STRC

21th Transport Research Conference

Monte Verità / Ascona, 12-14 September 2021

MAGnUM

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

European Research Council

Established by the European Commission

Recent advances in multimodal MFD urban models

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Université Gustave Eiffel

Université de Lyon

ENTPE

L'école de l'aménagement durable des territoires

Outline

- Macroscopic urban models
- New insights on multimodal MFD from the pNEUMA experiment
- The existing formulations for MFD models
- Multi-reservoir systems and traffic assignment
- Applications of NMFD approaches
  - Large-scale simulation of Lyon Metropolis
  - Overall assessment of a ride-sharing system
  - An optimal route guidance strategy based on avoidance maps
  - Trip length calibration and perimeter control

Introduction to macroscopic urban models

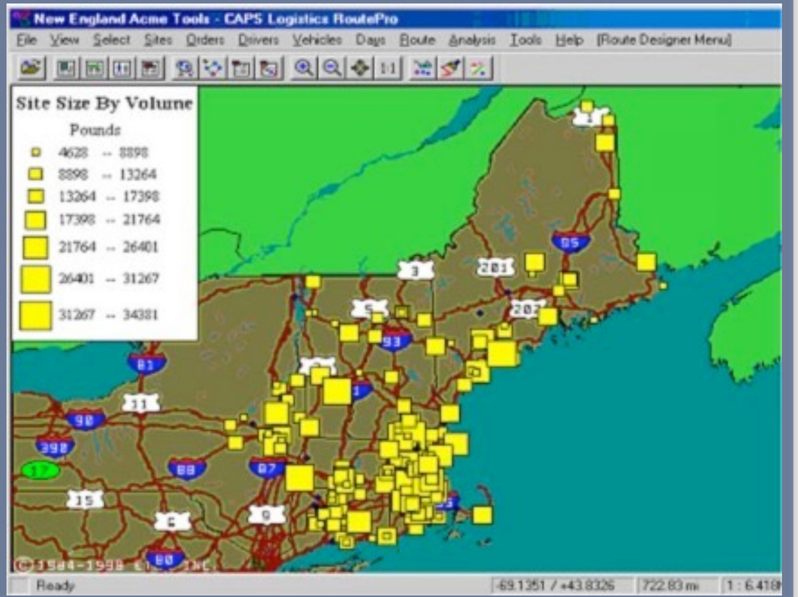
Transportation models

Local traffic dynamics

Open simulation plateform (Symuvia)

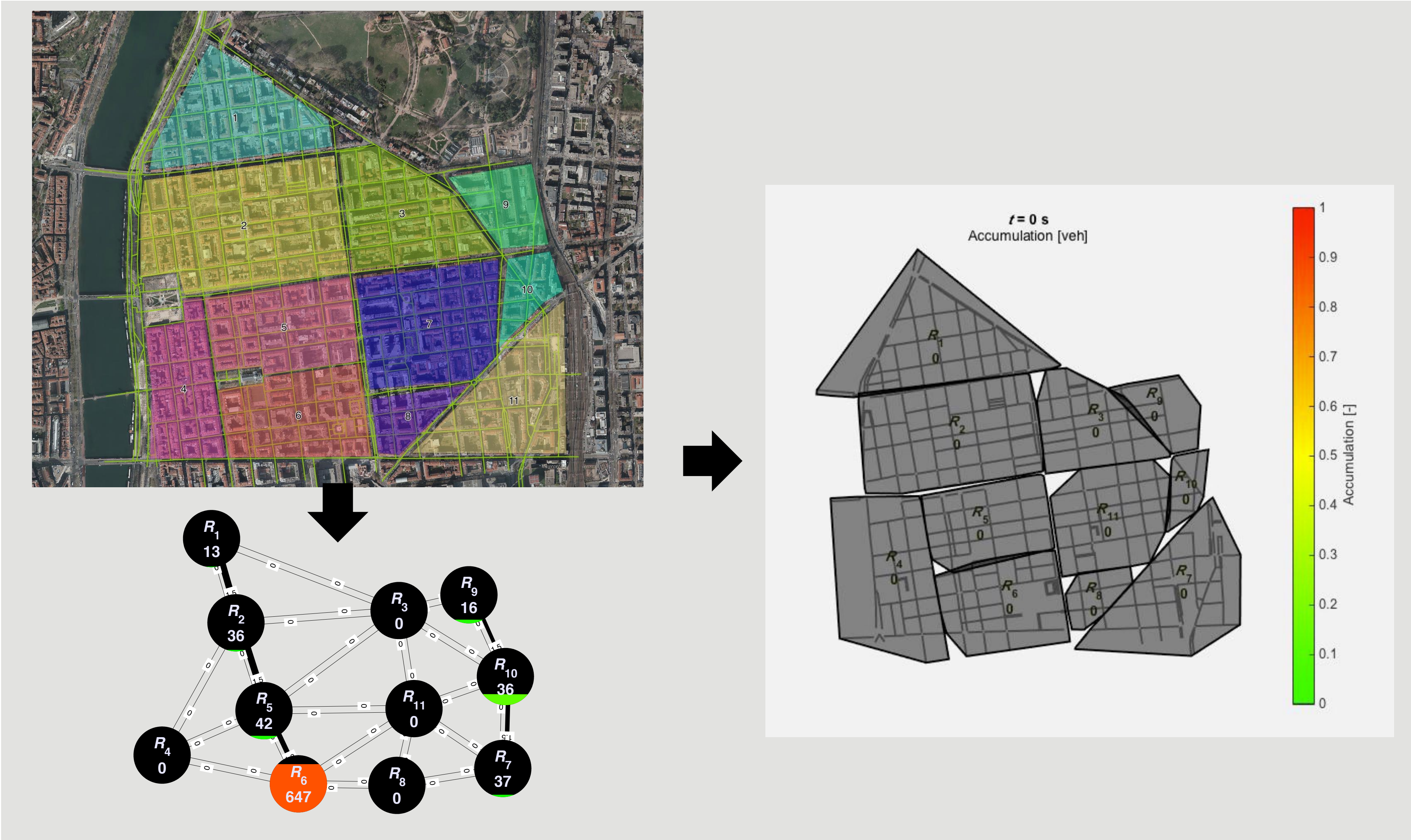
(Leclercq et *al*, 2009-2015)

