愛媛大学
EHIME UNIVERSITY

MAGnUM
European Research Council
Established by the European Commission
Multiscale and Multimodal Traffic Modelling Approach for Sustainable Management of Urban Mobility

Large-scale transportation systems: Monitoring and simulation based on the MFD concept

Ludovic Leclercq

Univ. Lyon, IFSTTAR, ENTPE

October, 13th, 2017

IFSTTAR
UNIVERSITÉ DE LYON
ENTPE
L'école de l'aménagement durable des territoires

References

- Aboudolas, K., Geroliminis, N., 2013. Perimeter and boundary flow control in multi-reservoir heterogeneous networks. Transportation Research Part B: Methodological 55, 265–281.
- Arnott, R., 2013. A bathtub model of downtown tra c congestion. Journal of Urban Economics 76, 110–121.
- Daganzo, C. F., 2007. Urban gridlock: Macroscopic modeling and mitigation approaches. Transportation Research Part B: Methodological 41 (1), 49–62.
- Daganzo, C.F., Geroliminis, N., 2008. An analytical approximation for the macroscopic fundamental diagram of urban traffic. *Transportation Research Part B*, 42(9):771-781.
- Fosgerau, M., 2015. Congestion in the bathtub. Economics of Transportation 4 (4), 241–255.
- Leclercq, L., Sénécat, A., Mariotte, G., 2017. Dynamic macroscopic simulation of on-street parking search: a trip- based approach. *Transportation Research part B*, 101, 268-282.
- Mariotte, G., Leclercq, L., Laval, J.A., 2017. Macroscopic urban dynamics: Analytical and numerical comparisons of existing models. *Transportation Research part B*, 101, 245-267.
- Leclercq, L., Chiabaut, N., Trinquier, B., 2014. Macroscopic fundamental diagrams: A cross-comparison of estimation methods. Transportation
- Research Part B: Methodological 62, 1–12.
- Leclercq, L., Parzani, C., Knoop, V. L., Amourette, J., Hoogendoorn, S. P., 2015. Macroscopic tra c dynamics with heterogeneous route patterns.
- Transportation Research Part C: Emerging Technologies 55, 292–307.
- Leclercq, L., Geroliminis, N., 2013. Estimating MFDs in Simple Networks with Route Choice. *Transportation Research part B*, 57:468-484.
- Mahmassani, H. S., Saberi, M., Zockaie, A., 2013. Urban network gridlock: Theory, characteristics, and dynamics. Transportation Research Part C: Emerging Technologies 36, 480–497.
- Ramezani, M., Haddad, J., Geroliminis, N., 2015. Dynamics of heterogeneity in urban networks: aggregated tra c modeling and hierarchical control. Transportation Research Part B: Methodological 74, 1–19.
- Yildirimoglu, M., Geroliminis, N., 2014. Approximating dynamic equilibrium conditions with macroscopic fundamental diagrams. Transportation Research Part B: Methodological 70, 186–200.
- Yildirimoglu, M., Ramezani, M., Geroliminis, N., 2015. Equilibrium analysis and route guidance in large-scale networks with MFD dynamics. Transportation Research Part C: Emerging Technologies 59, 404–420.

Outline

- Macroscopic urban models
- Estimating the NMFD for a given area
- The simple bathtub formulation
- The trip-based MFD formulation
- Application to surface parking simulation
- 3D congestion maps and travel time estimation at large urban scale

Macroscopic urban models

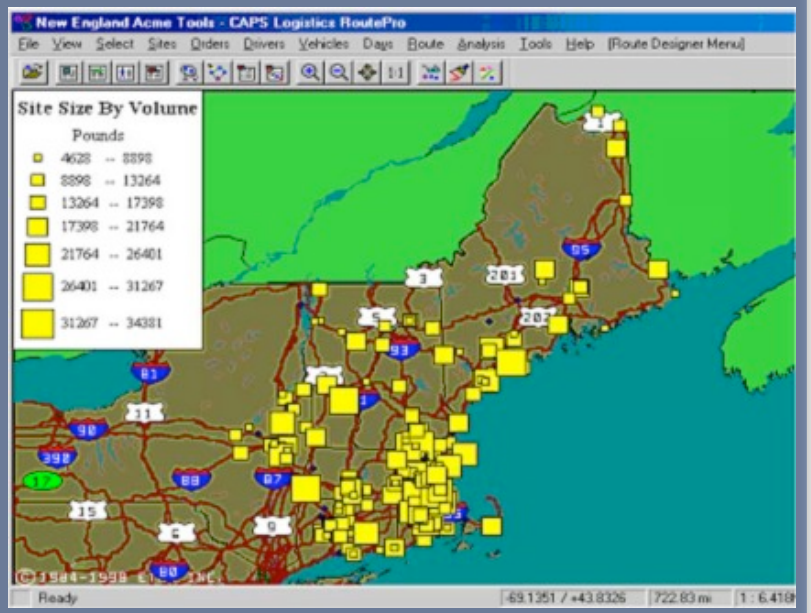
Transportation models

Local traffic dynamics

Open simulation plateform (Symuvia)

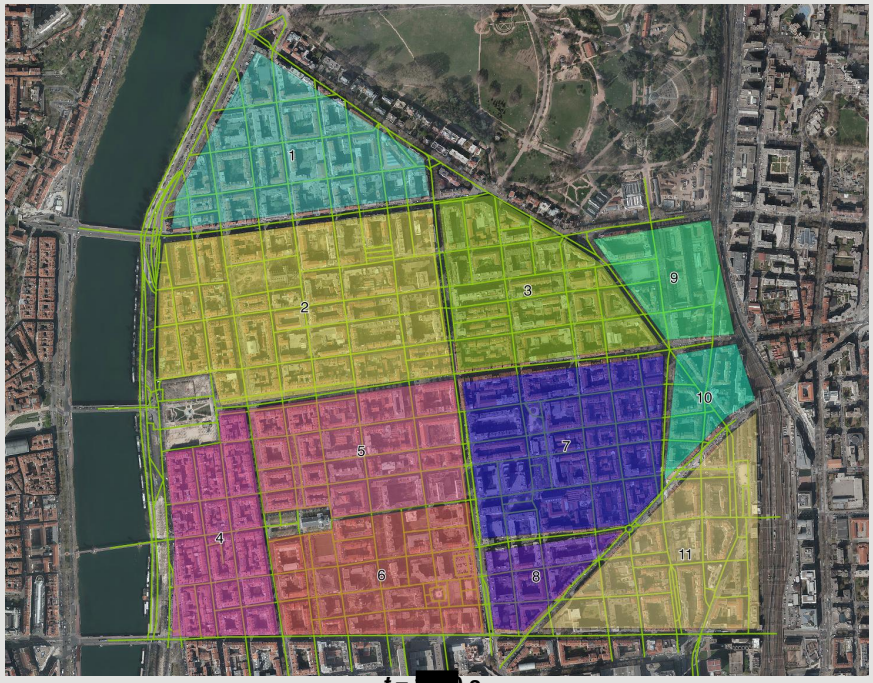
(Leclercq et *al*, 2009-2015)

