p < 0.01$)	-0.090 ($p < 0.01$)	0.53	0.01 to 0.03
London	1.13 ($p < 0.01$)	0.001 ($p < 0.01$)	0.19	> 0.02
Lucerne	2.30 ($p < 0.01$)	-0.003 ($p < 0.01$)	0.30	> 0.02
Paris	-0.24 ($p < 0.05$)	0.001 ($p < 0.01$)	0.006	> 0.02
Zurich	0.48 (p <. 0.01)	-0.002 ($p < 0.01$)	0.03	> 0.02

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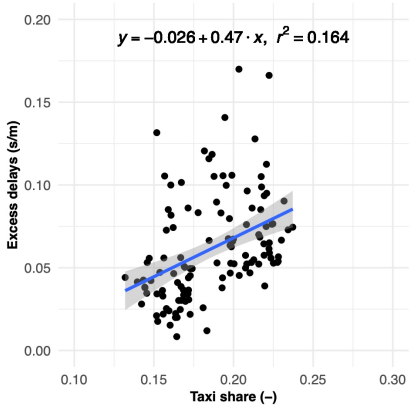
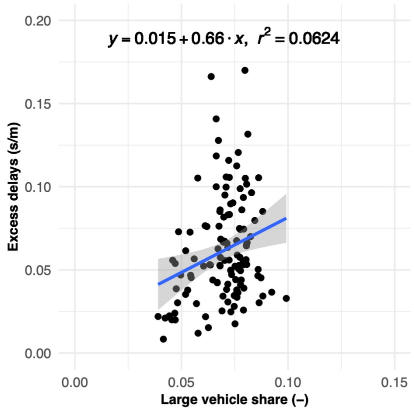
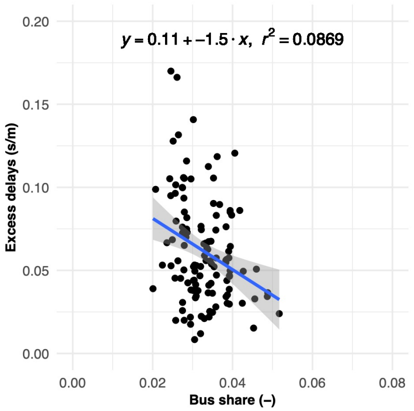
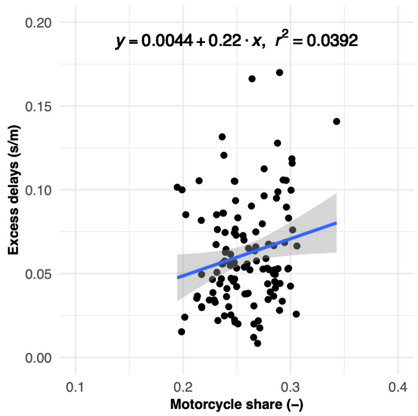
Results: Multimodal traffic in Athens