Static model for planing

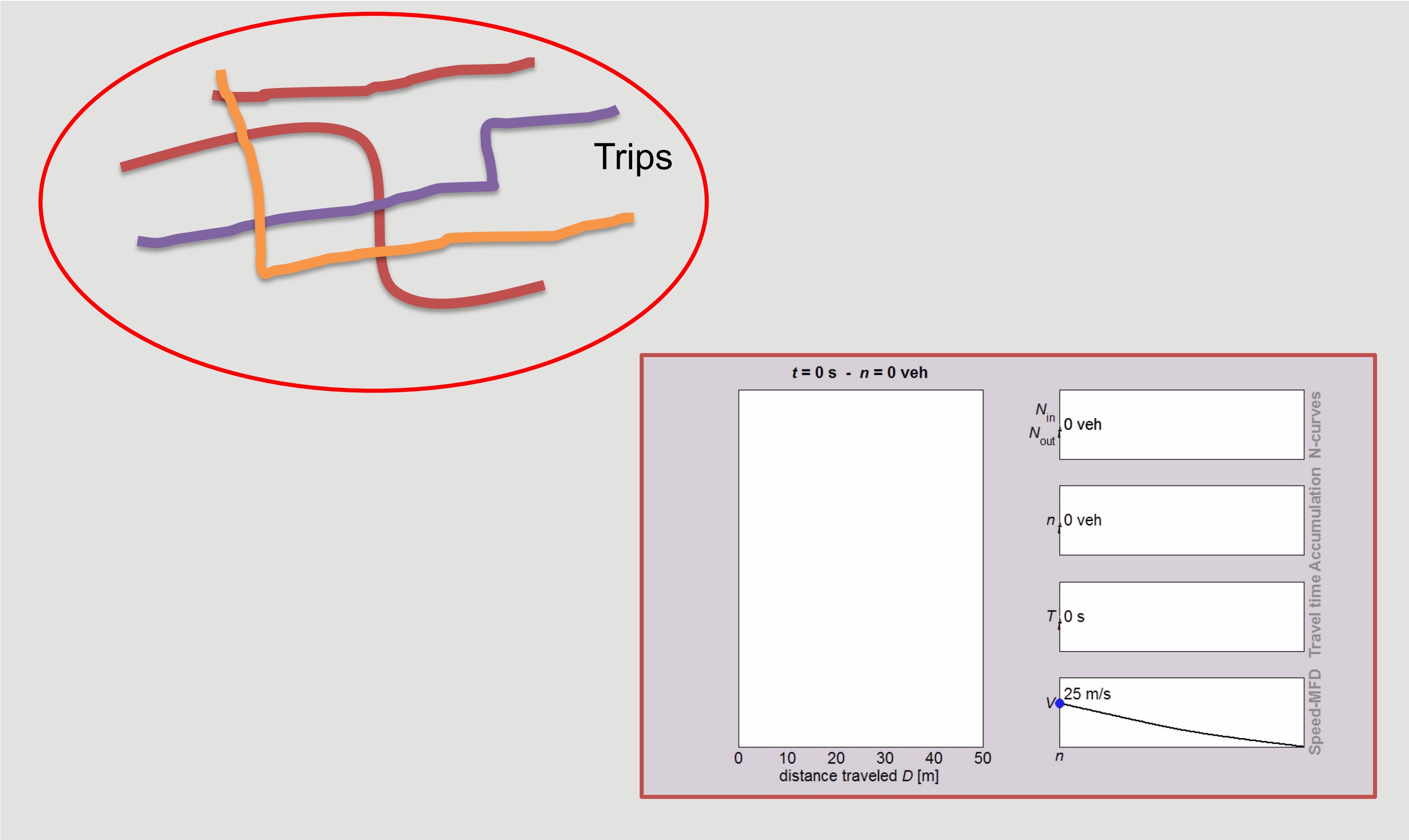


Room for large-scale dynamic models

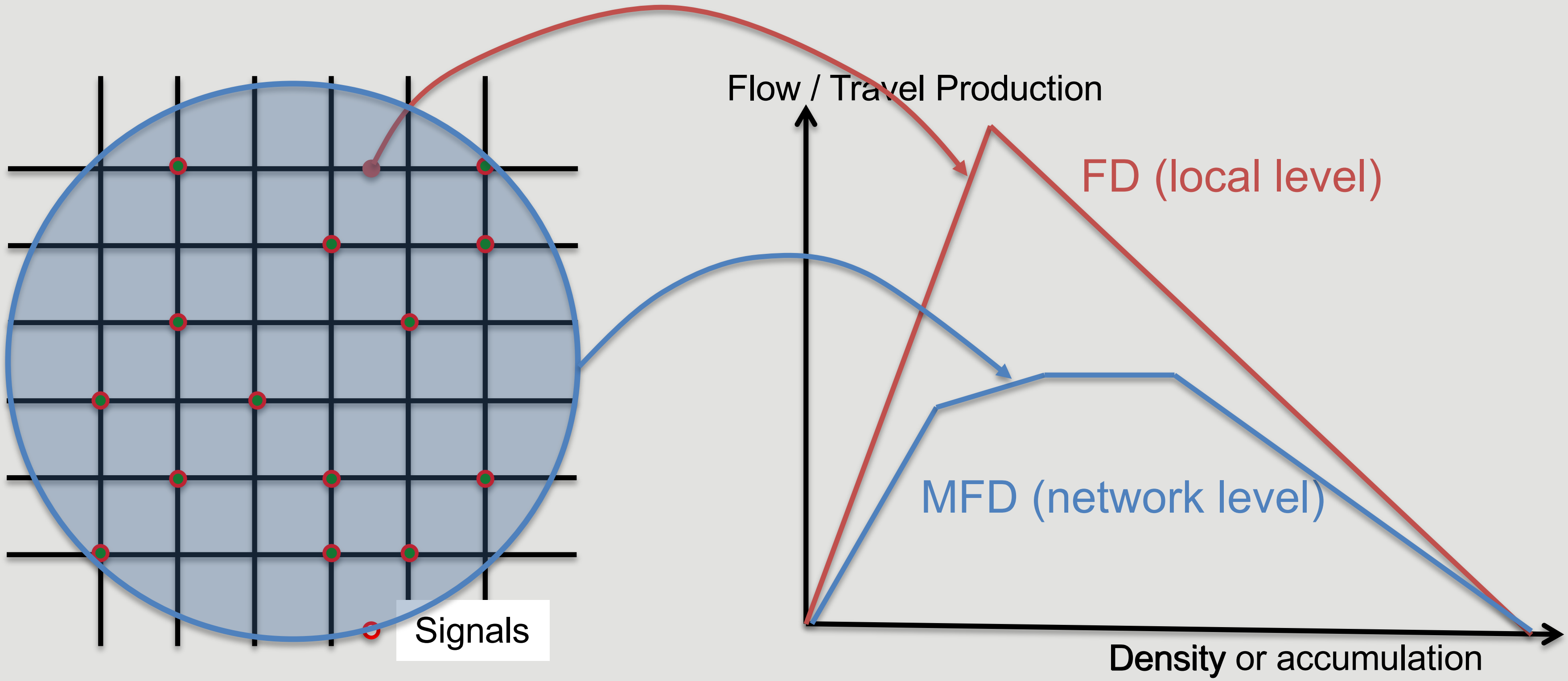
Large-scale dynamic urban simulation (1)



Large-scale dynamic urban simulation (2)