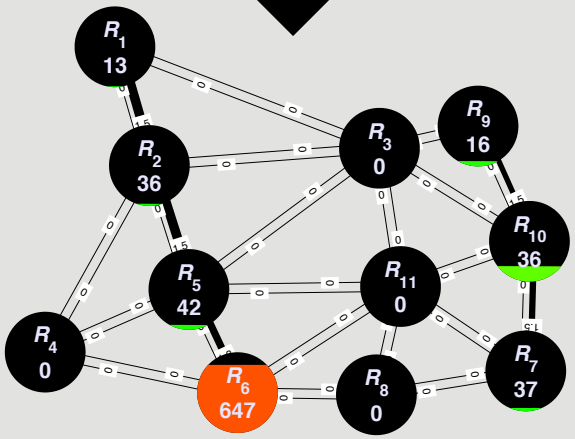
Static model for planing

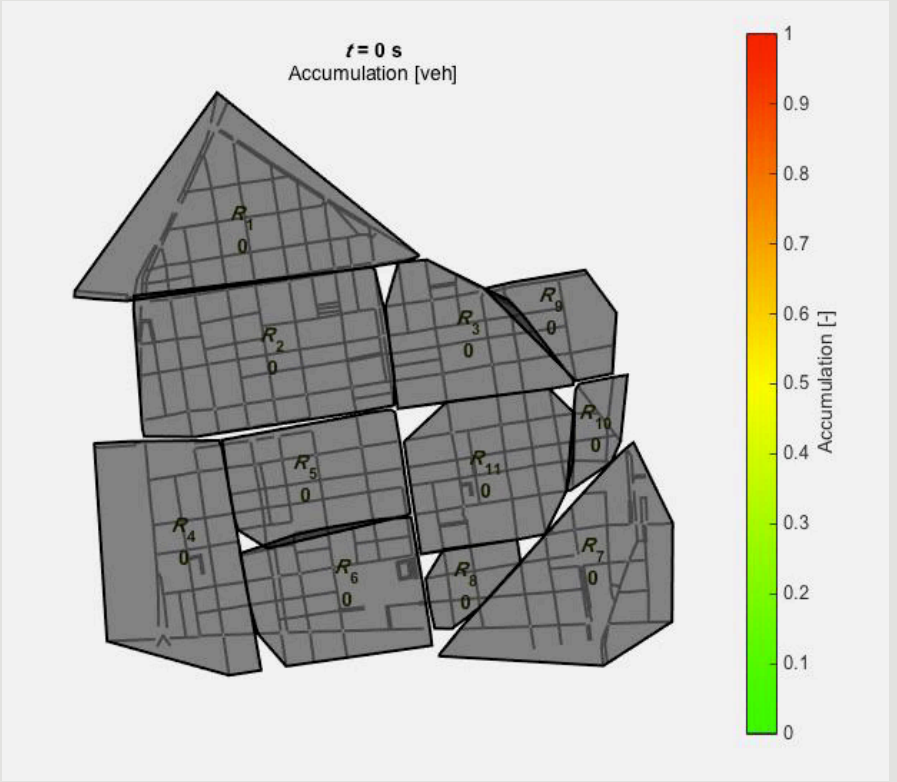


Room for large-scale dynamic models

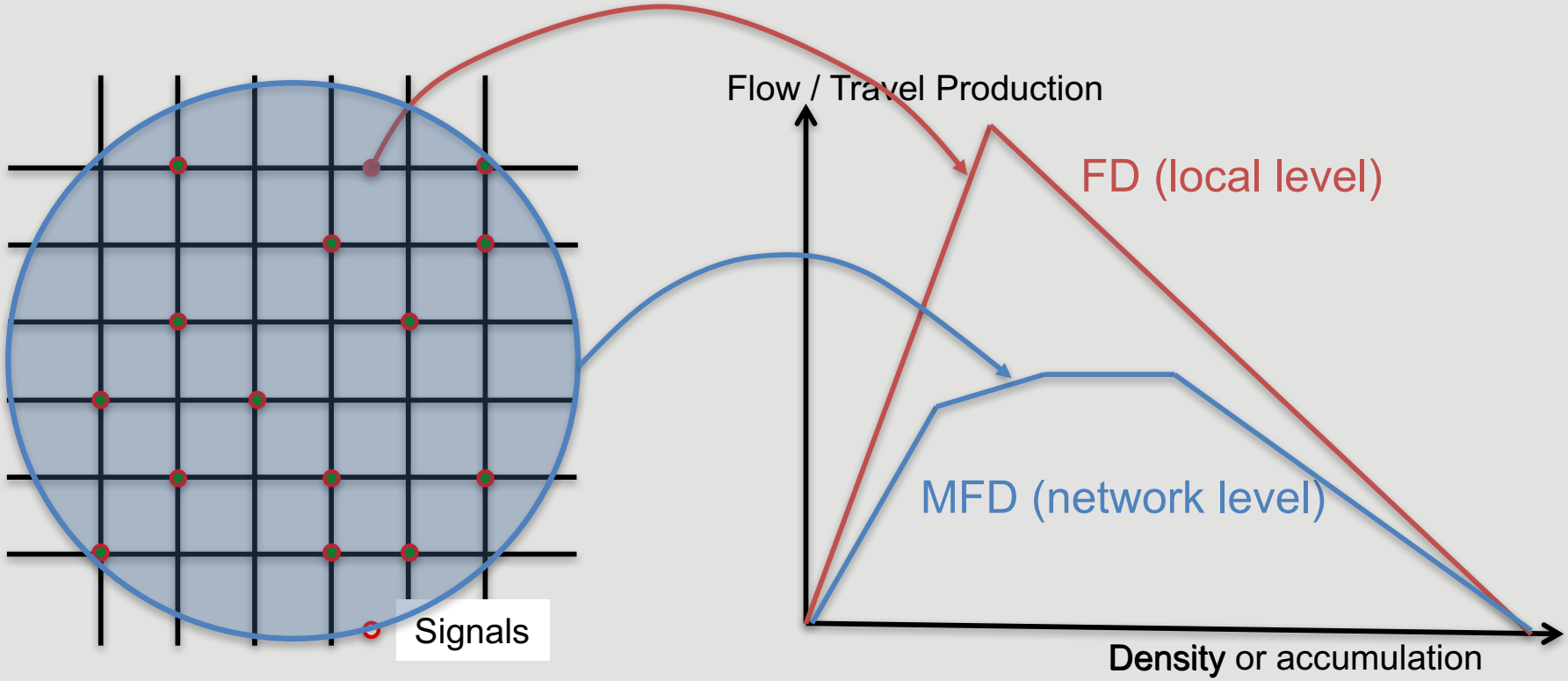
Large-scale dynamic urban simulation





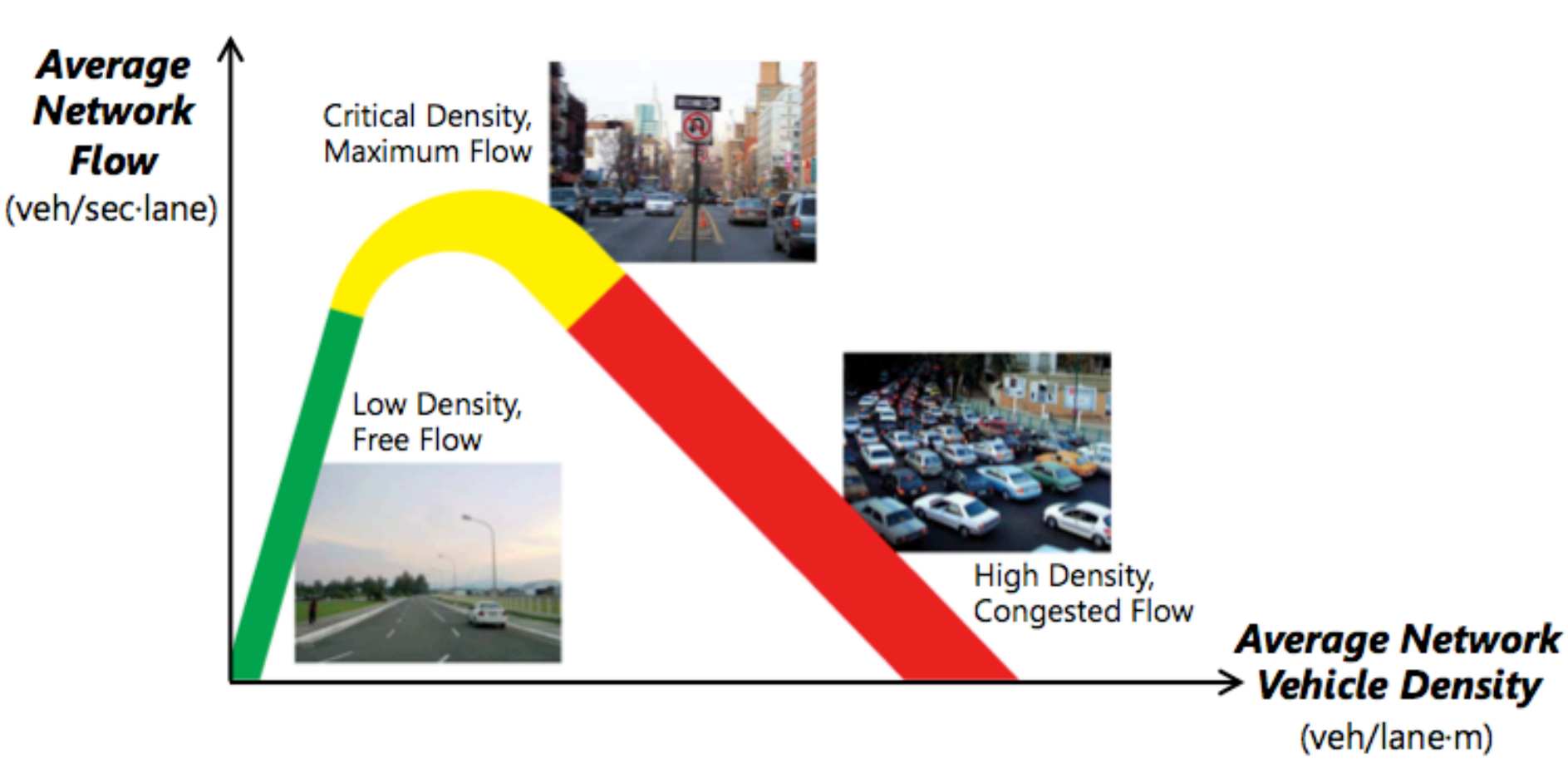


MFD definition



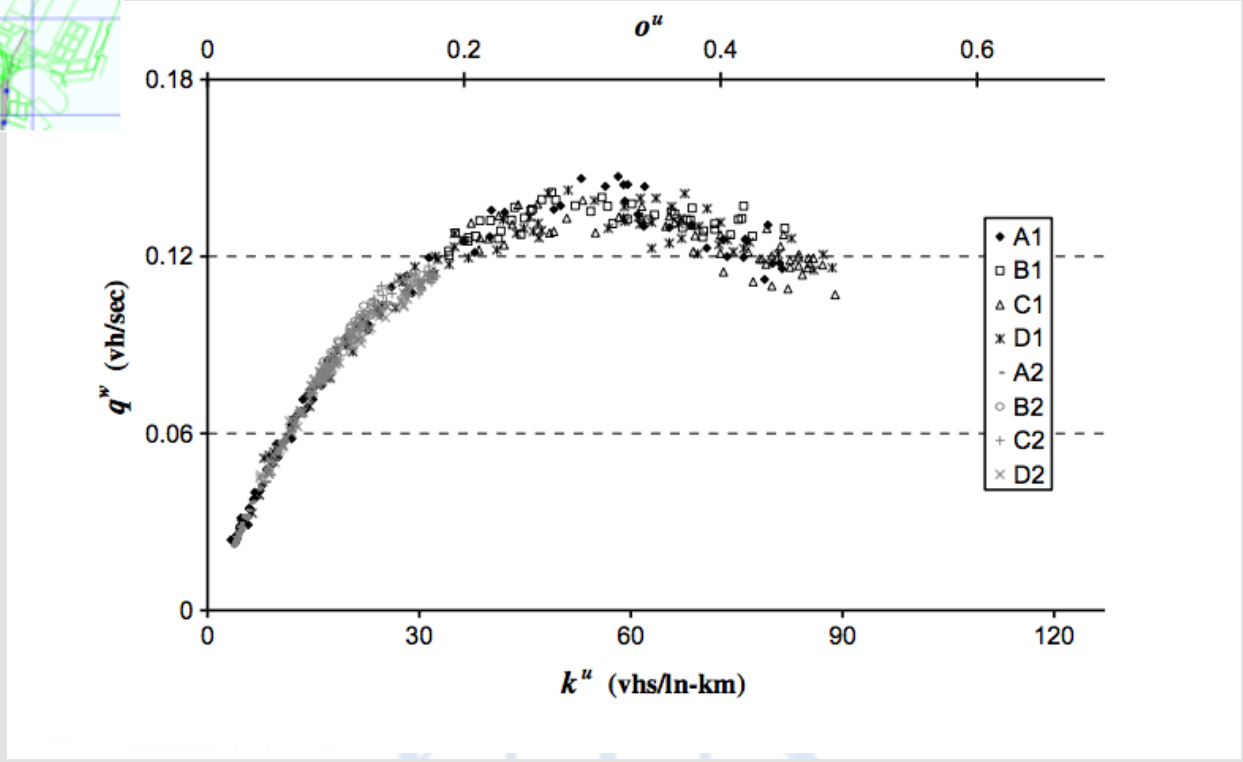
FD + Network structure (topology / signal timings) + Route choices = MFD

MFD definition (2)



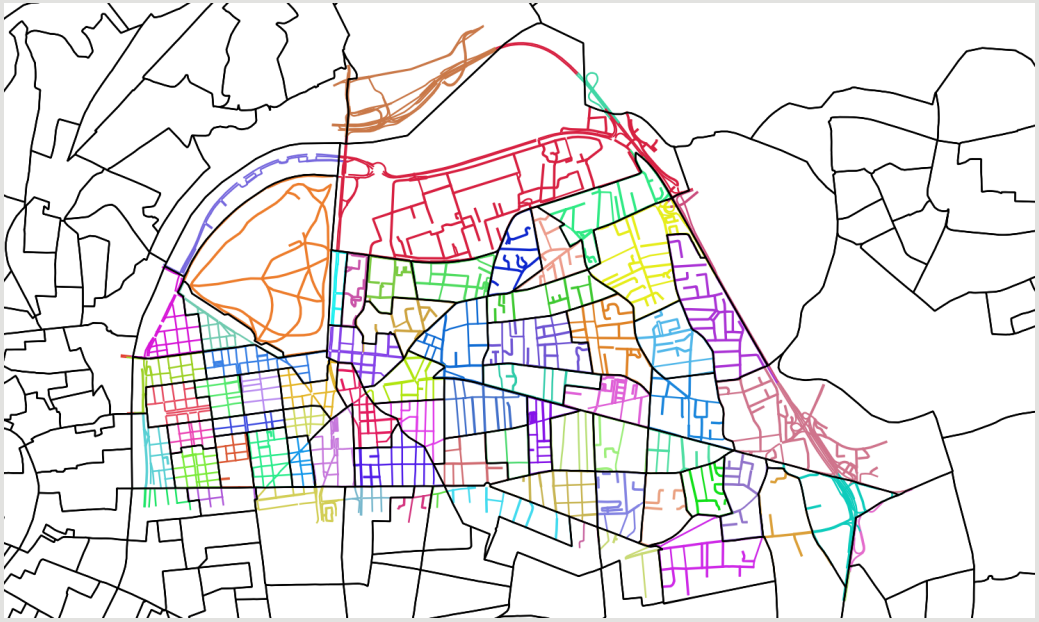
@Eric Gonzales (University of Massachusetts)

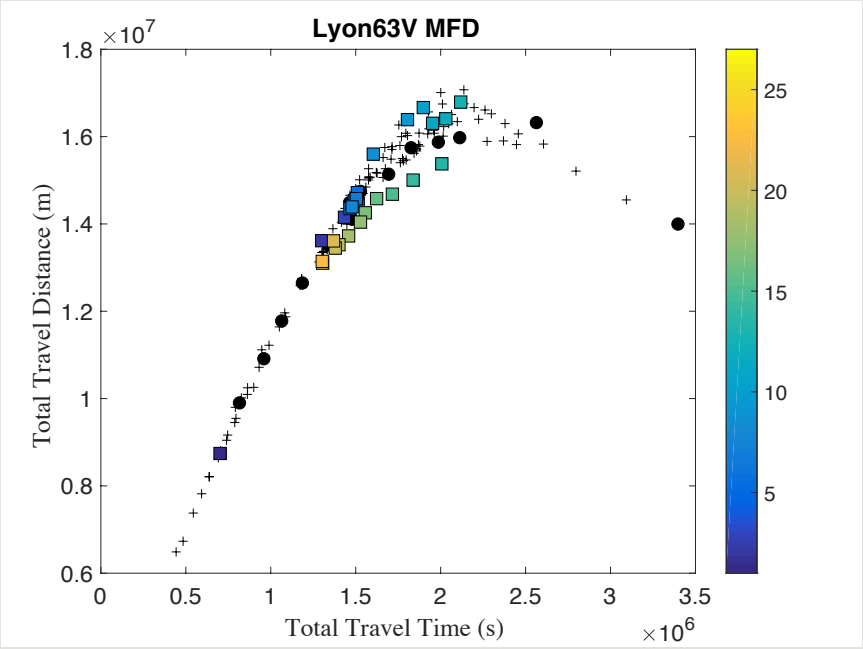
First experimental MFD - Yokohama



Courtesy @Prof. N. Geroliminis

Simulated MFD – North of Lyon





Estimating the NMFD for a given area

Travel production and accumulation

Travel Production *P*

$$P = \frac{DTT}{\Delta t} = \frac{1}{\Delta t}\sum_{i=1}^{n} d_i$$

Accumulation *N*

$$N = \frac{TTT}{\Delta t} = \frac{1}{\Delta t}\sum_{i=1}^{n} t_i$$

Aggregation over:

- Links
- Routes
- Probes…

Only these two variables are additive and are then scalable

Mean flow vs. outflow

Mean flow Q

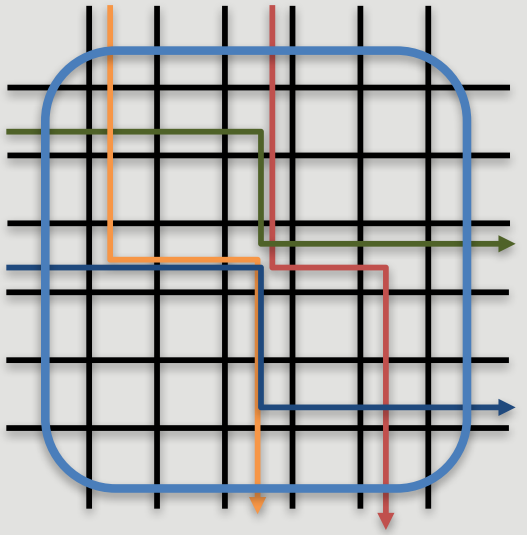
$$Q = \frac{P}{L_{tot}}$$

Similar in a link

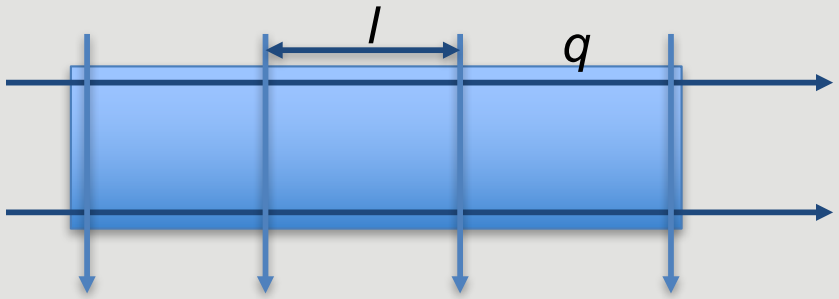
But not in a network

Outflow Q_{out}

$$Q_{out} = \frac{P}{L_{trip}}$$



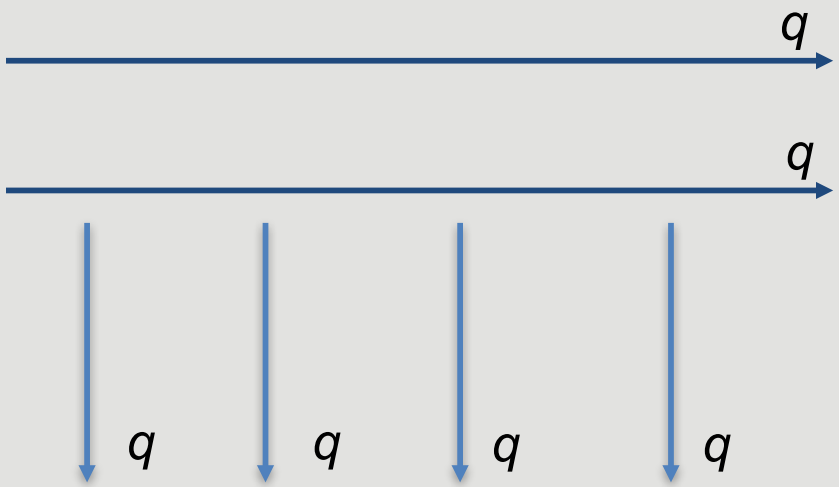
A simple example



$P=10ql$; $Q=q$ but $Q_{out}=?$

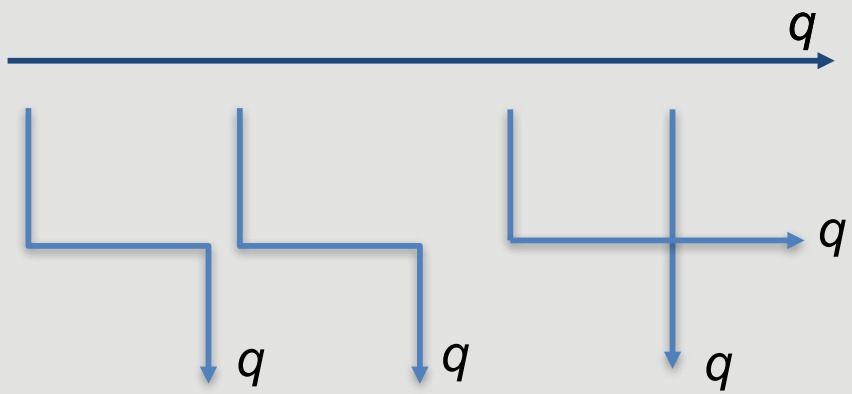
Q_{out} depends on the internal route flow pattern that defines L_{trip}

Case 1



$Q_{out}=6q$; $L_{trip}=(5/3)l$

Case 2



$Q_{out}=5q$; $L_{trip}=2l$

Estimation from loop detectors

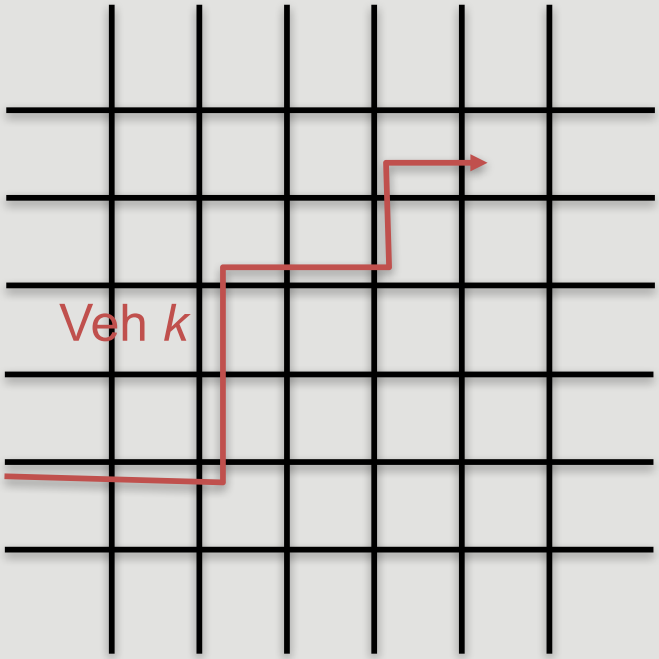
For the equipped network:

$$P = \sum q_i l_i \quad ; \quad N = \sum k_i l_i$$

Scaling factor for the full network ?

$$\frac{L_{tot,full}}{L_{tot,equiped}} ?$$

Estimation from Probe vehicles



Probe vehicles provide a direct estimate for the mean network speed *V*:

$$V = \sum_{k \in K} d''_k \Big/ \sum_{k \in K} \tau''_k$$

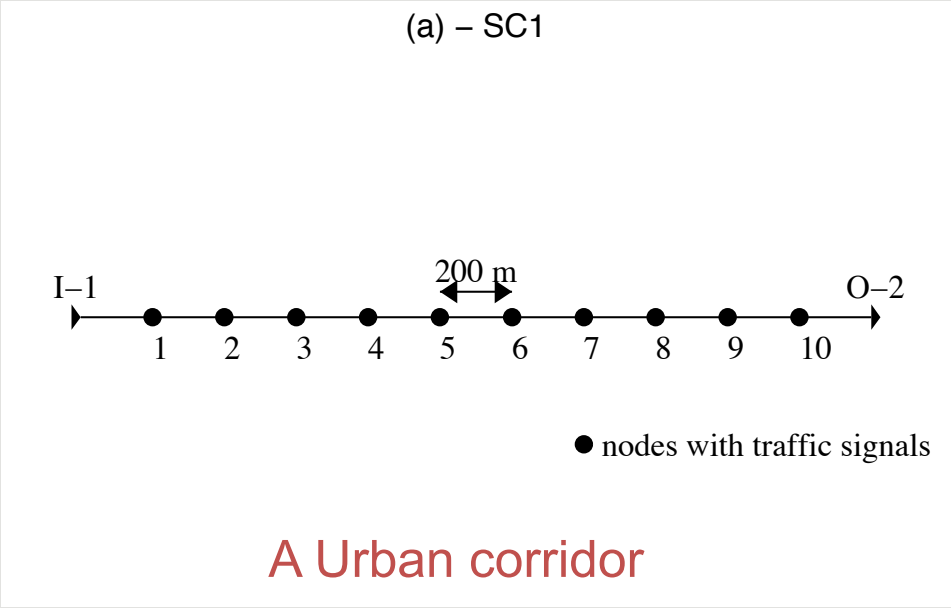
Distance traveled

Travel time related to the Δt period

$$P = V^* N$$

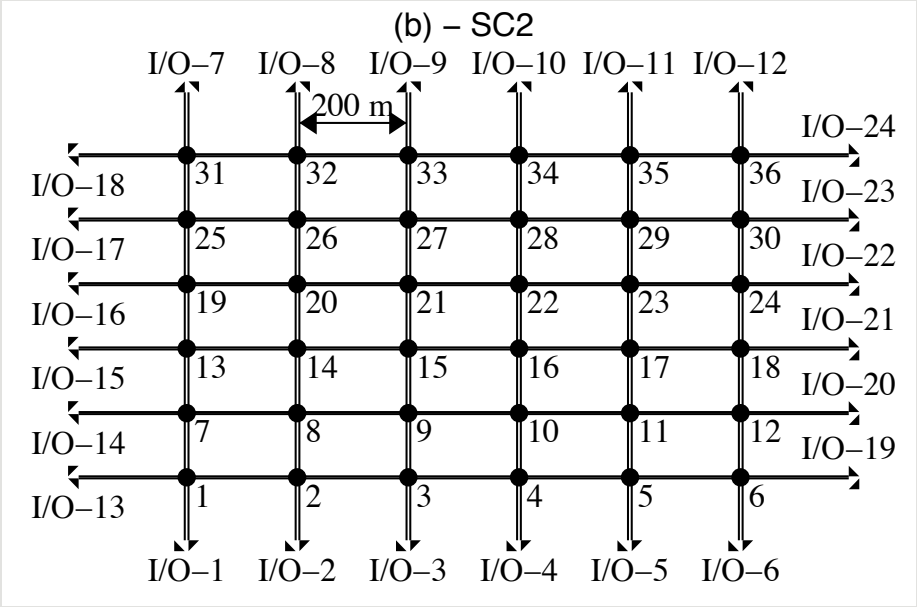
A direct estimation of *P* and *N* from probe data require to estimate the scaling factor (penetration rate)