Drone data



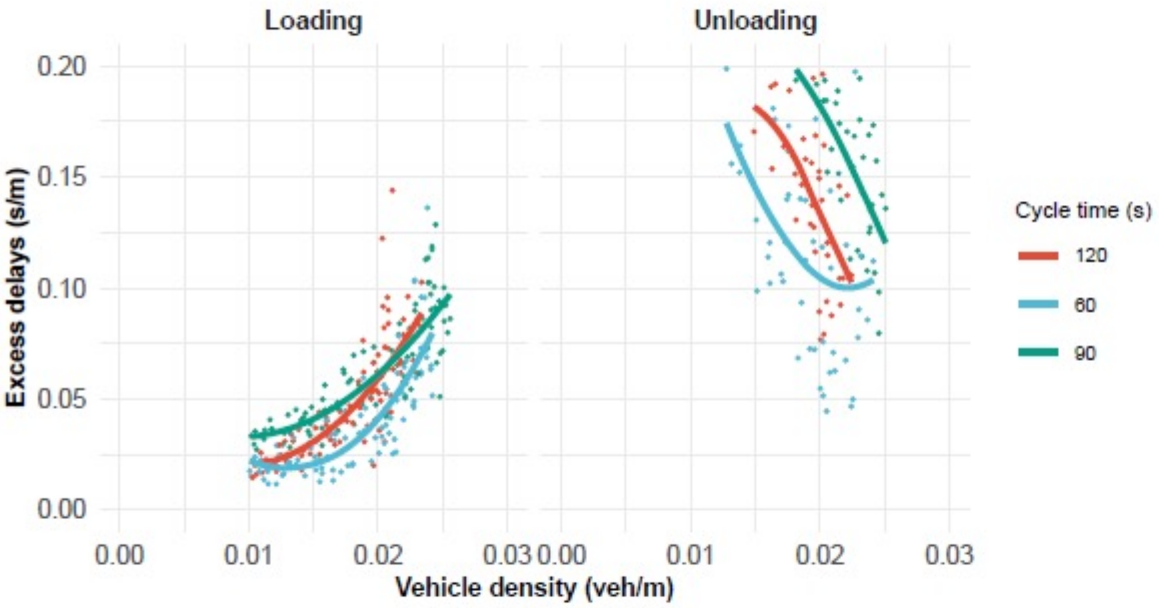






Results: Traffic control

Simulation data



Conclusions

Conclusion

Summary:

- Excess delays as performance indicator for urban road networks
- Using different data sources from six European cities
- Approach might simplify modeling of hysteresis effects
- Enables more realistic capacity planning; can be used for traffic management (e.g., road pricing, perimeter control)

Outlook:

- Sound methodological formalization
- Investigation of the role of network topology
- Better understanding of the network dynamics

References

Ambühl, L., A. Loder, M. C. Bliemer, M. Menendez, and K.W. Axhausen. (2020) A functional form with a physical meaning for the macroscopic fundamental diagram. Transportation Research Part B: Methodological, Vol. 137, pp. 119–132.

Ambühl, L., Loder, A., Leclercq, L., & Menendez, M. (2021). Disentangling the city traffic rhythms : A longitudinal analysis of MFD patterns over a year. Transportation Research Part C, 126(January), 103065. https://doi.org/10.1016/j.trc.2021.103065

Barmpounakis, E. and N. Geroliminis. (2020) On the new era of urban traffic monitoring with massive drone data: The pNEUMA large-scale field experiment. Transportation Research Part C: Emerging Technologies, Vol. 111, pp. 50–71. doi:10.1016/j.trc.2019.11.023.

Buisson, C., & Ladier, C. (2009). Exploring the Impact of Homogeneity of Traffic Measurements on the Existence of Macroscopic Fundamental Diagrams. *Transportation Research Record: Journal of the Transportation Research Board*, *2124*, 127–136. https://doi.org/10.3141/2124-12

Daganzo, C.F., Geroliminis, N. (2008) An analytical approximation for the macroscopic fundamental diagram of urban traffic. Transp. Res. Part B Methodol. 42, 771–781.

Daganzo, C. F., & Lehe, L. J. (2016). Traffic flow on signalized streets. Transportation Research Part B, 90, 56–69. https://doi.org/10.1016/j.trb.2016.03.010

Loder, A., L. Ambühl, M. Menendez, and K. W. Axhausen. (2020) UTD19. Understanding traffic capacity of urban networks. doi:10.3929/ethz-b-000437802.

Loder, A., Dakic, I., Bressan, L., Ambühl, L., Bliemer, M. C., Menendez, M., & Axhausen, K. W. (2019). Capturing network properties with a functional form for the multi-modal macroscopic fundamental diagram. *Transportation Research Part B: Methodological*, *129*, 1-19.

Loder, A., Bressan, L., Wierbos, M. J., Becker, H., Emmonds, A., Obee, M., ... & Axhausen, K. W. (2019). A general framework for multi-modal macroscopic fundamental diagrams (MFD). *Arbeitsberichte Verkehrs-und Raumplanung*, *1444*.

Ortigosa, J., Menendez, M., Zheng, N. & Geroliminis, N. (2015) Analysis of the3D-vMFDs of the urban networks of Zurich and San Francisco.

Underwood, R. T. (1961) Speed, Volume and density relationships. In Quality and Theory of Traffic Flow. Pennsylvania State University, University Park, pp. 141–188.