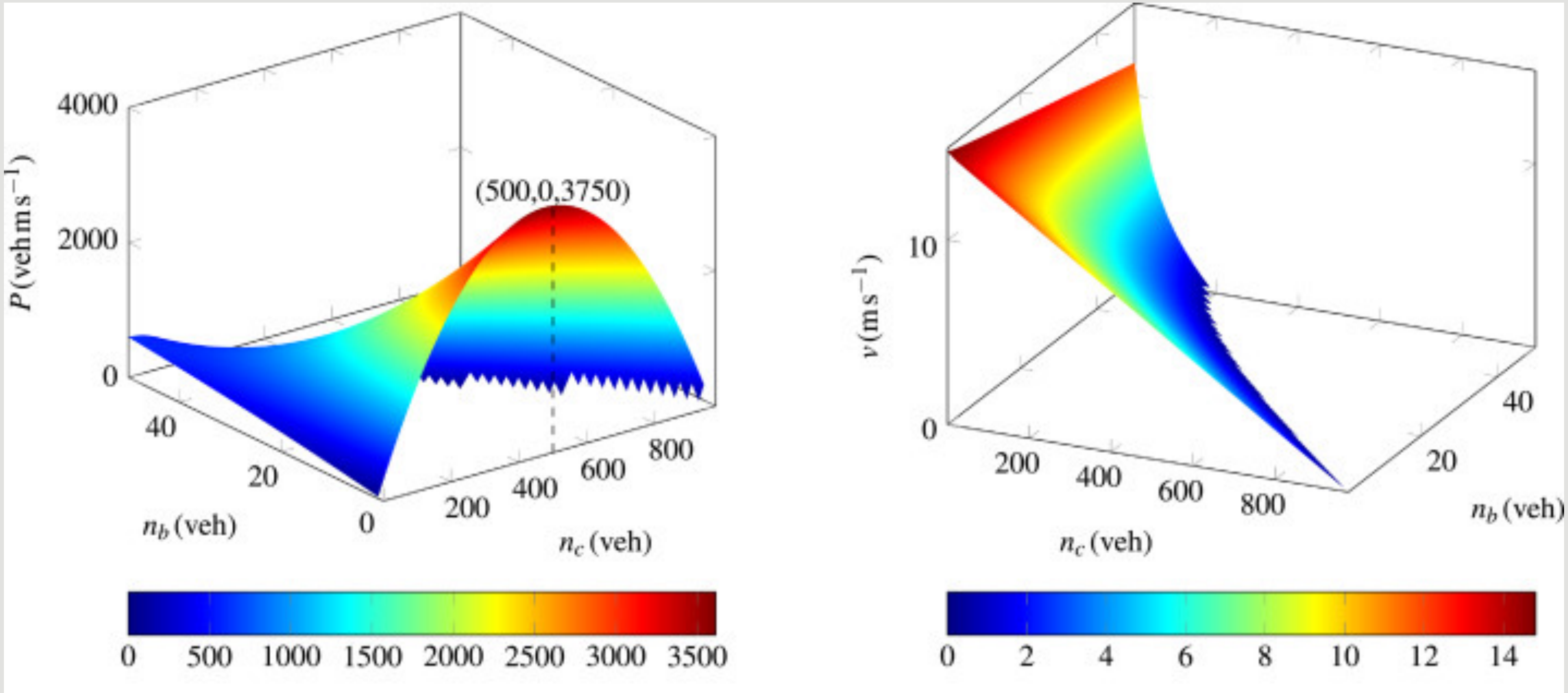


MFD definition



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

Multimodal MFD extension



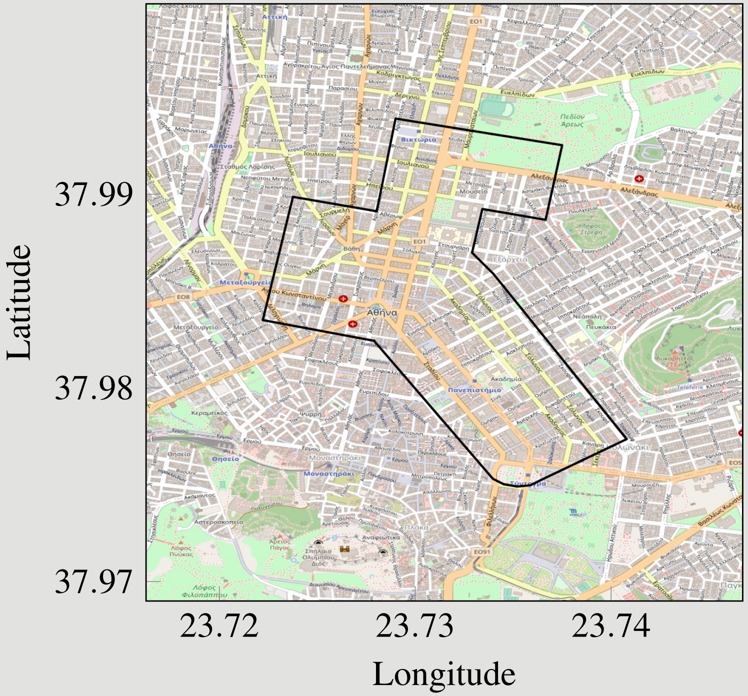
(a) Production MFD surface.

(b) Velocity MFD surface.

New insights on multimodal MFD from the pNEUMA experiment

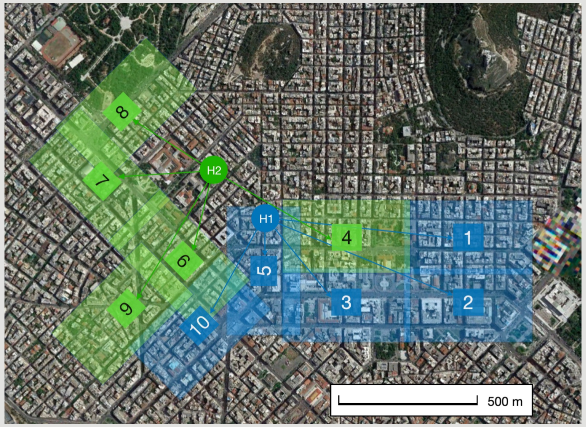
Paipuri, M., Barmpounakis, E., Geroliminis, N., Leclercq, L., 2021. Empirical Observations of Multi-modal Network-level Models: Insights from the pNEUMA Experiment. *Transportation Research part C.*

Experimental setting



https://open-traffic.epfl.ch/

pNEUMA at a glance



TEN DRONES
Hovering simultaneously over different areas

5 DAYS
Monday to Friday

MASSIVE URBAN TRAJECTORY DATASET
More than 0.5 million trajectories

OPEN ACCESS
Free distribution.
No barriers.

MORNING PEAK-HOUR
Five flight sessions for 2.5 hours per day

100+ INTERSECTIONS
Signalised or not

GLOBAL IMPACT
Made for researchers around the world

PERFECT FOR PHD
Stop searching for data and start your analyses!