Studied Networks



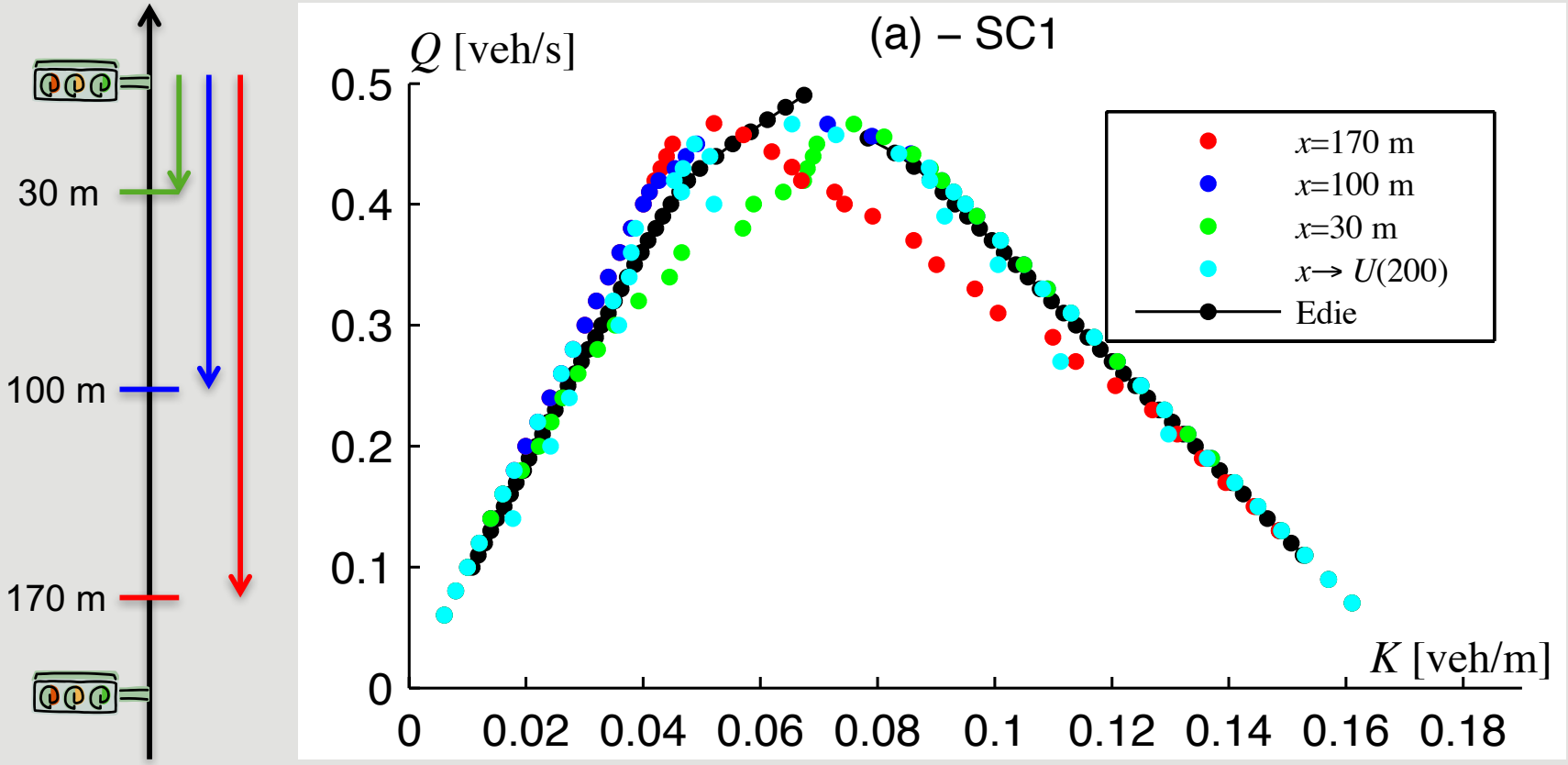
A Urban corridor

A Mahnattan network



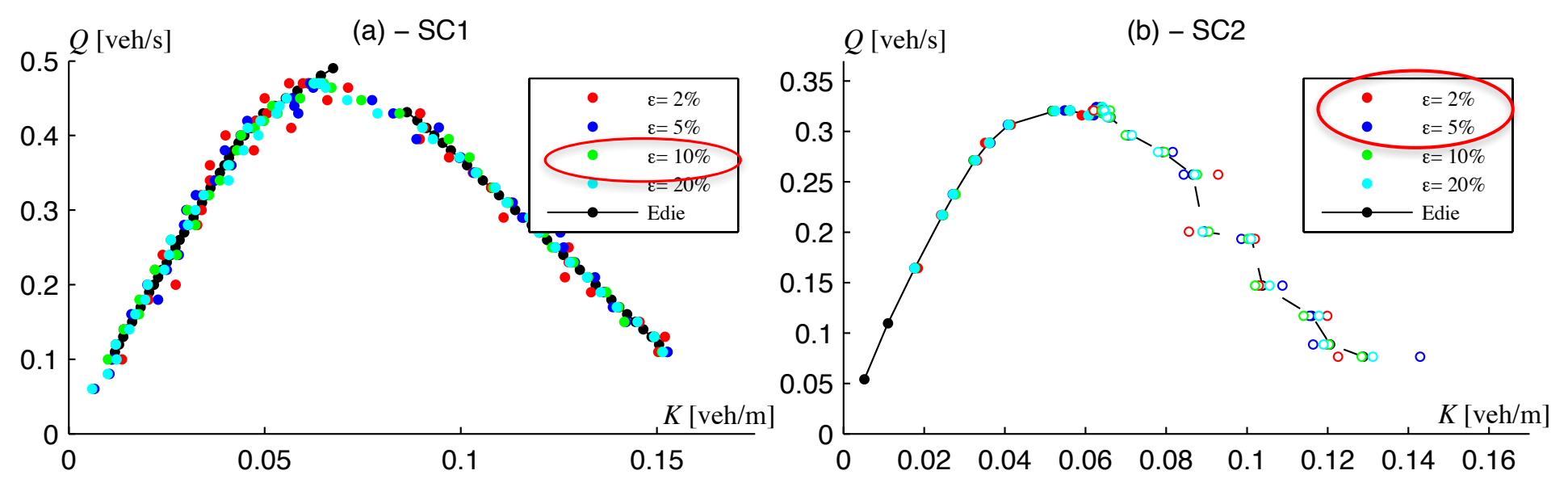
Numerical simulations are provided by a LWR mesoscopic simulator (Leclercq and Becarie, 2012)

Loops VS. Edie methods



Loops are not able to capture the spatial dynamics within links

Probes VS Edie methods

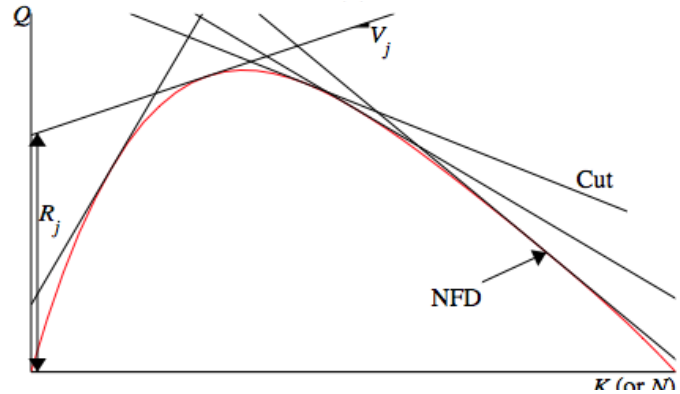


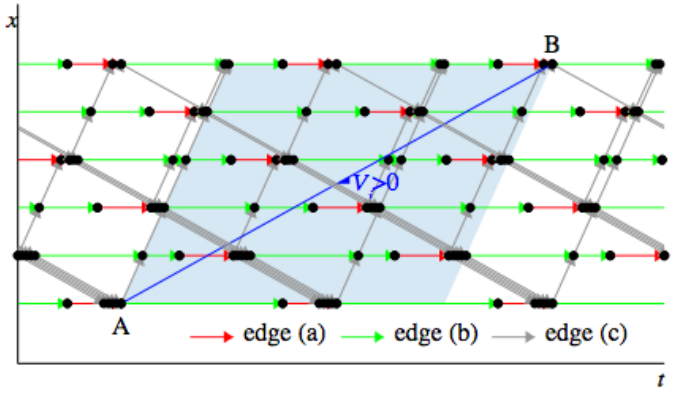
Low penetration rates provide accurate estimation for the mean speed

Loops are still needed to capture the mean flow

Cross-comparison of estimation methods

The cut method with variational graphs

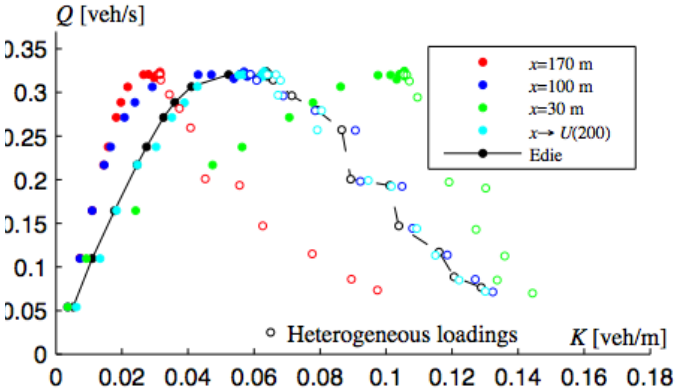




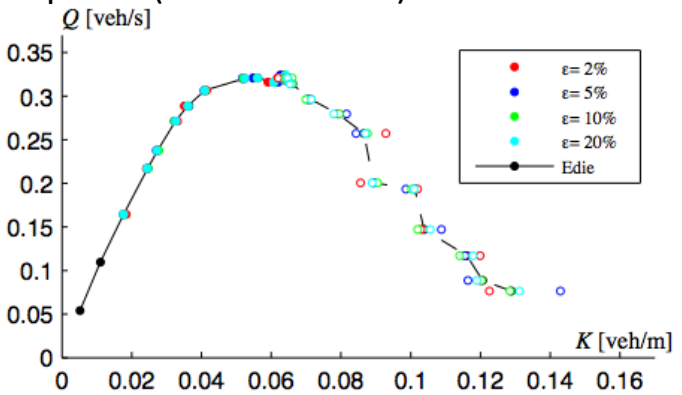
(Leclercq et *al*, partB, 2013)

Analytical methods (cuts, variational graphs…) stick to the homogeneity conditions (flows)

Loop only (6*6 grid network)



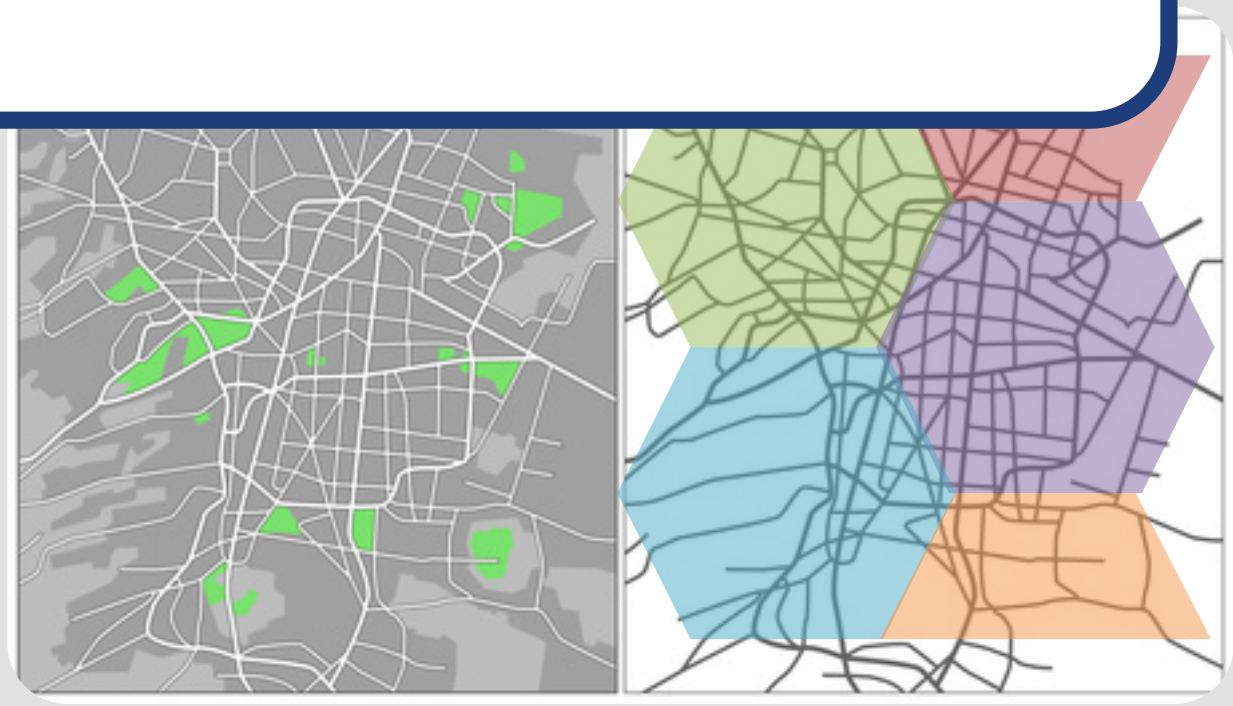
Loop & probe (same network)



(Leclercq et *al*, partB, 2014)

Data-based methods are only fully accurate if loops & probe data are available

Current limitations of the simple bathtub formulation

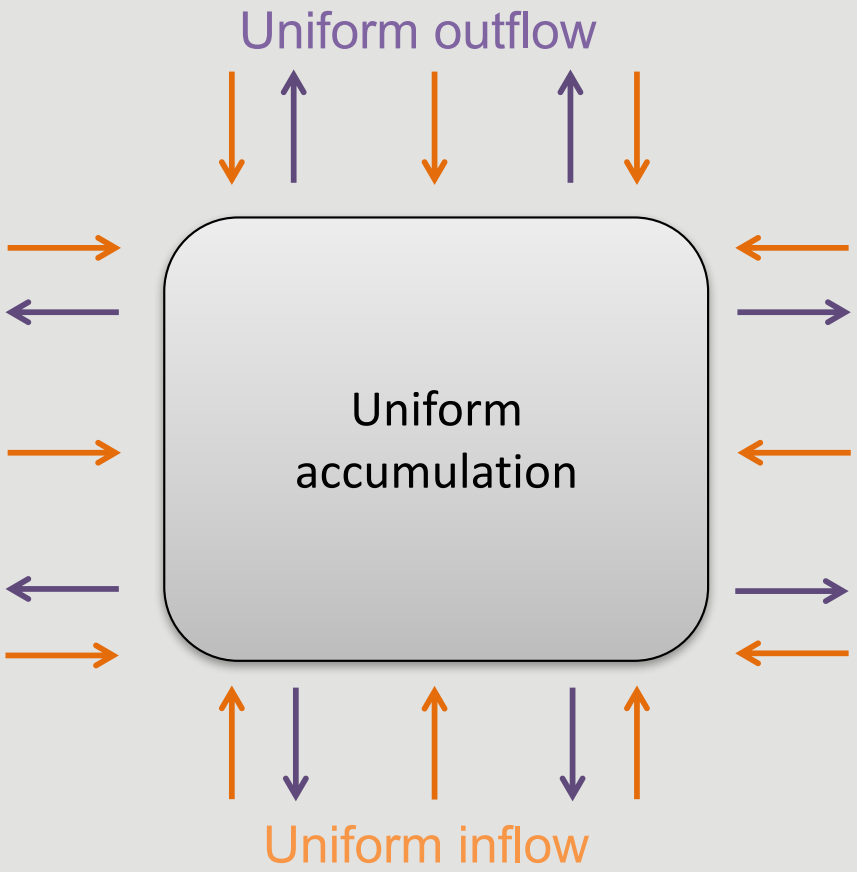


Traffic simulation

Classical dynamic approach

© Symuvia platform

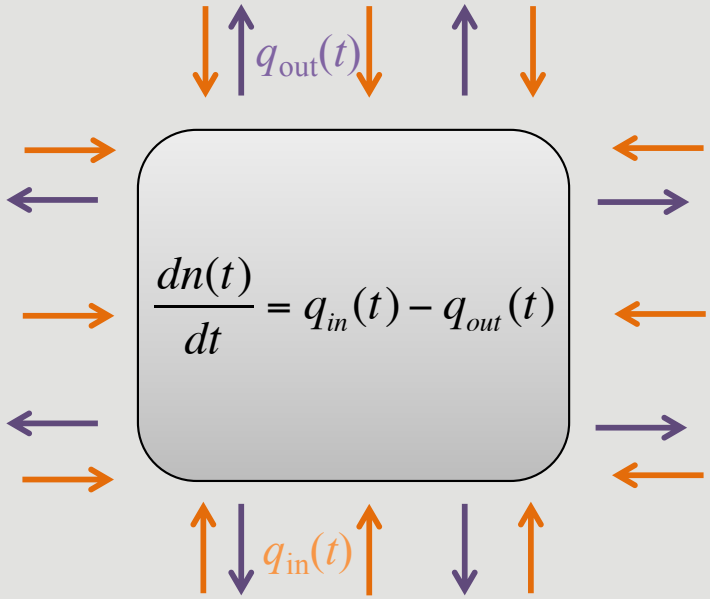
Reservoir (NMFD) approach



Only very recent works distinguish perimeter flows per OD

(Yildirimoglu and Geroliminis, 2014; Ramezani, Haddad and Geroliminis, 2015; Knoop and Hoogendoorn, 2014, 2015)