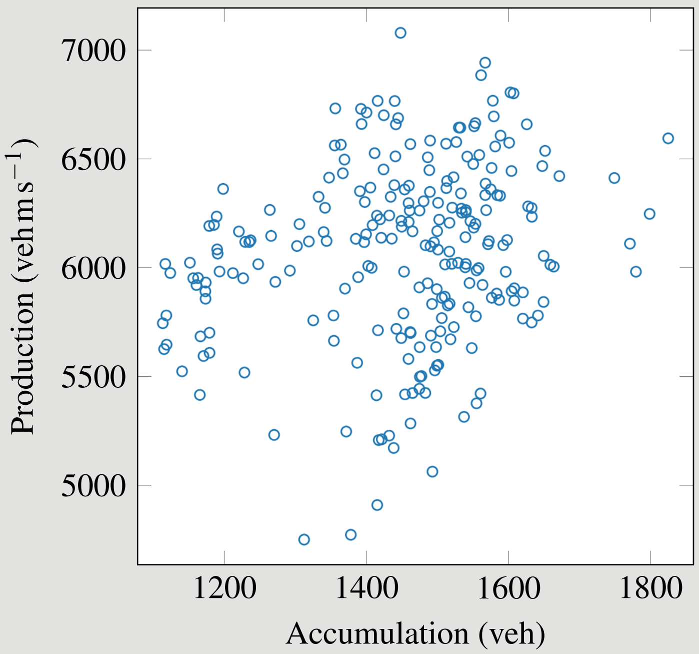
Ideal for multimodal research

Cars | Taxis | Buses | PTWs | Medium and Heavy Vehicles

EPFL

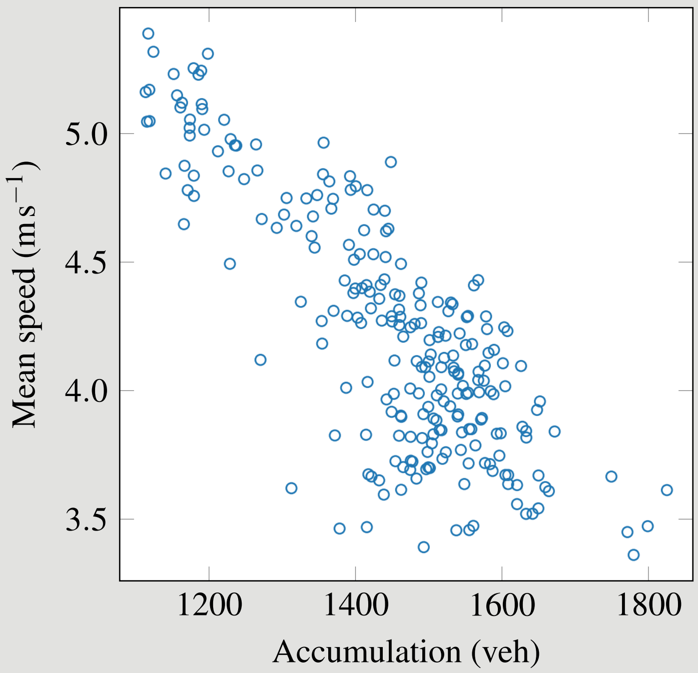
Barbounakis and Geroliminis, 2020, part-C

2D MFD



7000
6500
6000
5500
5000
Production (veh m s^{-1})
1200
1400
1600
1800
Accumulation (veh)

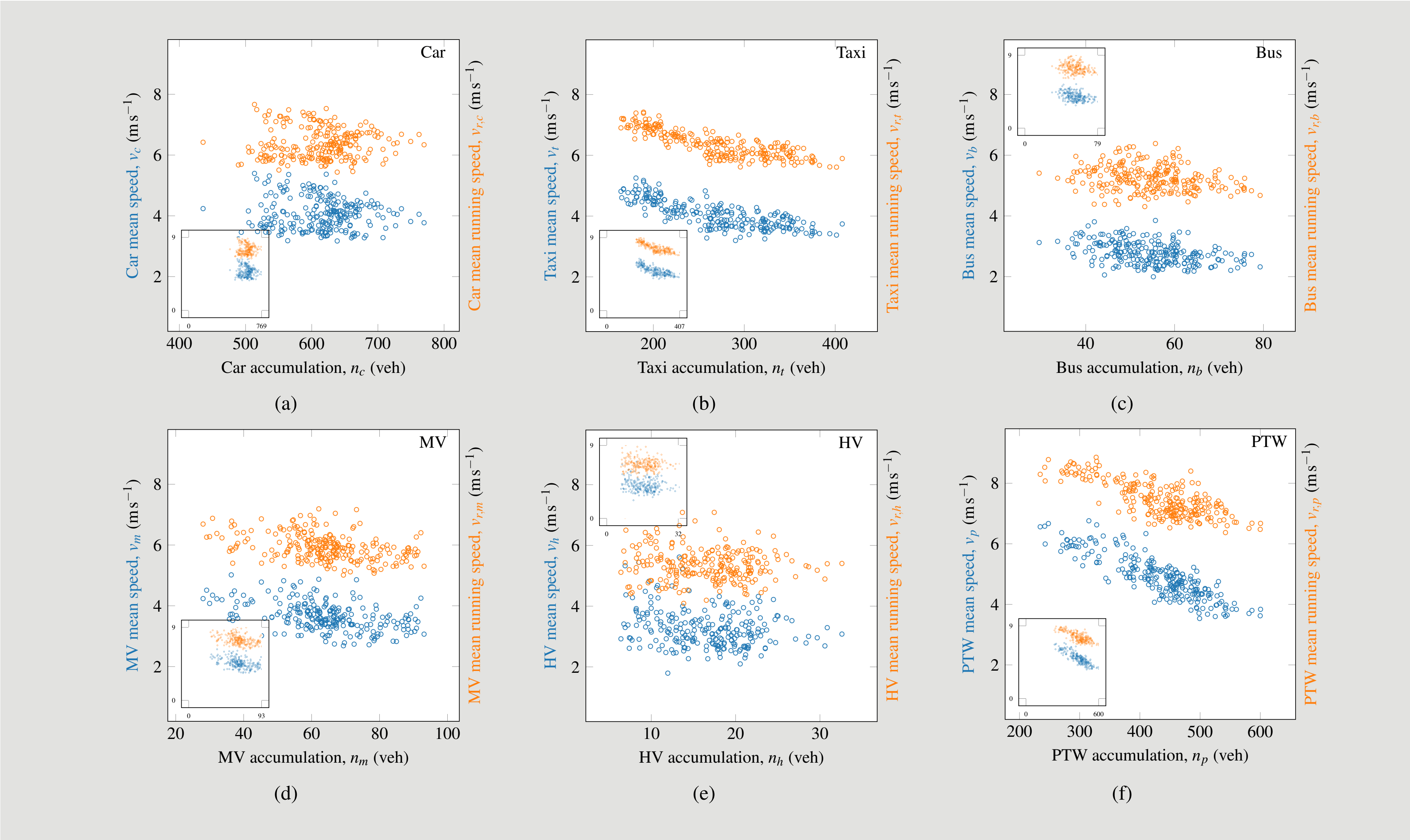
(a)



5.0
4.5
4.0
3.5
Mean speed (m s^{-1})
1200
1400
1600
1800
Accumulation (veh)

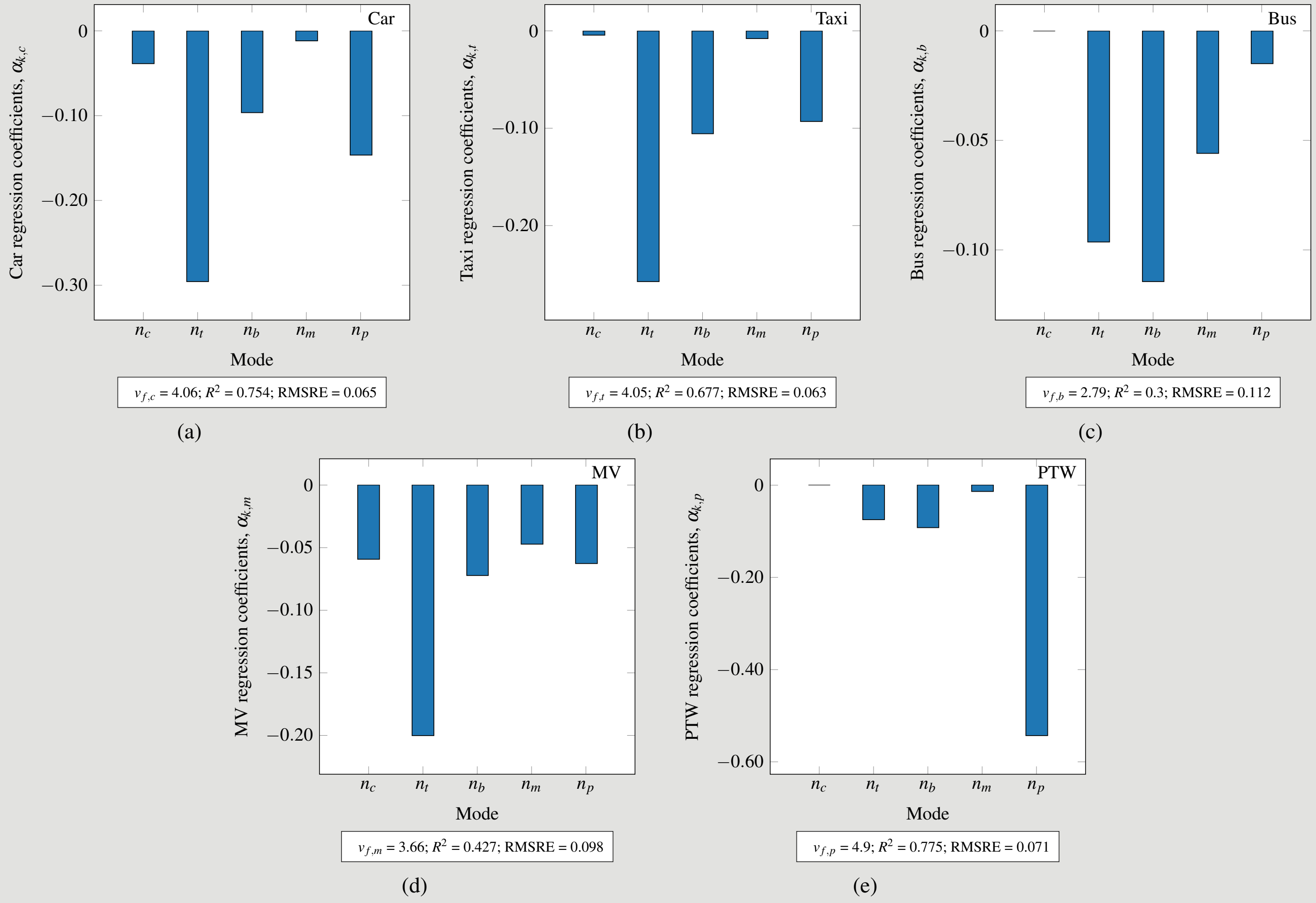
(b)

Unimodal speed regression



Multimodal speed regression

$$v_j = v_{f,j} + \alpha_{c,j} n_c + \alpha_{t,j} n_t + \alpha_{b,j} n_b + \alpha_{m,j} n_m + \alpha_{p,j} n_p, \quad \forall \; j = \{c, t, b, m, p\},$$



Comparison uni vs. multi regression

Mode	p-values						$v_{f,j}$		R^2		RMSRE	
	Uni-	Multi-					Uni-	Multi-	Uni-	Multi-	Uni-	Multi-
	n_m	n_c	n_t	n_b	n_m	n_p						
Car	0.01	0.01	0	0	0.60	0	4.06	4.06	0.01	0.75	0.125	0.065
Taxi	0	0.80	0	0	0.72	0	4.05	4.05	0.60	0.68	0.071	0.063
Bus	0	0.14	0	0	0.06	0.48	2.79	2.79	0.15	0.30	0.123	0.112
MV	0	0.01	0	0	0.12	0.07	3.66	3.66	0.19	0.43	0.114	0.098
PTW	0	0	0.06	0	0.63	0	4.90	4.90	0.04	0.78	0.074	0.071

The multimodal two-fluid model

Running speed $$v_r = v_{f,r}\,(f_r)^{\check{n}} \equiv v_{f,r}\,(1-f_s)^{\check{n}},$$

Mean speed $$v = v_{f,r}\,(f_r)^{\check{n}+1} \equiv v_{f,r}\,(1-f_s)^{\check{n}+1}.$$

Fraction of vehicles that are stopped during a given time internal, i.e.,
The mean stoped time / m over the mean travel time / m $$f_s = \frac{T_s}{T},$$

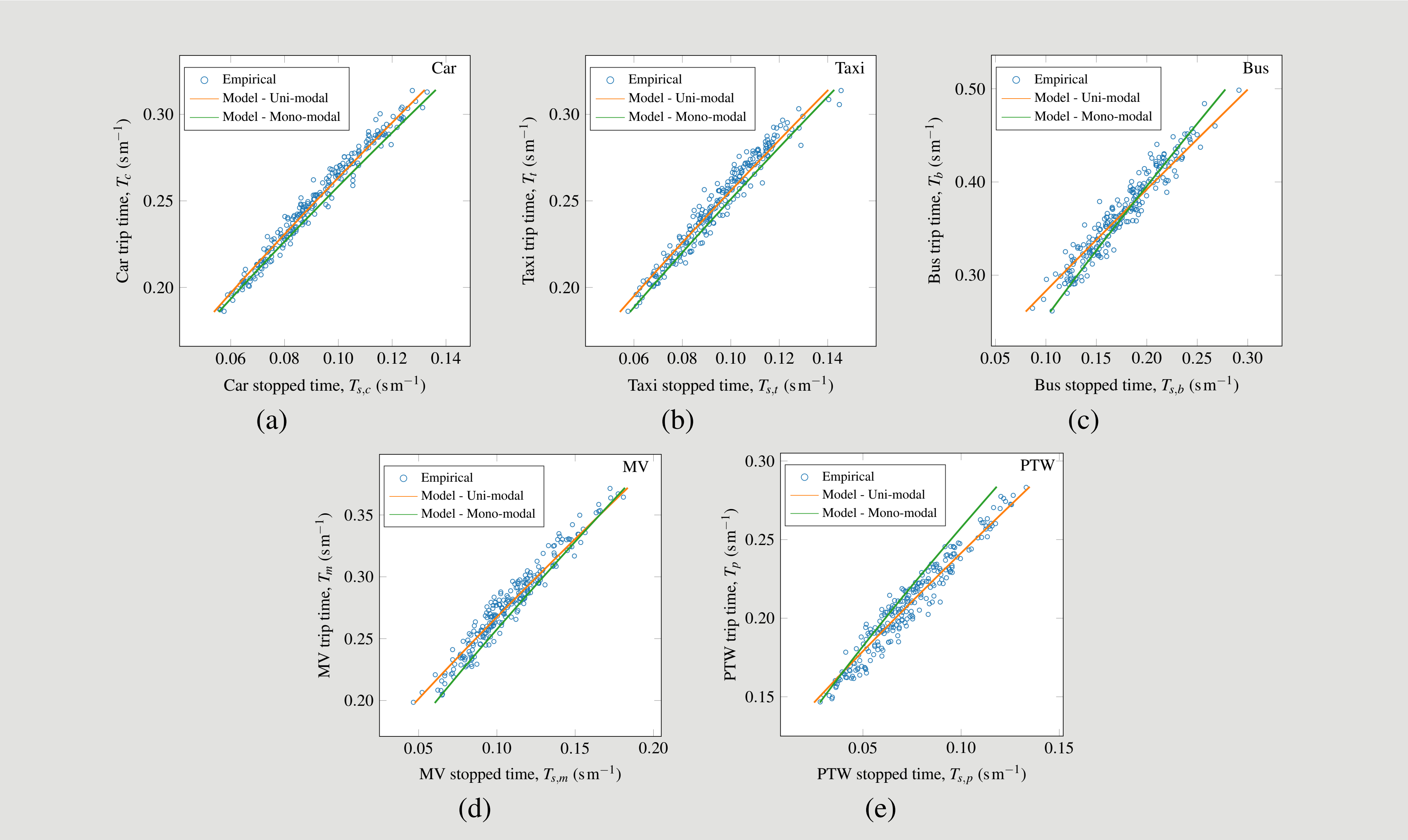
(Herman and Prigogine, 1979)