Analytical investigations of the single reservoir dynamics

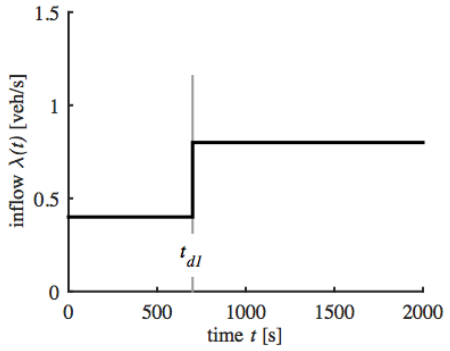


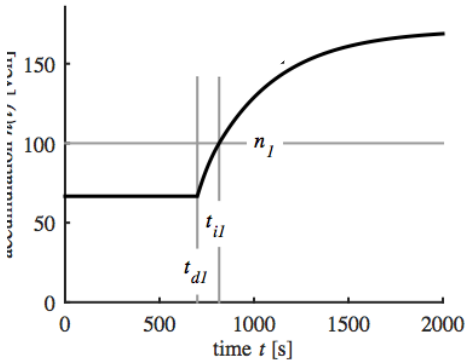
NMFD-based traffic simulation

$$q_{out}(t) = \frac{Q(n(t))}{L_{trip}}$$

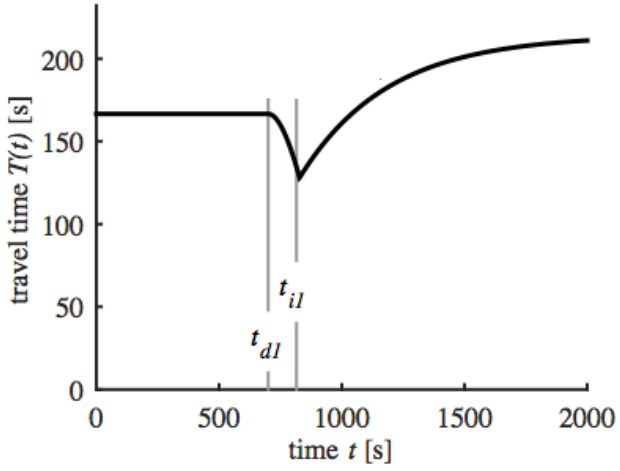
Wave propagation in a single reservoir

Wave propagation



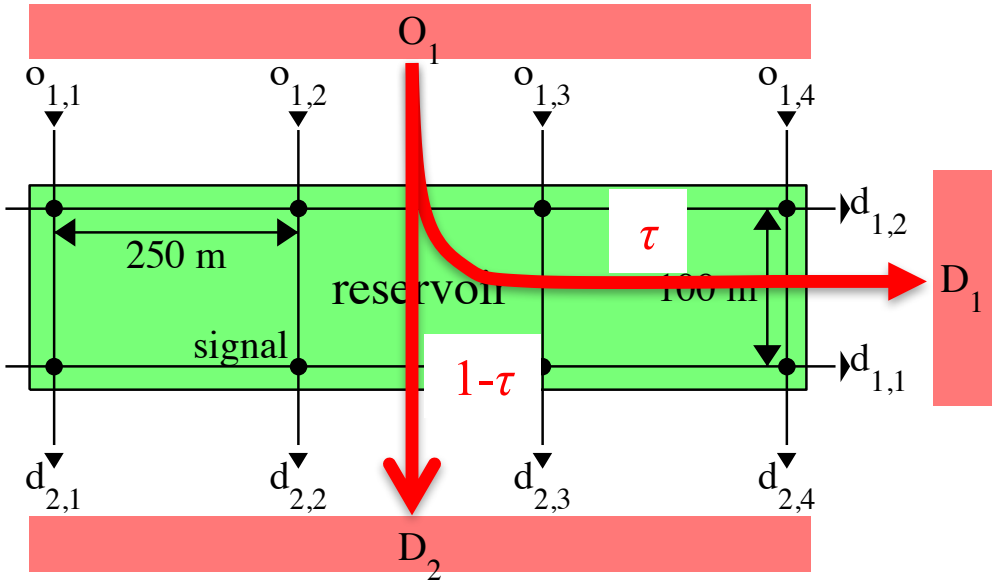


Demand surge



(Mariotte et *al* - Leclercq, TRptB, 2017)

Numerical investigations of a single reservoir dynamics

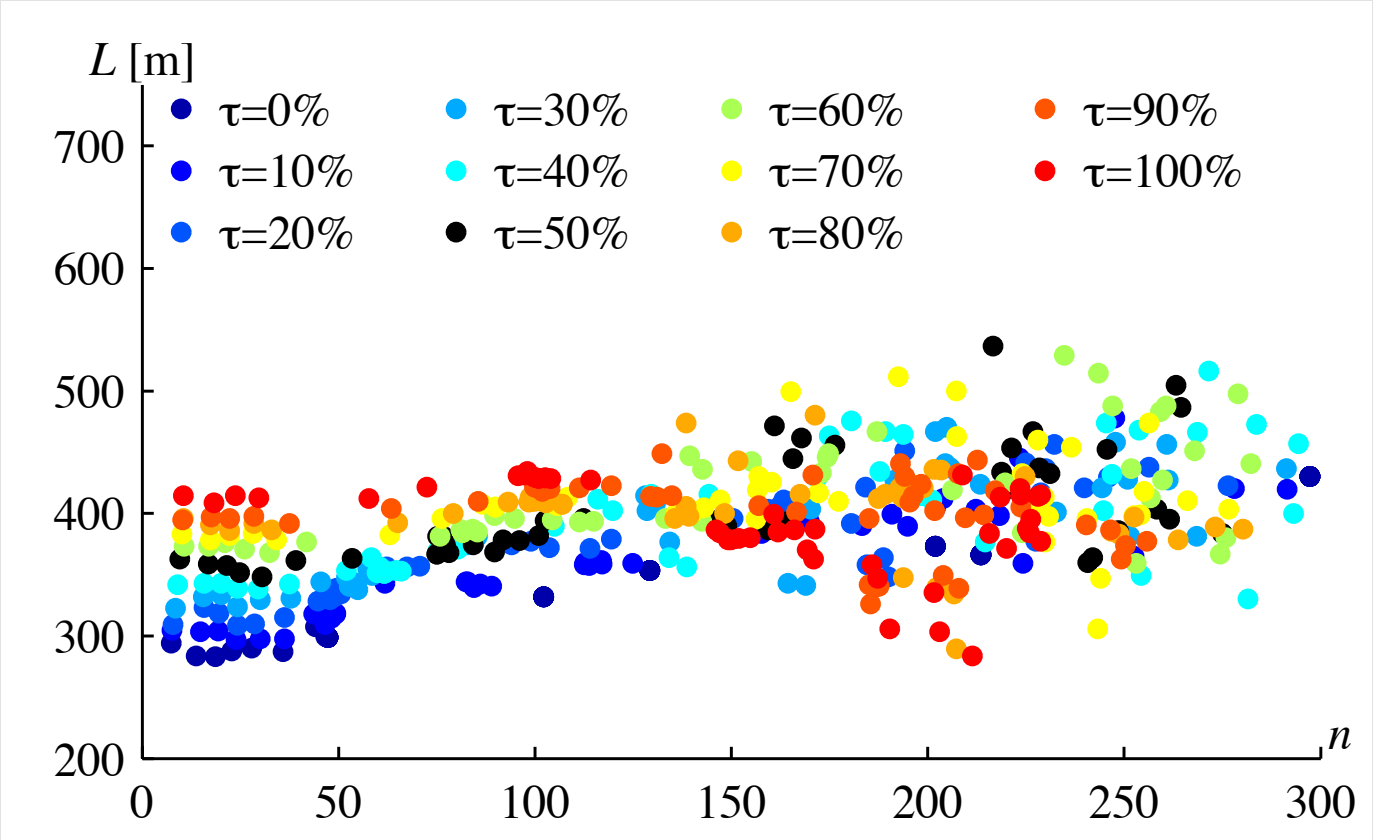


Design to magnify the effect of heterogeneous loadings

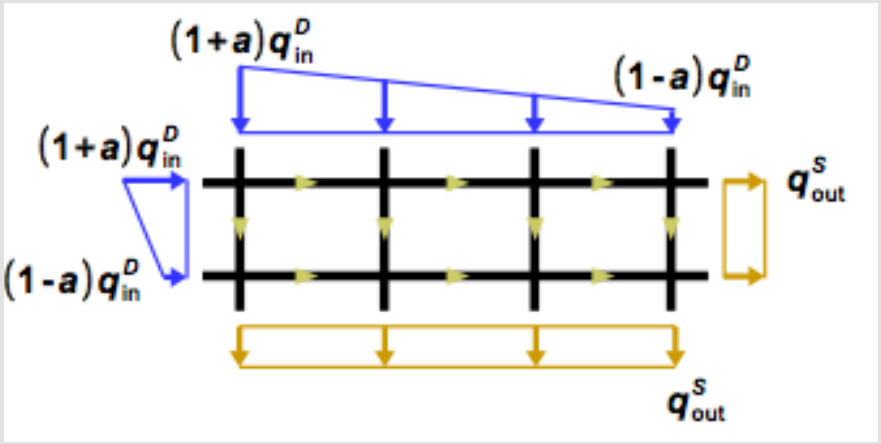
- LWR mesoscopic simulation with a triangular FD
- Traffic signals with equal green time and a common cycle
- Wardrop User Equilibrium
- Various input demand and output capacity profiles to represent a maximum of different loadings
- Global variations of the OD matrix parameterized by τ
- We consider (quasi-) stationary situations at the network level and monitor (20 min period):
  - The number of vehicles n
  - The travel production P
  - The mean speed V
  - The outflow Q
  - The mean travel distance L

Sensitivity of L to τ and n

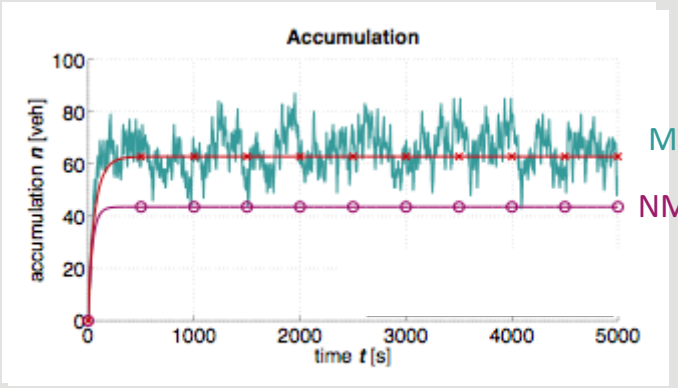
$$L = P/Q$$



Sensitivity to the boundary conditions (1)



Heterogeneous demand distributions

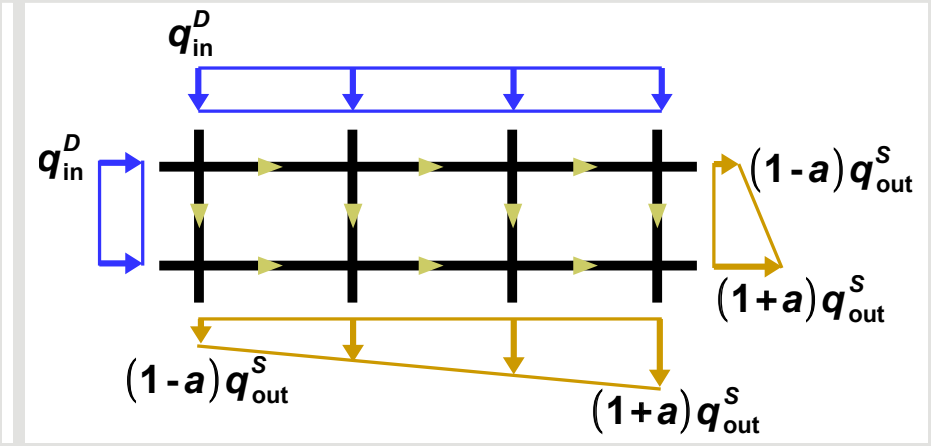


NMFD ☒ (a=0) ☒ (a=0.8)

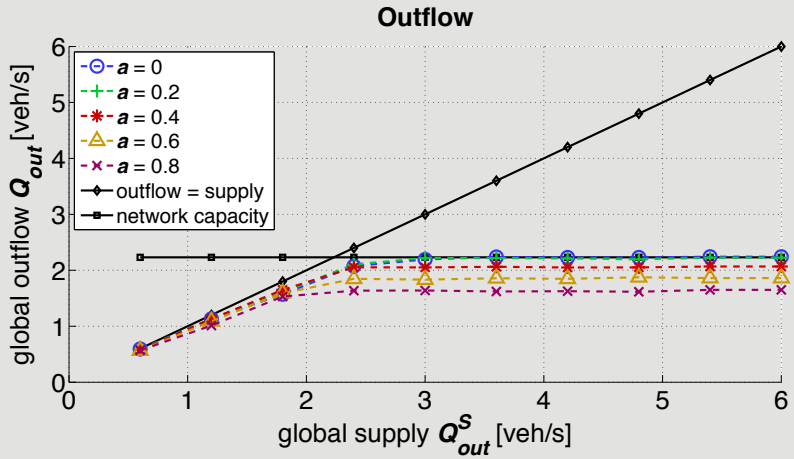
L_{trip} ☒ (a=0) ☒ (a=0.8)

(Mariotte & Leclercq, Heart, 2016)

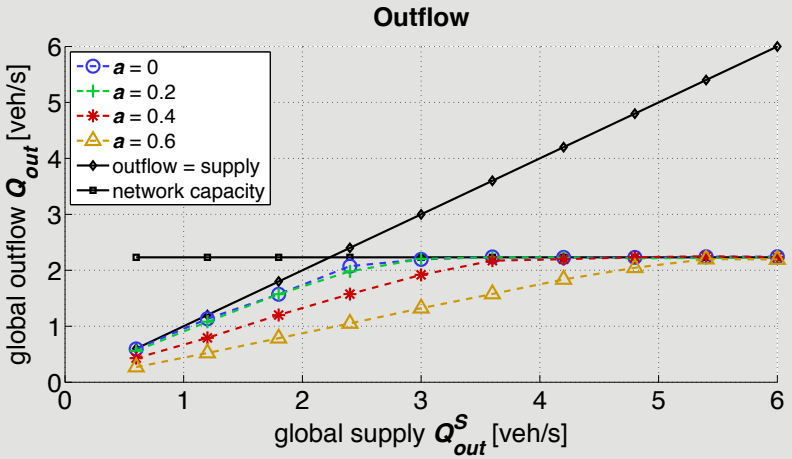
Sensitivity to the boundary conditions (2)



Heterogeneous supply distributions

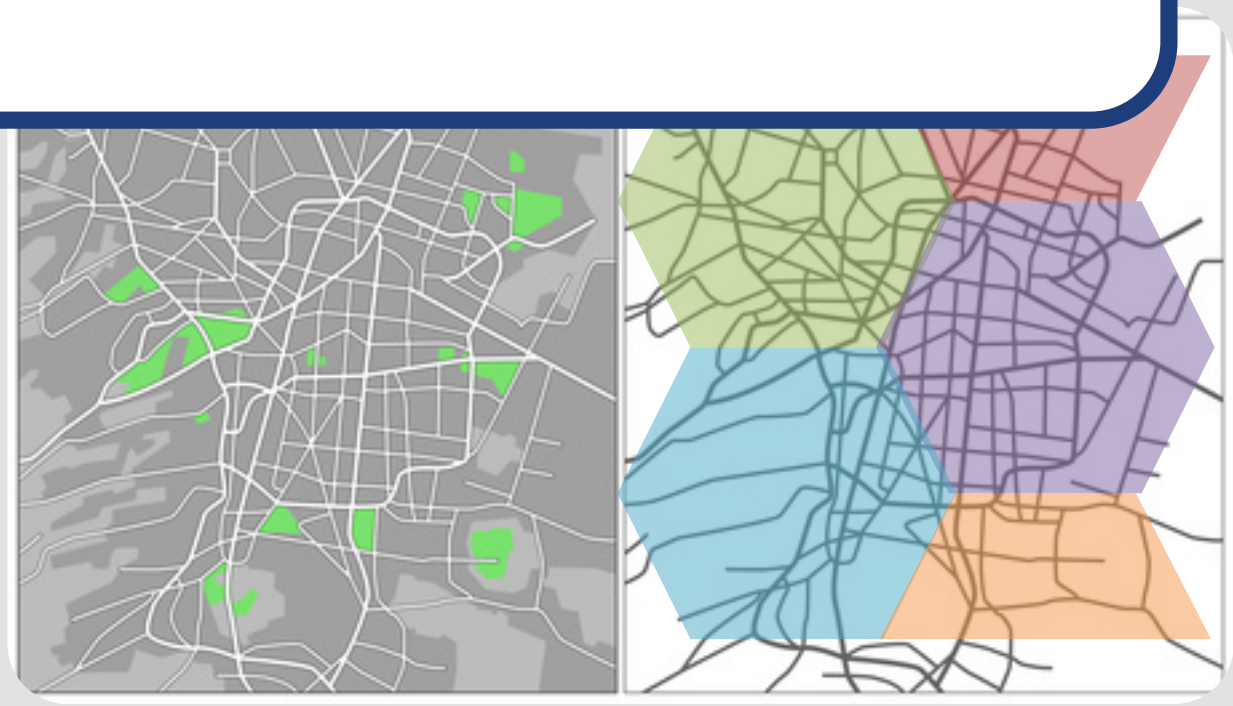


heterogeneous demand



heterogeneous supply

The trip-based NMFD formulation



Trip-based NMFD model (1)