The multimodal counterpart

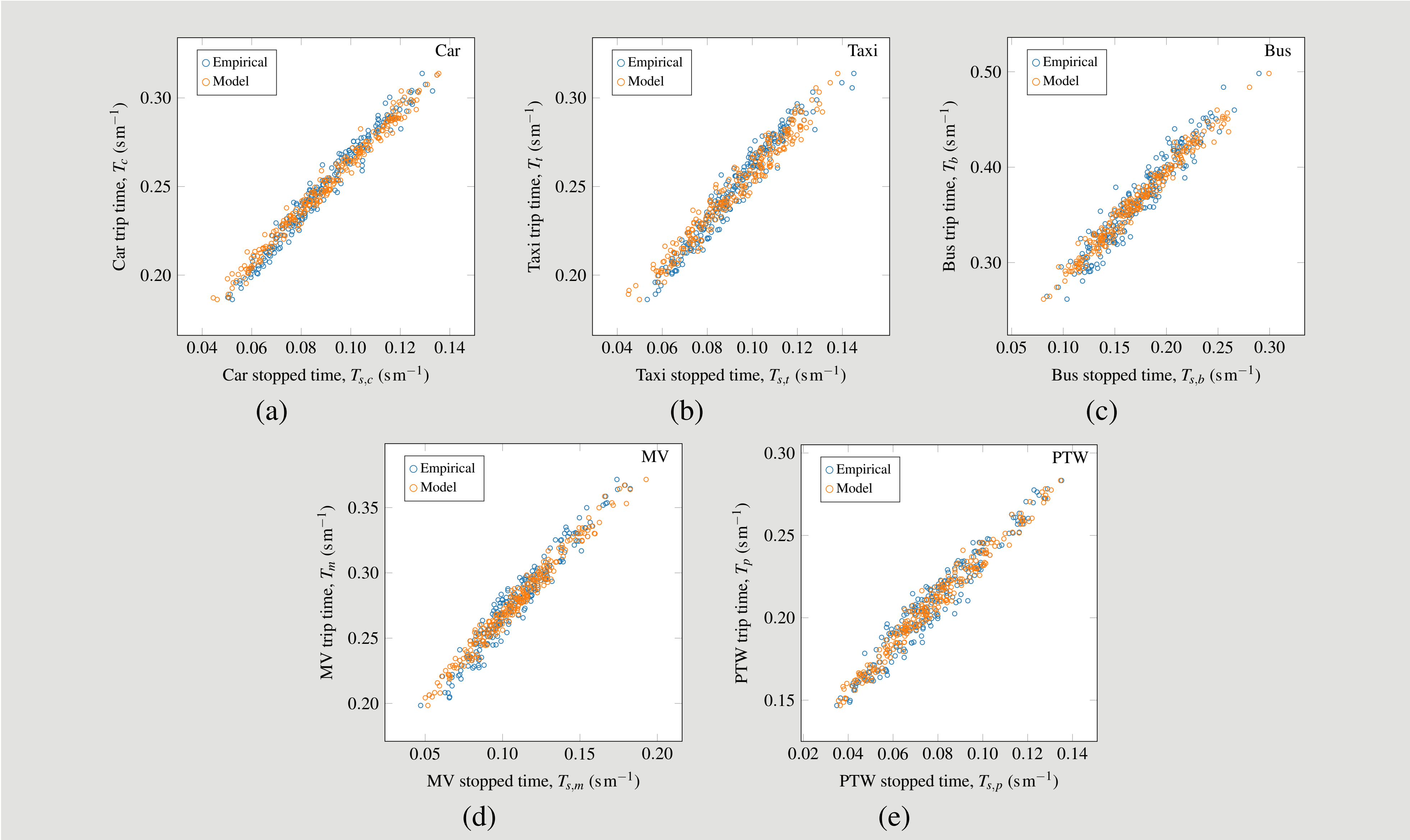
$$v_{r,j} = v_{f,r,j} \prod_{k \in \mathscr{M}} \left(1 - f_{s,k}\right)^{\check{n}_{k,j}}, \ \forall j \in \mathscr{M} \ \text{ and } \ \mathscr{M} = \{c,t,b,m,p\},$$

$$v_j = v_{f,r,j}\,(1 - f_{s,j}) \prod_{k \in \mathscr{M}} \left(1 - f_{s,k}\right)^{\check{n}_{k,j}}, \ \forall j \in \mathscr{M} \ \text{ and } \ \mathscr{M} = \{c,t,b,m,p\}.$$

The Uni two-fluid model



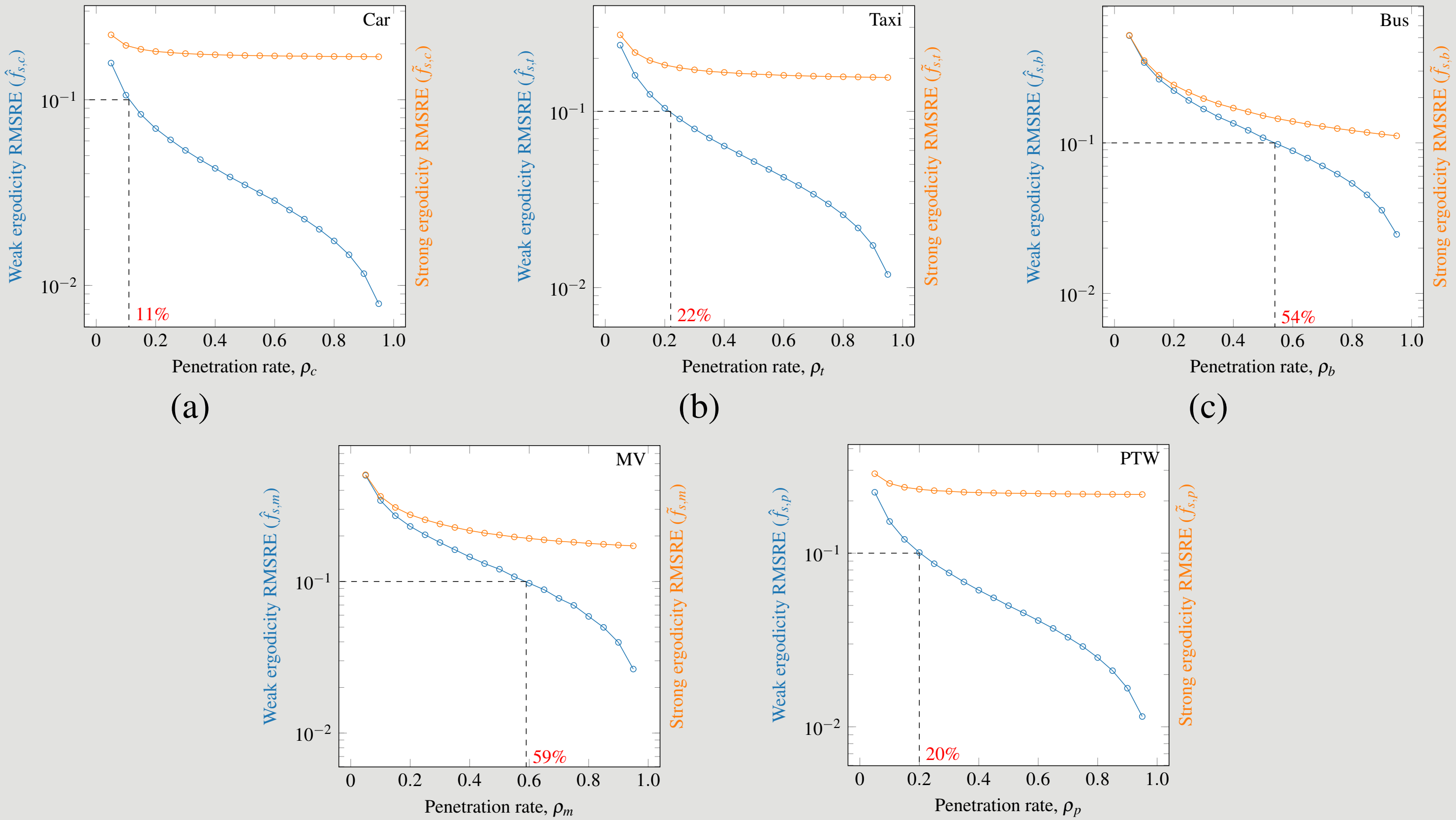
The Multi two-fluid model



Estimating fs - ergodicity assumption

Weak ergodicity (based on probe sampling) $\hat{f}_s = \frac{\overline{T}_s}{\overline{\overline{T}}},$

Strong ergodicity (based on probe sampling) $\tilde{f}_s = \left\langle \frac{T_s}{T} \right\rangle.$ (Ardekani, 1984)



The existing formulations for MFD models

Mariotte, G., Leclercq, L., 2019. Flow exchanges in multi-reservoir systems with spillbacks. *Transportation Research part B*, 122, 327-349.

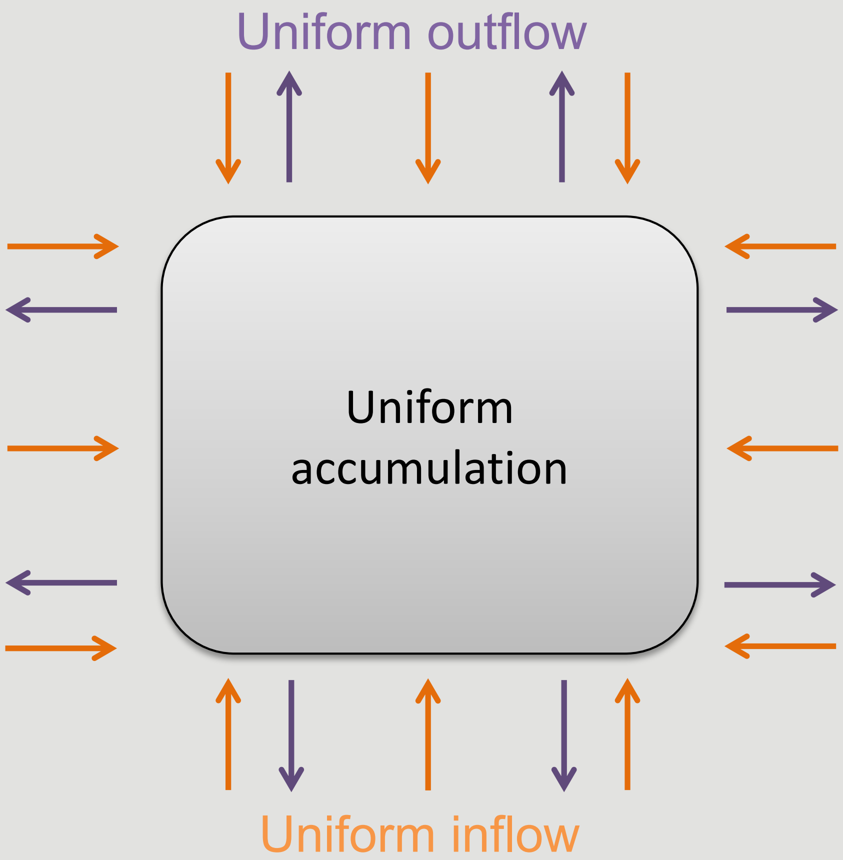
Mariotte, G., Leclercq, L., Laval, J.A., 2017. Macroscopic urban dynamics: Analytical and numerical comparisons of existing models. *Transportation Research Part B*,

The single reservoir setting

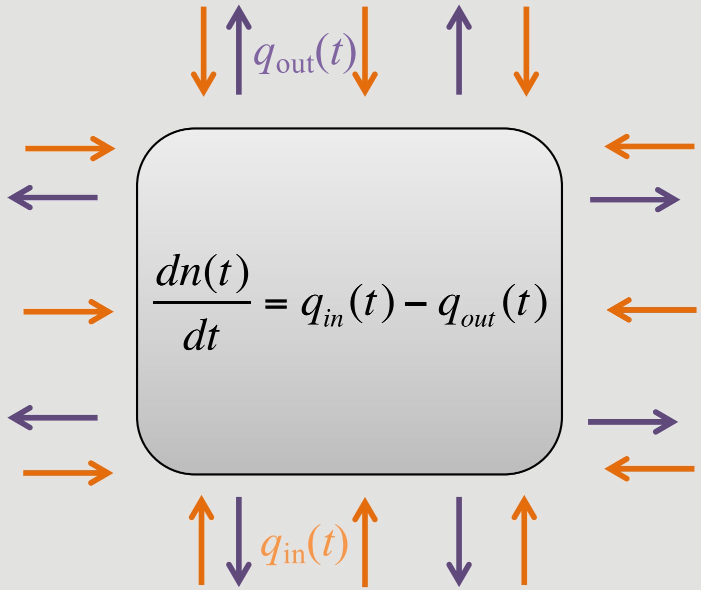
Classical dynamic approach

© Symuvia platform

Reservoir (NMFD) approach



The accumulation-based (bathtub) model

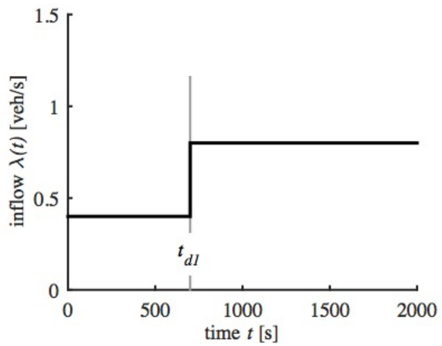


The outflow-MFD is hard to calibrate in practice this is why the steady-state approximation is used