Model formulation

Analytical resolution (piecewise cst inflows)

$$\int_{t-T(N_{out}(t))}^{t} V(n(s))ds = L$$

(Arnott, 2013)
(Lamotte & Geroliminis, 2016)

$T(N_{out}(t))$: experimented travel time for vehicle N_{out} that exits at time t

$$\Leftrightarrow \quad Q_{out}(t) = \frac{Q_{in}\left(t - T\left(N_{out}(t)\right)\right)V\left(n(t)\right)}{V\left(n\left(t - T\left(N_{out}(t)\right)\right)\right)}$$

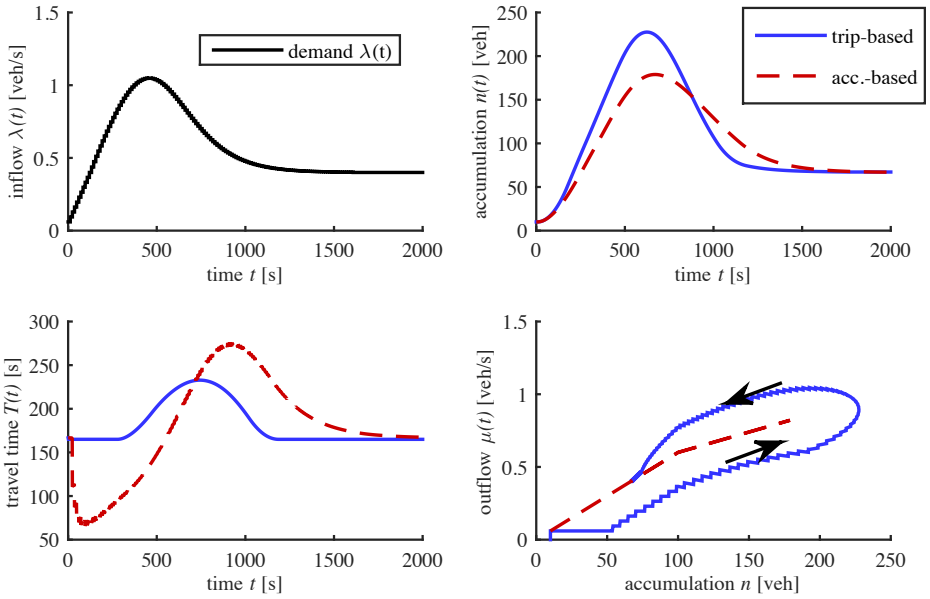
(Delay differential equation with endogenous delay)

$$Q_{out}(t) = Q_{in}(t) + n'(t)$$

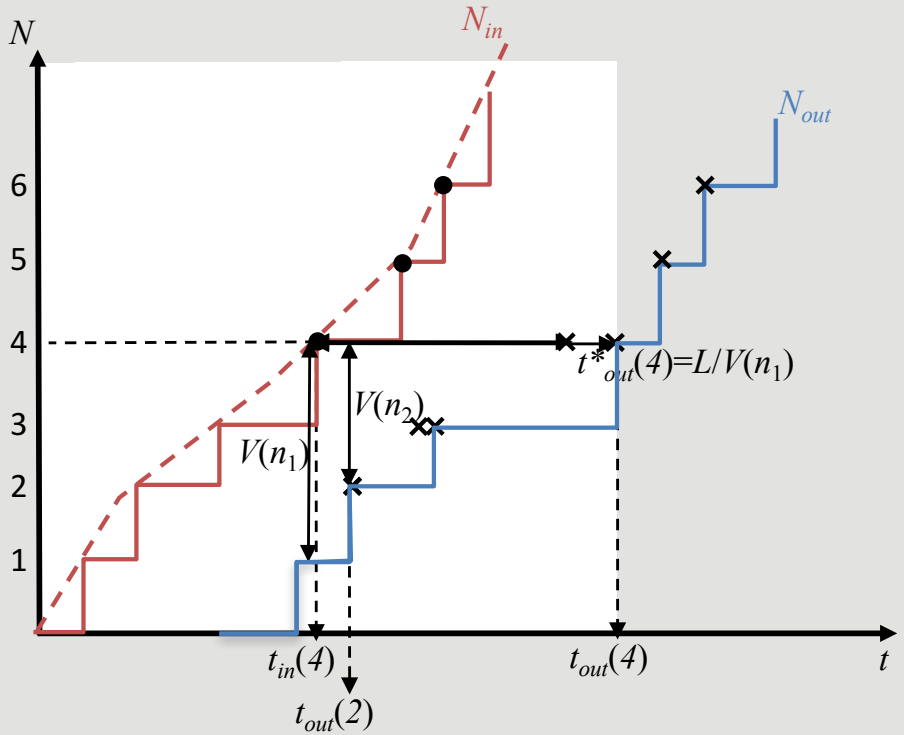
(Accumulation-based MNFD model)

(Mariotte et *al* - Leclercq, TRB, 2017)

Model solutions



Trip-based MNFD model (2)



An event-based numerical scheme

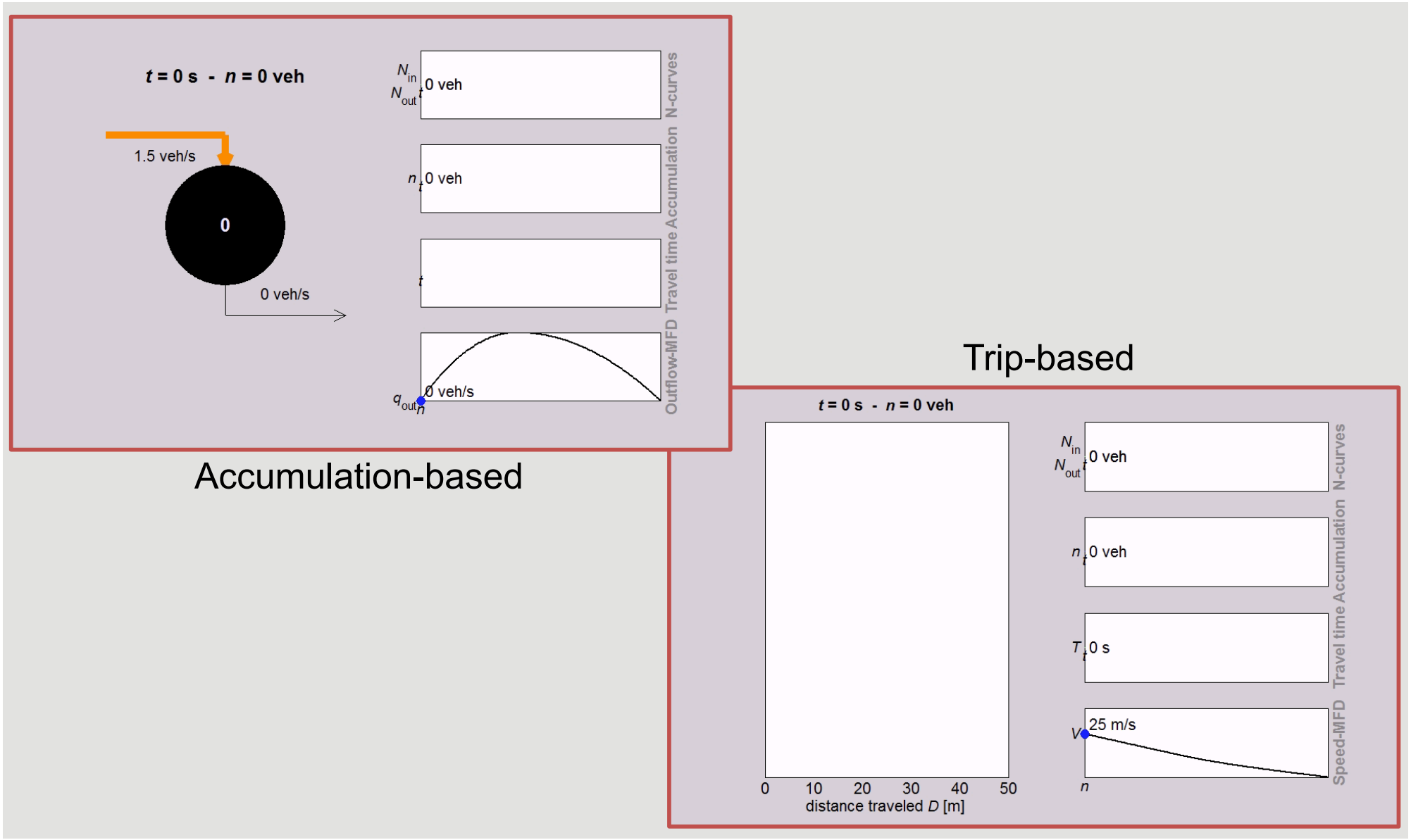
Advantages

- Direct access to entry and exit times for all individual vehicles
- Efficient numerical scheme as only the next vehicle to exit should be updated in practice at each event
- Straightforward extension to account for heterogeneous travel distances

Heterogeneous boundary conditions is still an open problem

(Leclercq et *al*, TRB, 2017)

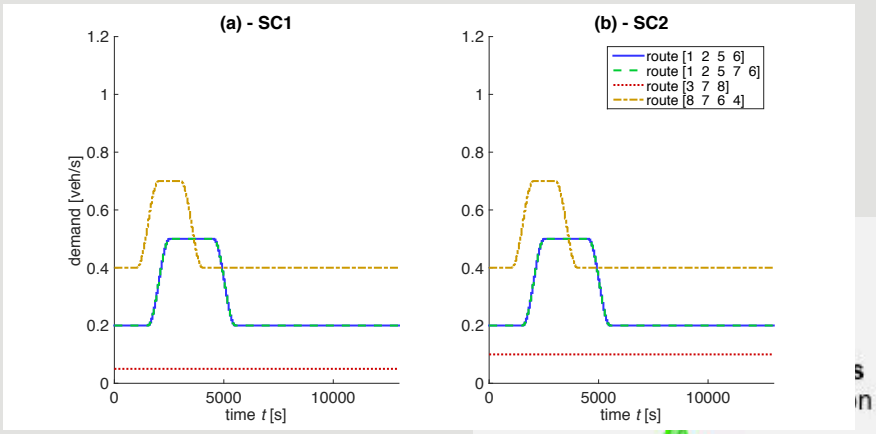
Trip-based MNFD model (3)

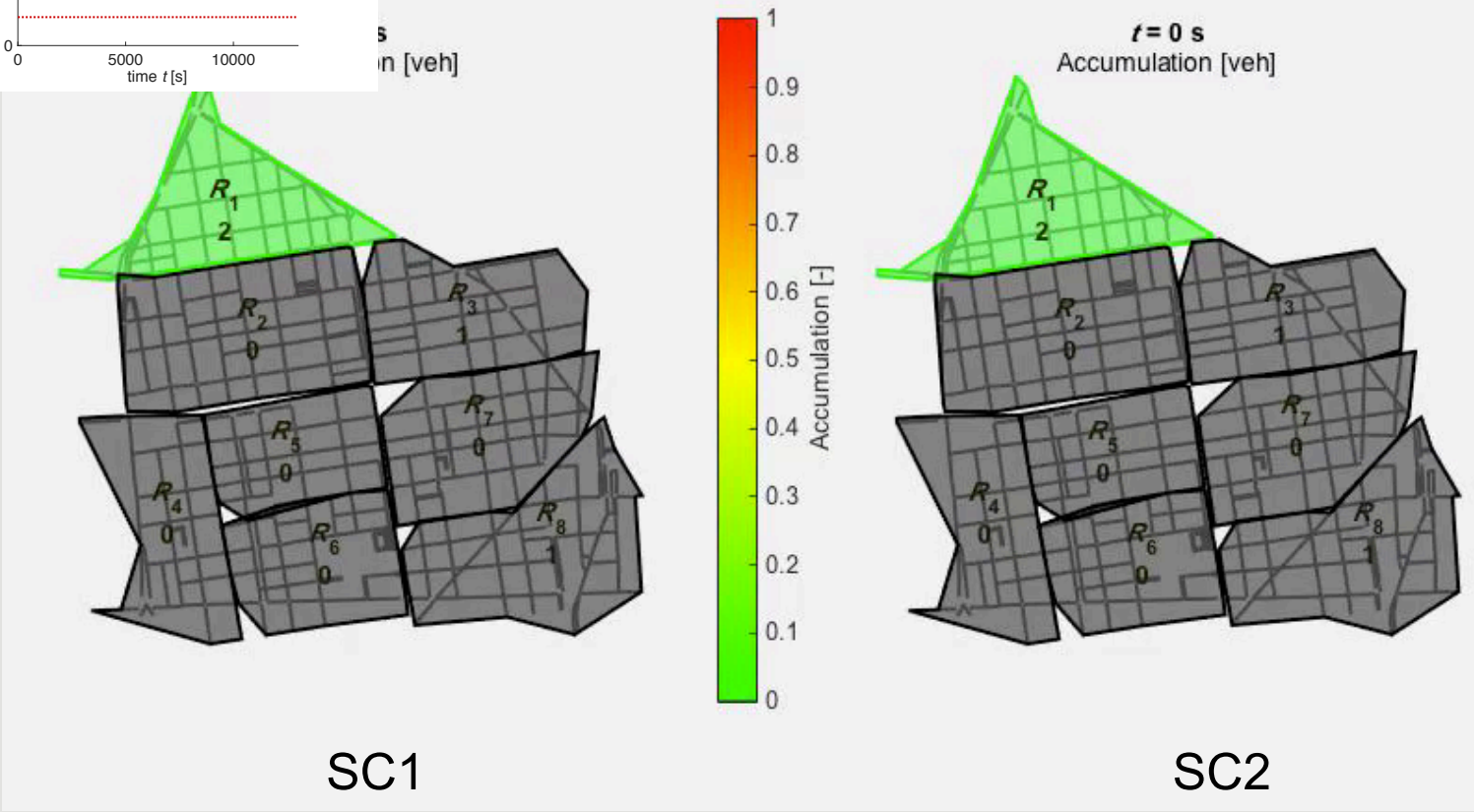


Towards a multi-reservoir trip-based simulator

- Proper treatment of merges and diverges between multiple reservoirs
- Proper treatment of congestion spillbacks between reservoir – definition of a reservoir supply
- Proper treatment of internal trip lengths depending on routes
- Coupling with a routing engine (DTA)
- ….

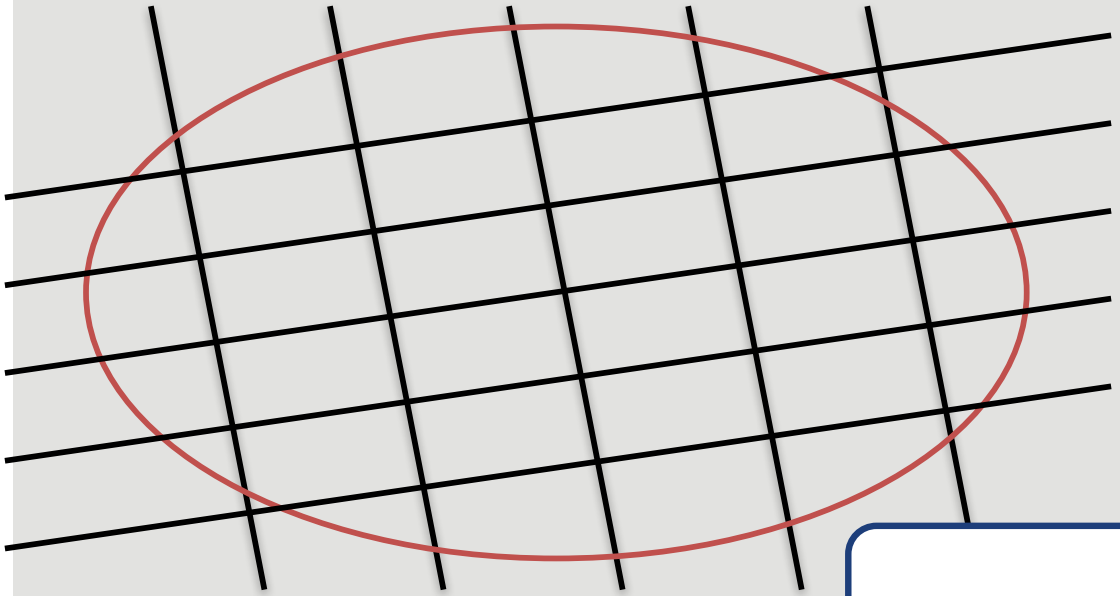
Effect of the demand pattern

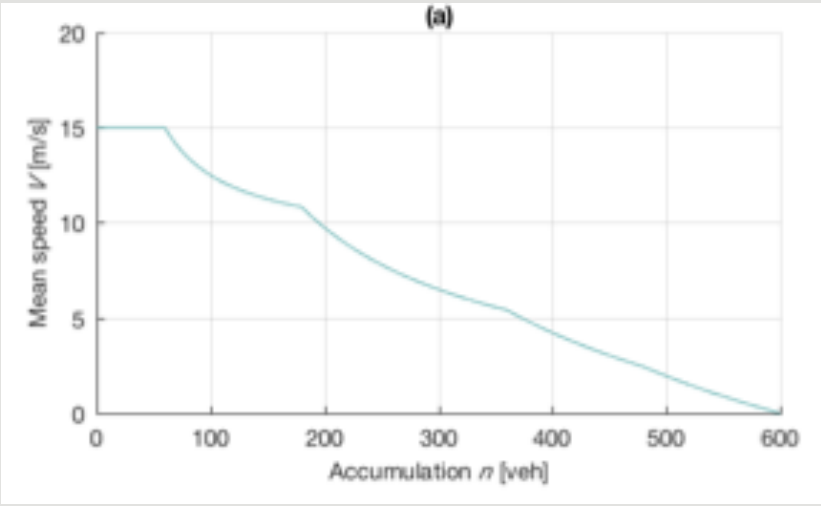




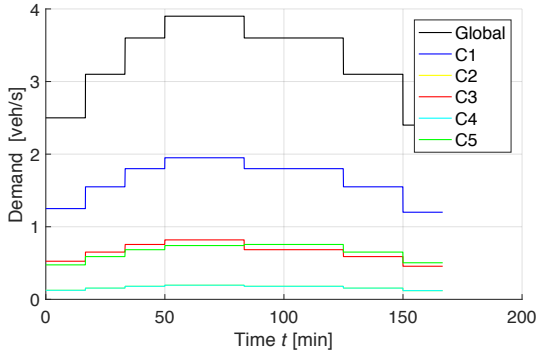
Application to surface parking

Modeling framework





Scenario



Starting outside

- C1: passing-by
- C2: off-street parking
- C3: on-street parking

Starting inside

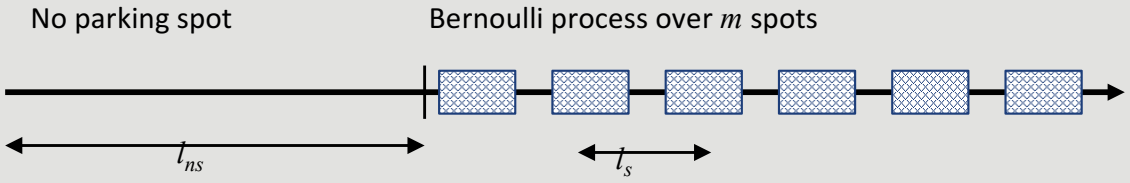
- C4: off-street parking
- C5: on-street parking

Network length	3000 m
# links	24
l_{ns}	50 m
l_s	5 m
# parking spots	360
# free spots (t=0)	150
$L_{trip,1}$	500 m
$L_{trip,2\rightarrow5}$	250 m

(Leclercq et *al*, TRptB, 2017)

Regular search process

A link



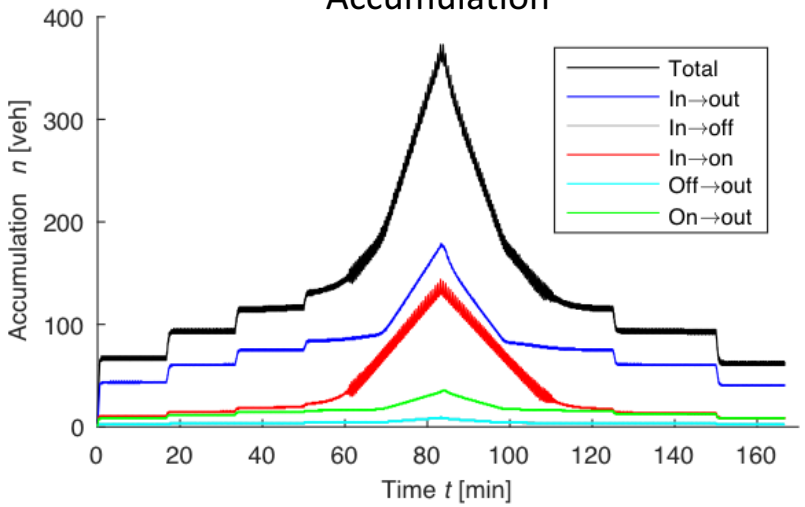
Mean searching distance:

$$D = \frac{l_{ns}}{1-\tau^m} + \frac{l_s}{1-\tau}$$

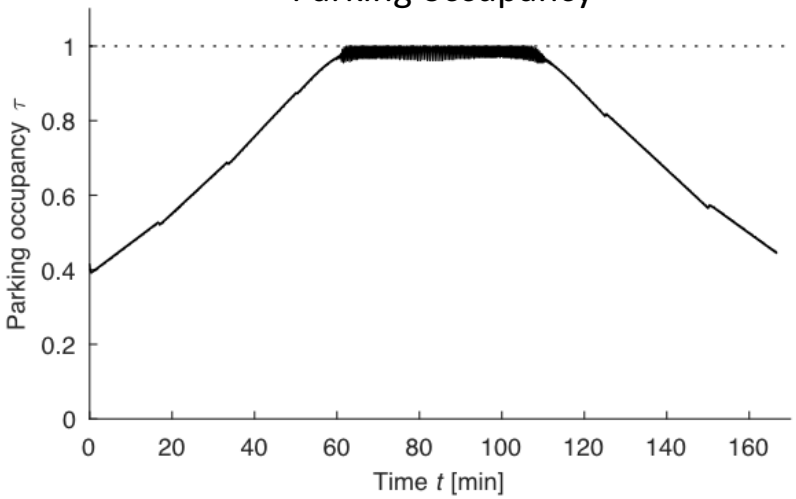
Extension from (Axhausen et *al*, 1994) (Geroliminis, 2009)

Simulation results

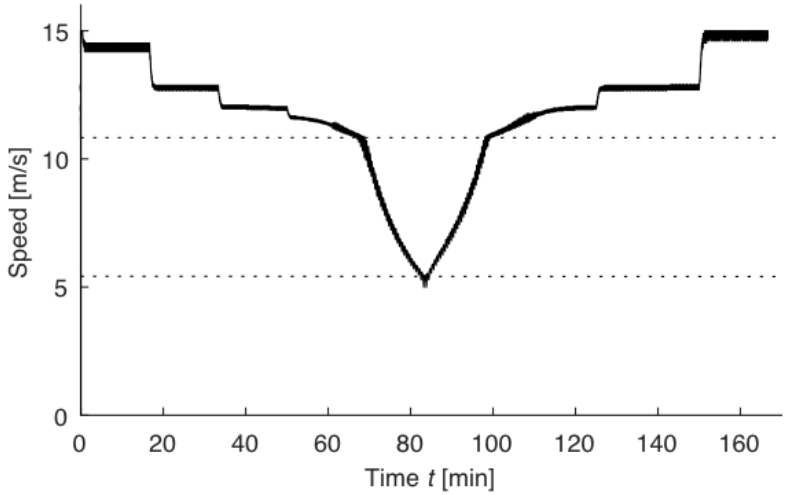
Accumulation



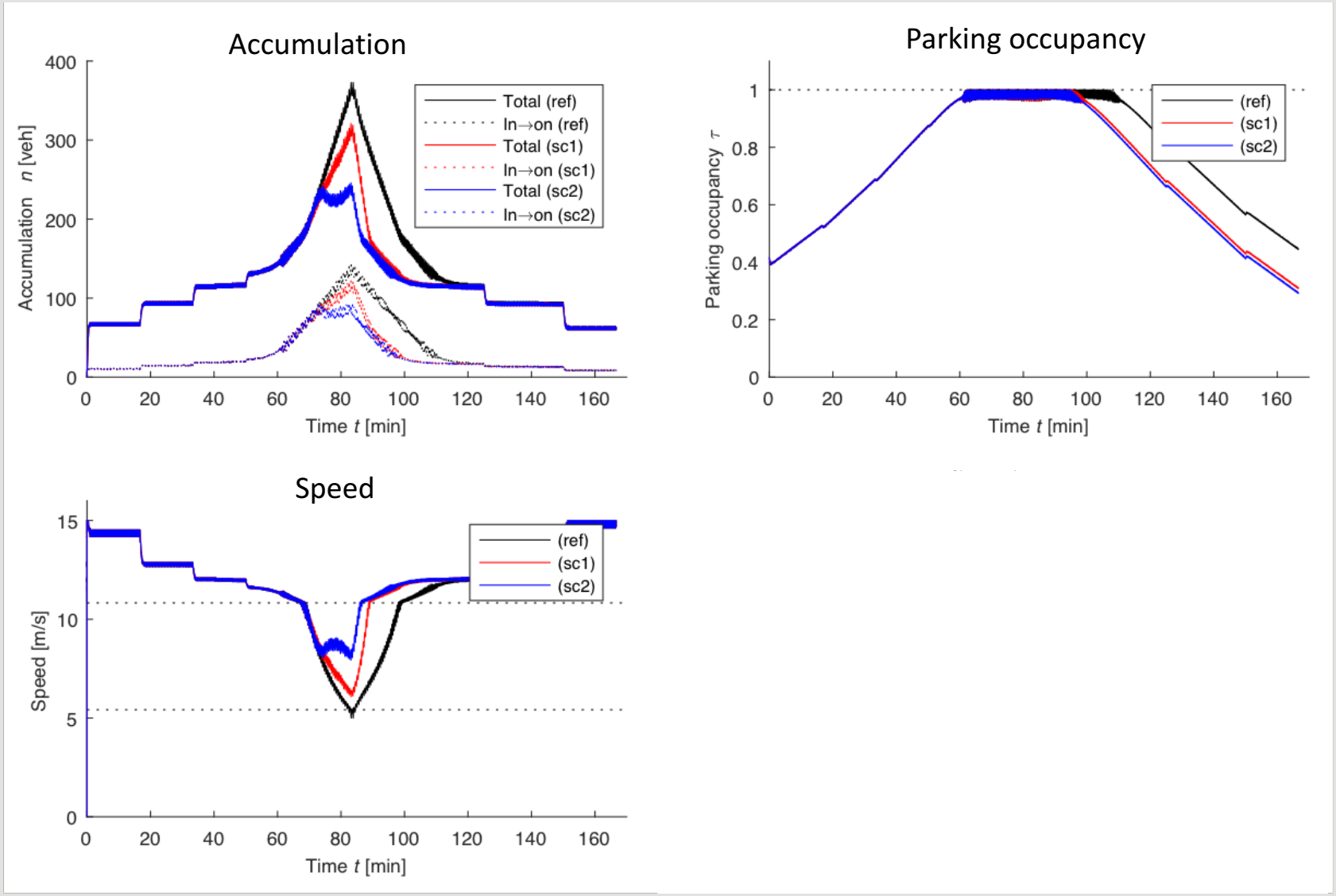
Parking occupancy



Speed

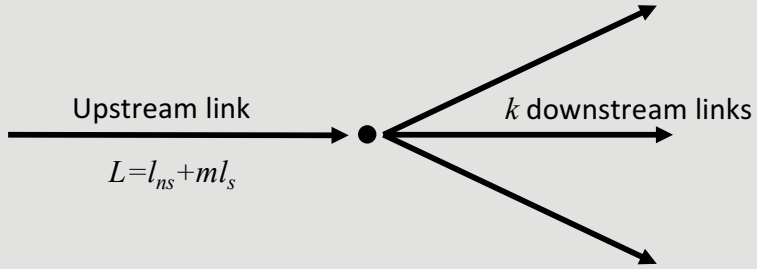


Reactive demand switch to off-street parking



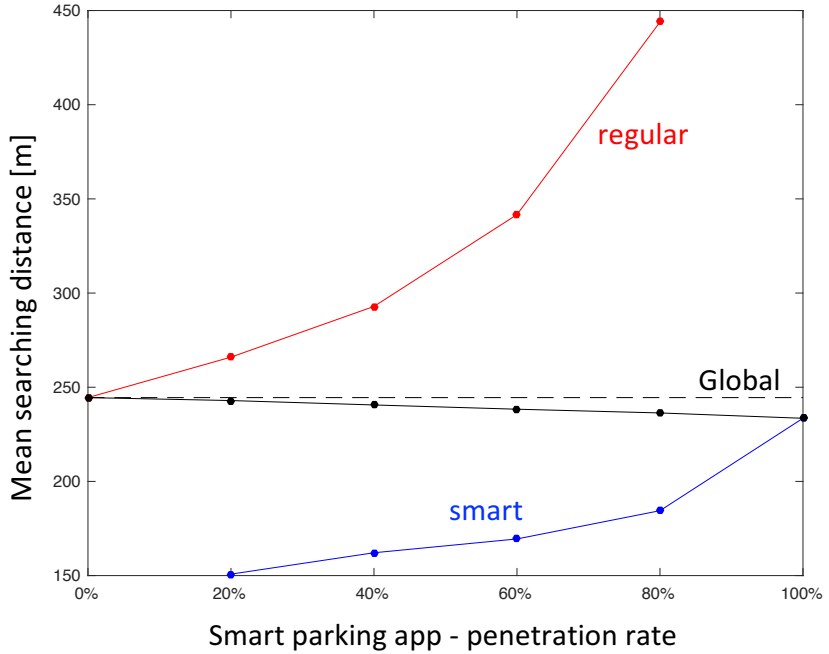
Smart parking application

Search process for equipped vehicles



Probability for a free spot to exist downstream: $1-\tau^{mk}$

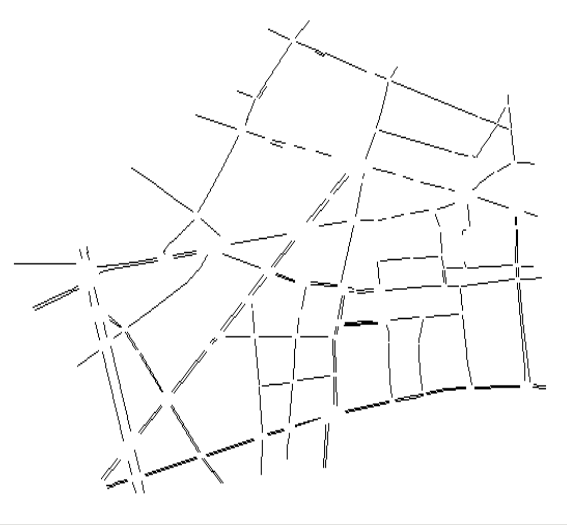
Influence of the penetration rate



3D congestion maps and applications to travel time prediction

Network partitioning

- Network clustering has received lots of attention in the recent literature (Prof. Geroliminis – EPFL)
- Usual objectives:
  - Defining relevant area for MFD definition
  - Perimeter control

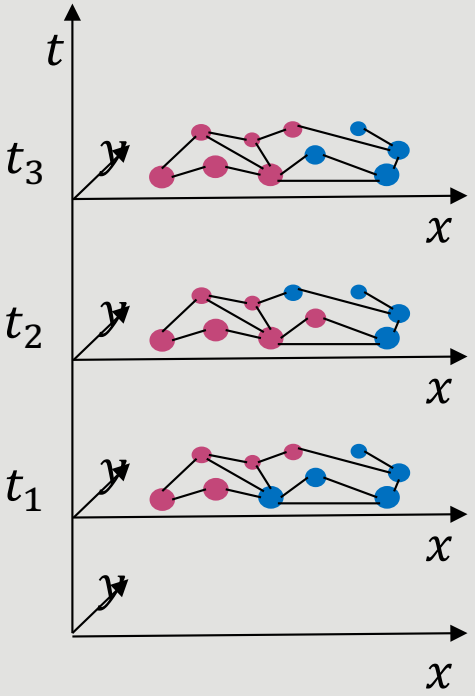


Original network

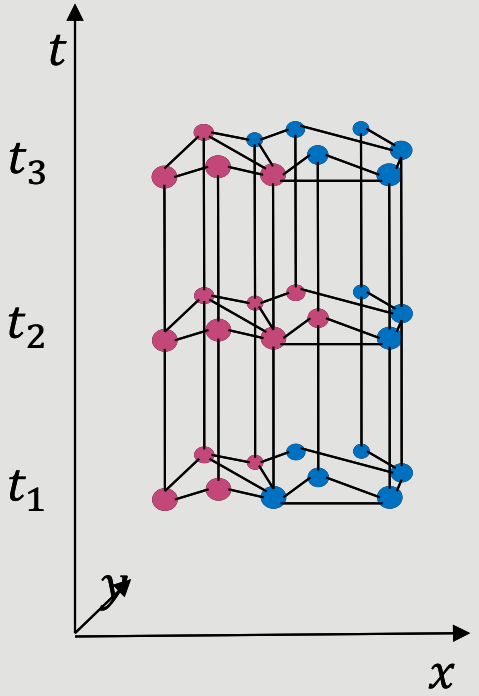
Clustered network

3D network partitioning (1)

2D approach



3D approach



Collaboration with Ditlab from TU-Delft

3D Network clustering (2)

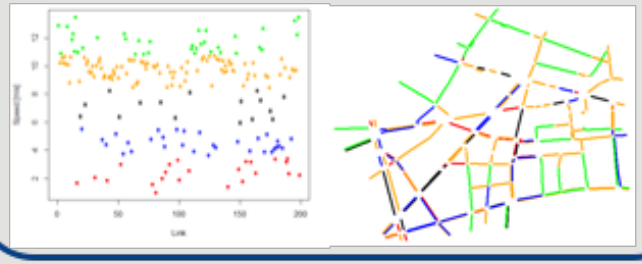
- Three criteria for the clustering operation:
  - Minimizing the link speed standard deviation within cluster (intra-cluster similarity)
  - Maximizing the difference in speed between clusters (inter-cluster dissimilarity)
  - Each cluster should contain a single connected graph

Partitioning methods

Data preparation

- Reasonable 3D Graph
- Speed variable for every 3D link

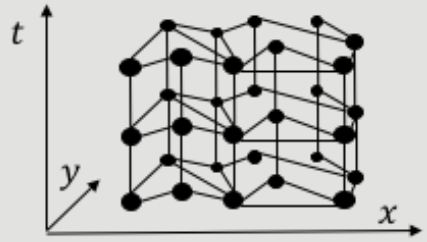
Partitioning based on **data point** clustering



DBSCAN (Ester et *al.*, 1996) + Post-Treatment

K-means + Post-Treatment

Partitioning based on **graph** clustering



NCut based on *snakes* similarities (Shi and Malik, 2000 ; Saeedmanesh and Geroliminis, 2015)

Data preparation: from GIS to graph

Input

- GIS environment
  - 147.059 links
- Individual Travel Times
  - More than 6 millions
  - From 312 OD cameras
  - 42 days measured
- Shortest path per OD

Amsterdam network

Data preparation: network coarsing

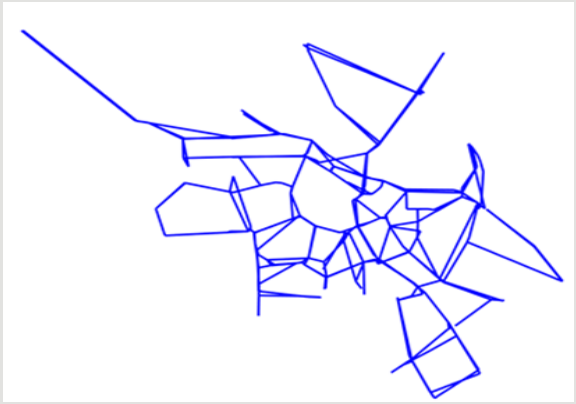
Context:

- The number of edges is t times larger with the 3D approach
- Partitioning methods used are NP-complete

Reduce the network keeping the traffic dynamic:

- Macro link: contraction rules based on speed
- Simplify the network structure (e.g., cross-section instead of roundabout)

~10.000 links

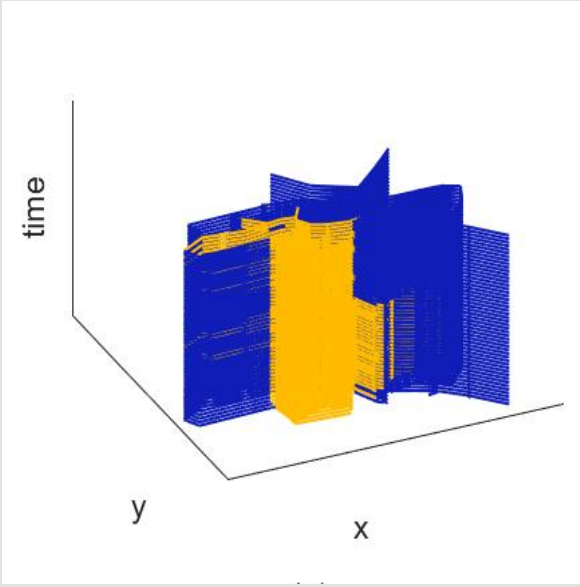


~200 links

Quality of the clustering operations

- Total Variance normalized (TVn)
  - Measure of internal or intra-cluster variance
  - An extension from TV (Saeedmanesh and Geroliminis, 2015)

$$TVn = \frac{1}{N} \frac{\sum_{A \in C} N_A * Var(A)}{S^2}$$



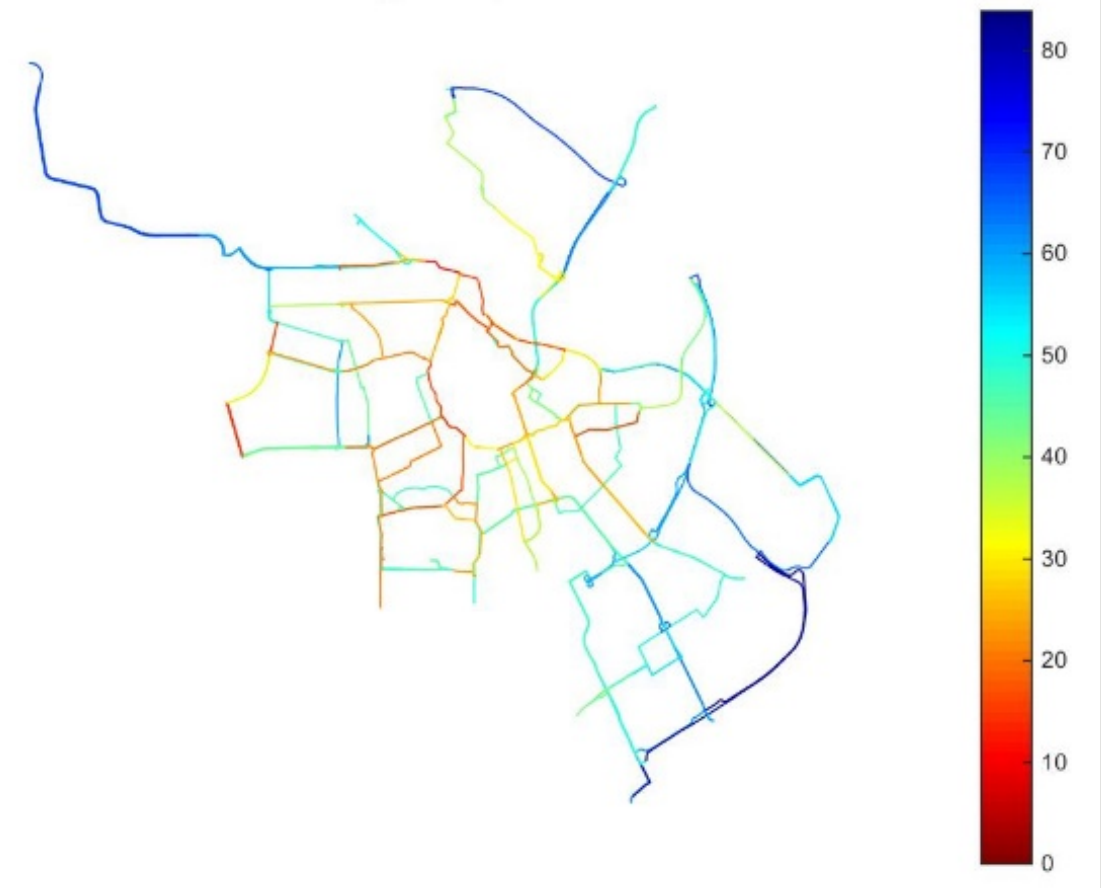
- Connected Clusters Dissimilarity (CCD)
  - Measure of external cluster dissimilarity

$$\mathrm{CCD} = \frac{\sum_{i=1}^{n} \sum_{k=1+i}^{n} \delta_{ik} |\bar{x}_i - \bar{x}_k|}{\sum_{i=1}^{n} \sum_{k=1+i}^{n} \delta_{ik}}$$

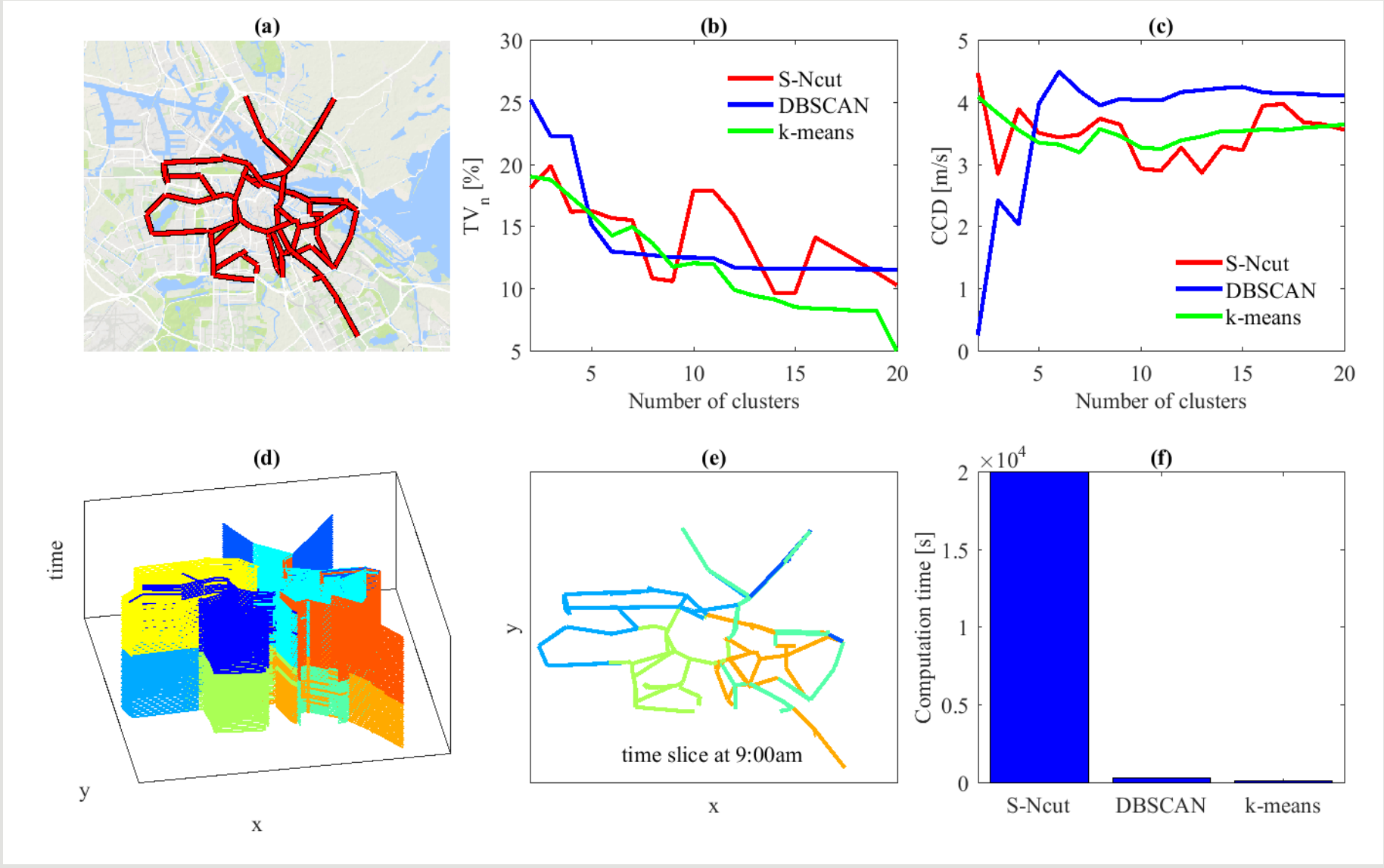
Data preparation: link speed estimation

From OD travel time to speed links

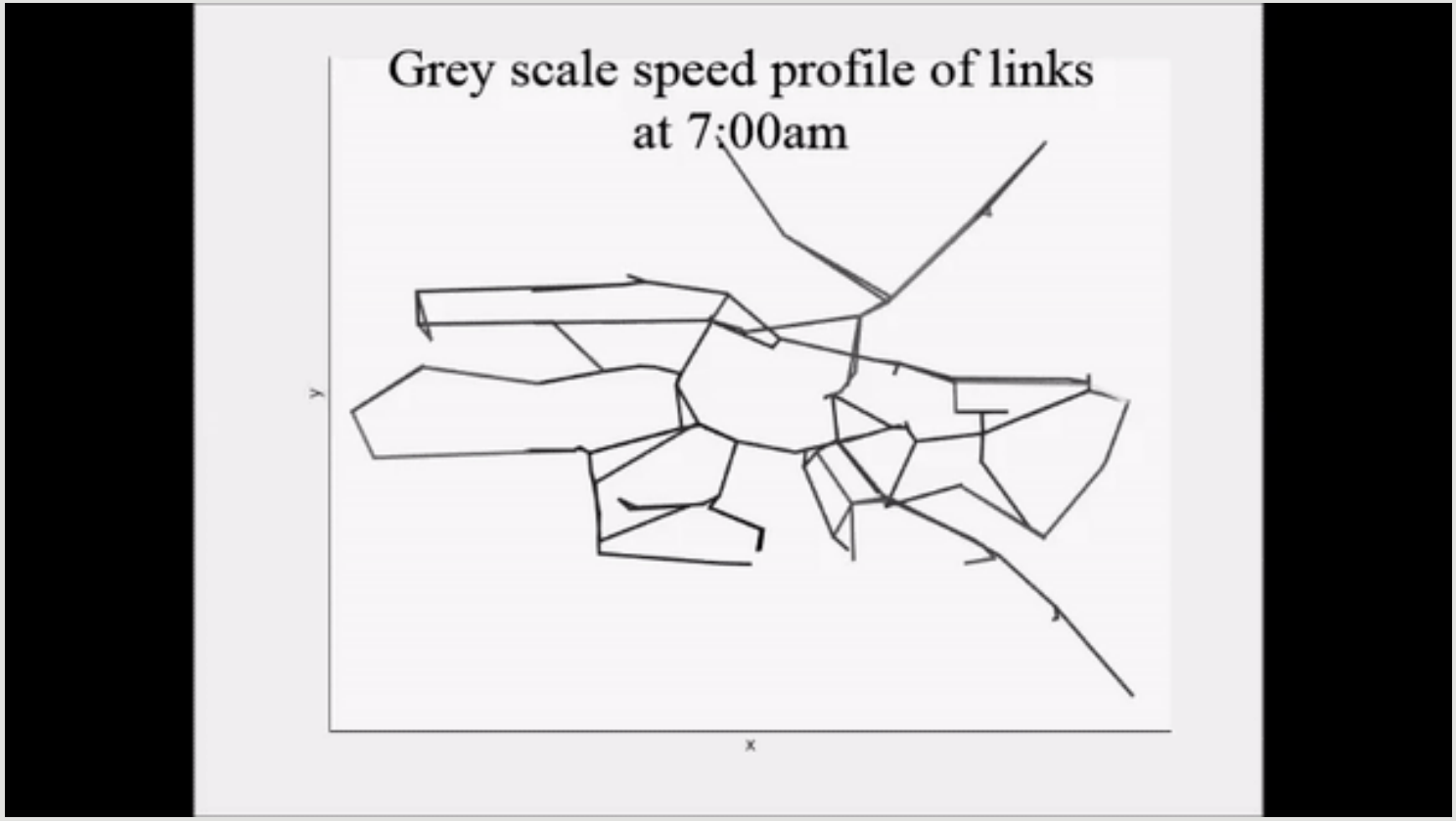
- Estimating speed link
  - Average common link speeds
- Missing data speed estimation
  - Duplicate speed of the most relevant adjacent link
  - Weighted based considering directions



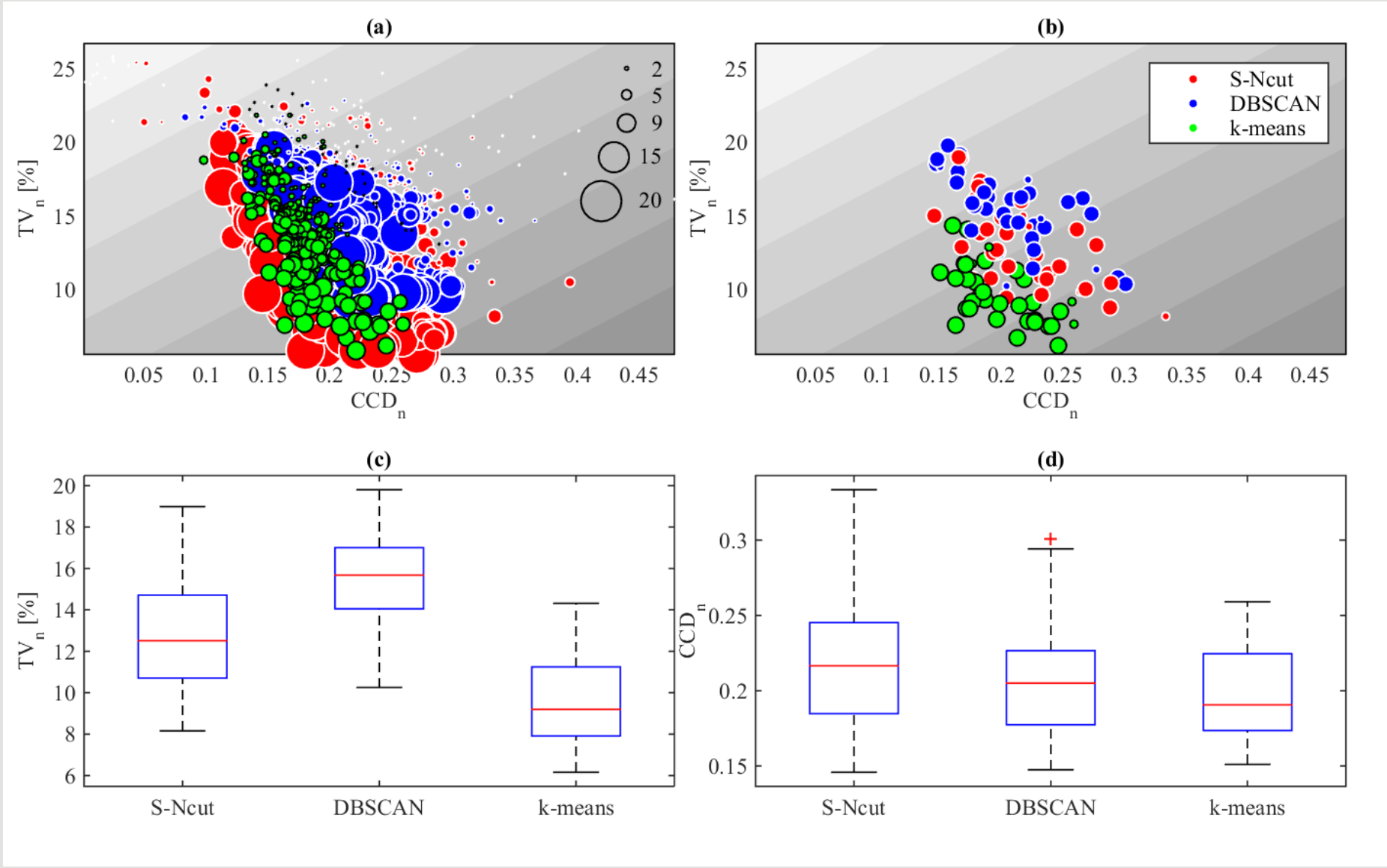
Clustering results for one specific day (1)



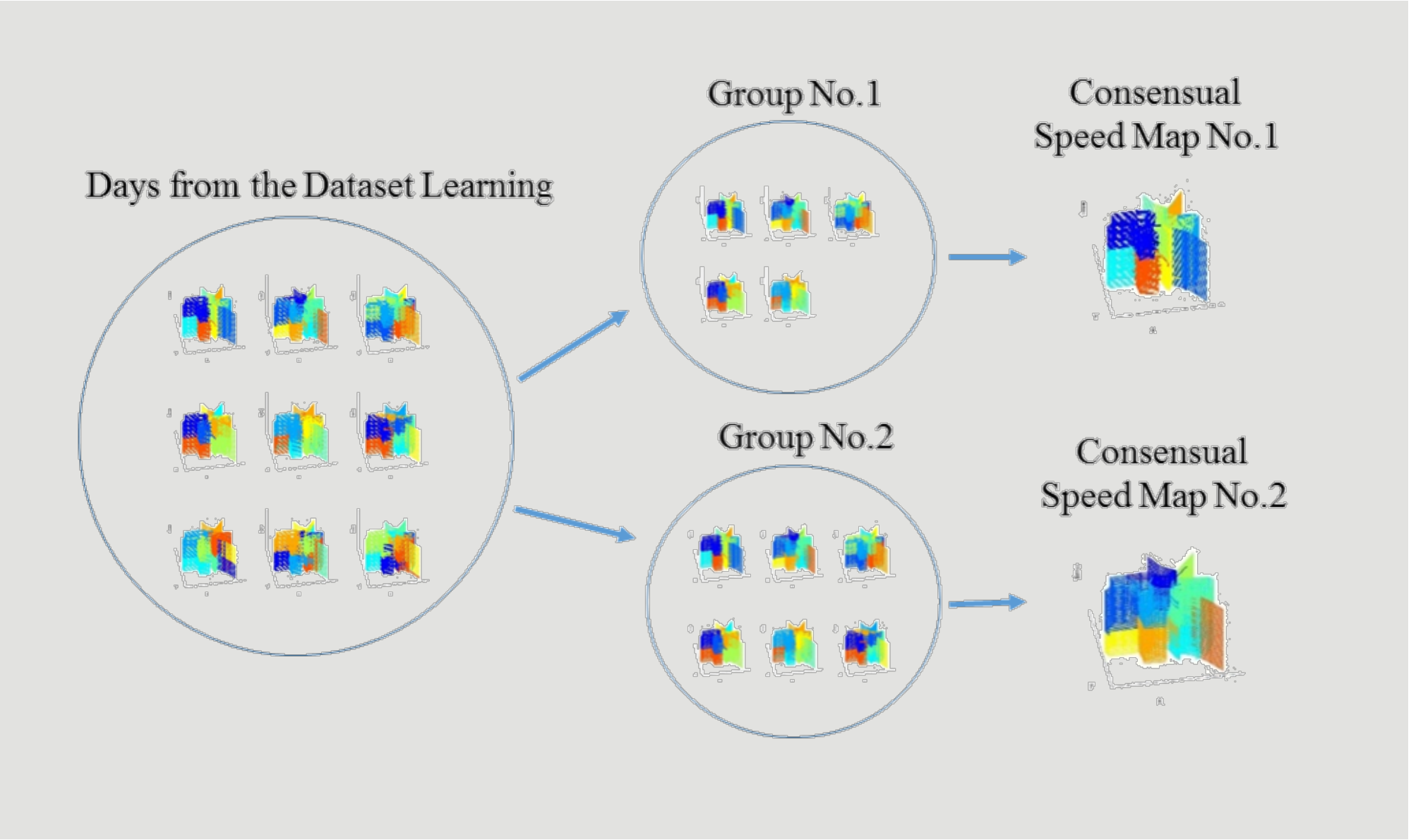
Clustering results for one specific day (2)



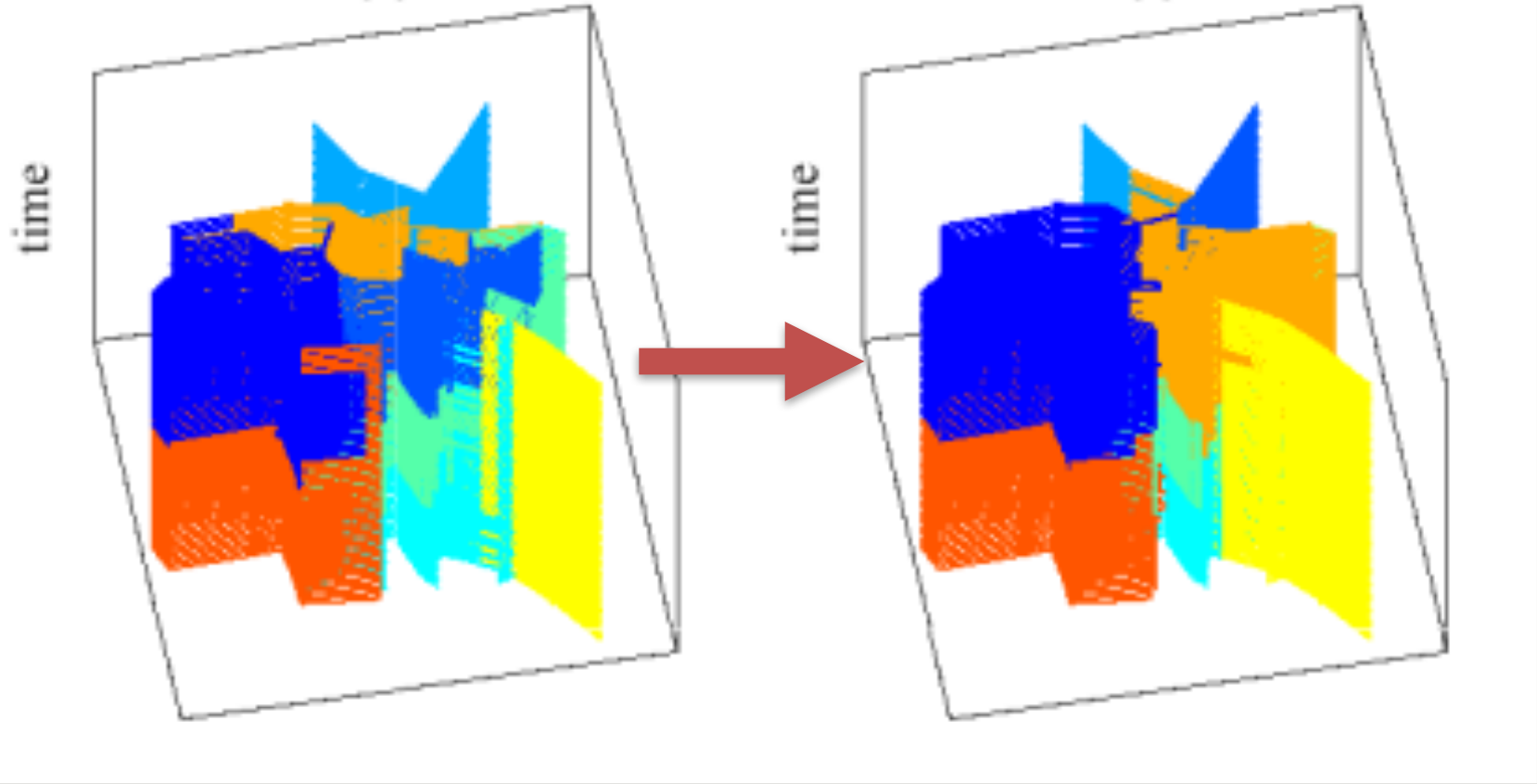
Clustering results for all days



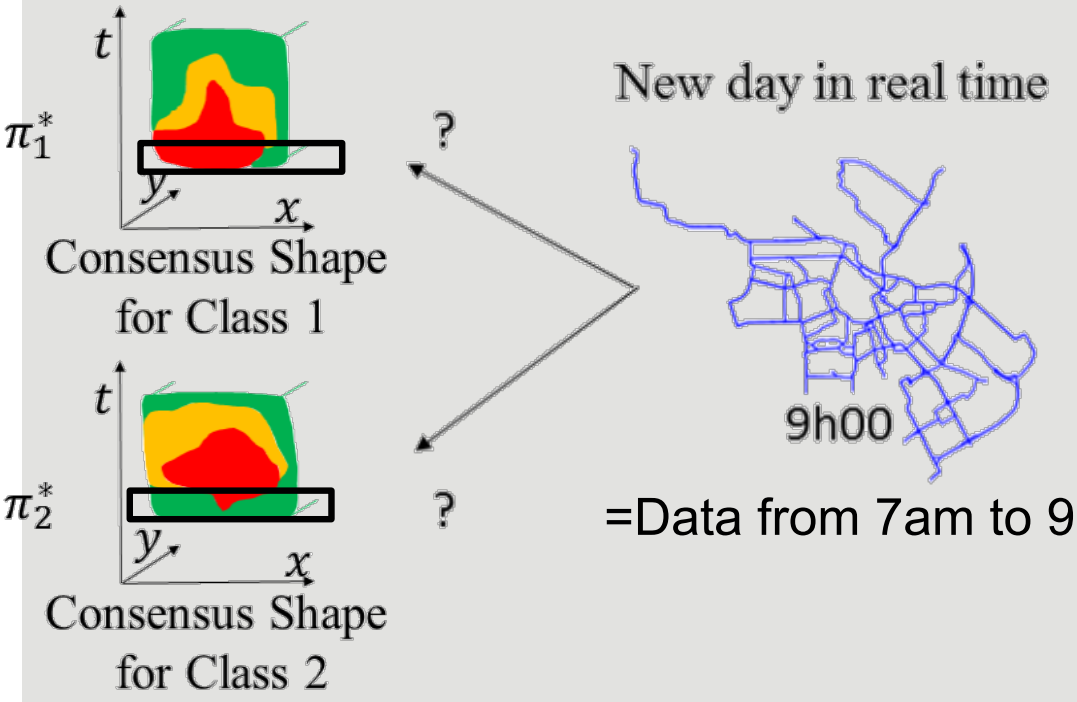
Meta-partitioning and consensus learning



Consensual 3D speed maps



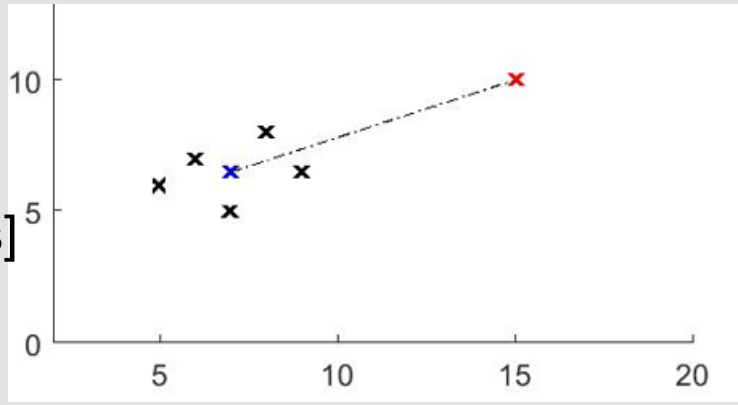
Application to travel time estimation (1)



=Data from 7am to 9am

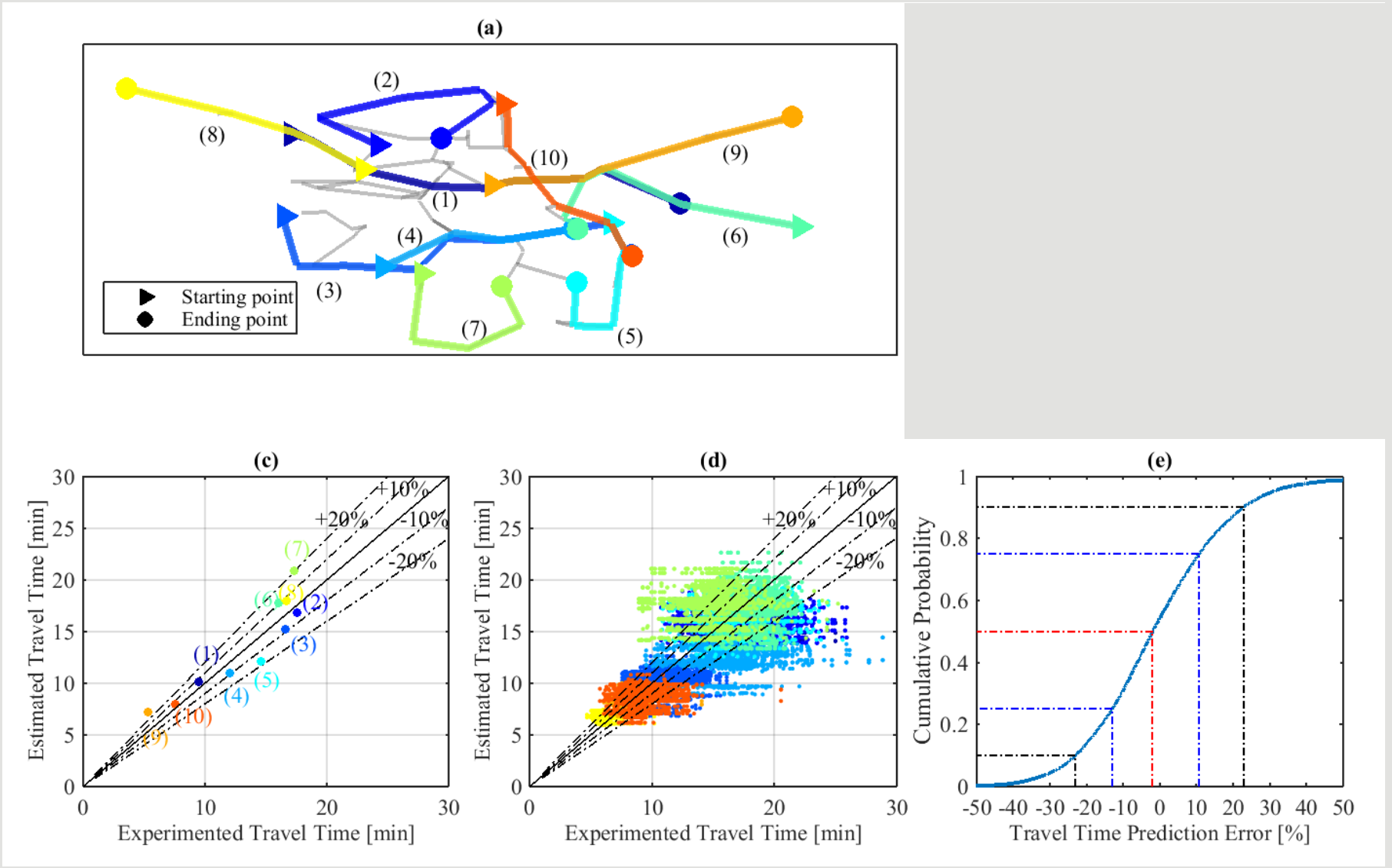
Minimizing the distance between the mean speed in each cluster between the new day and the consensal speed maps

Mean speed of the zone No.2 [m/s]



Mean speed of the zone No.1 [m/s]

Application to travel time estimation (2)



Conclusion

Conclusion

- The MFD concept is very appealing for monitoring and simulating large-scale network
- A lot of research effort is still required in particular to tune large-scale simulators
- Implementation to the real-field of advanced control strategies based on MFD are still rare

European Commission

MAGnUM

European Research Council

Multiscale and Multimodal Traffic Modelling Approach for Sustainable Management of Urban Mobility

Thank you for your attention

@LudoLeclercq
@erc_magnum