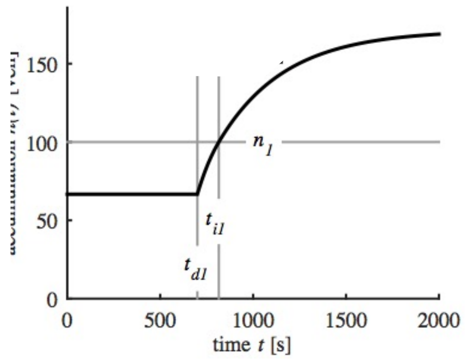
$$q_{out}(t) = \frac{Q\left(n(t)\right)}{L_{trip}}$$

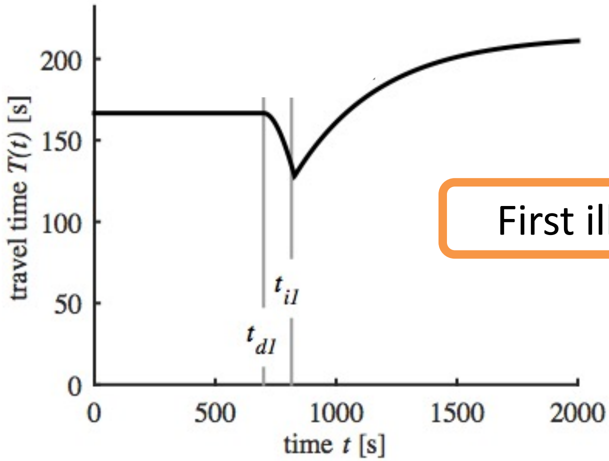
Wave propagation in a single reservoir

Wave propagation



Demand surge





First illustration of the causality effect

Trip-based model

Model formulation

Analytical resolution
(piecewise cst inflows)

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

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

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

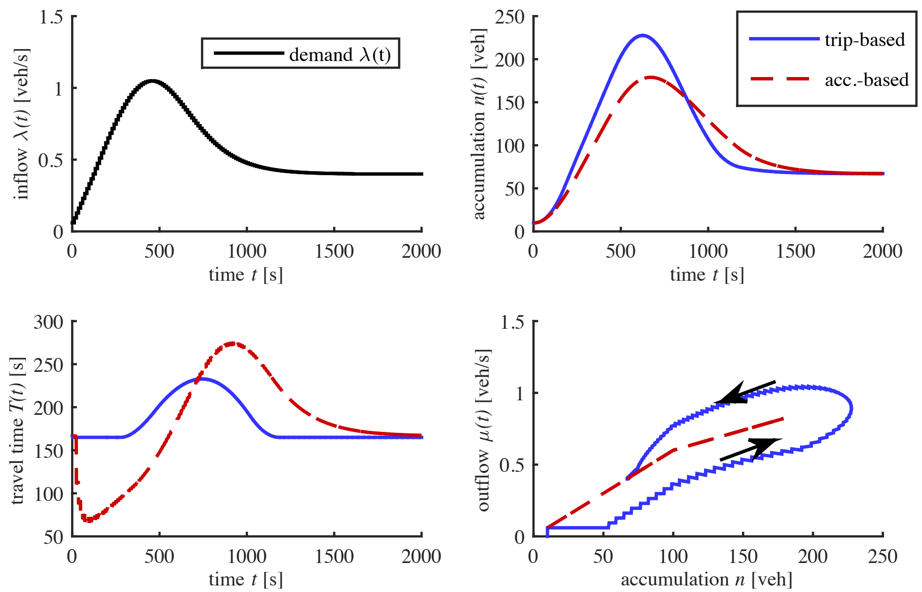
$$\Leftrightarrow\ Q_{out}(t) = \frac{Q_{in}\left(t - \underline{T\left(N_{out}(t)\right)}\right)V\left(n(t)\right)}{V\left(n\left(t - \underline{T\left(N_{out}(t)\right)}\right)\right)}$$

(Delay differential equation with endogenous delay)

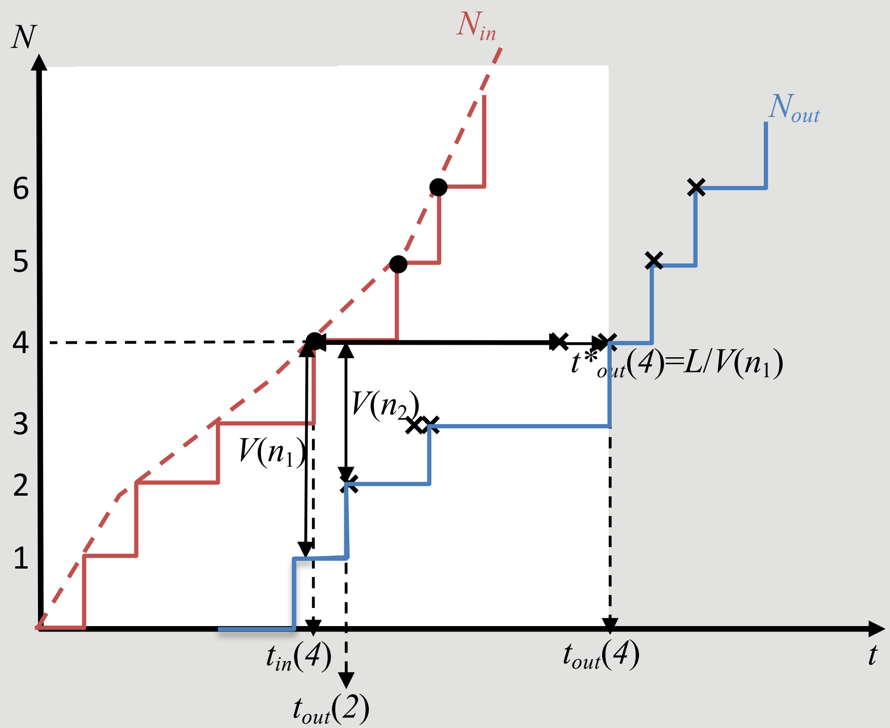
$$Q_{out}(t) = Q_{in}(t) + n'(t)$$

(Accumulation-based MNFD model)

Model solutions



Trip-based 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

(Leclercq et *al*, TRptB, 2017)

Multimodal extensions

- Accumulation-based version

$$\frac{dn_i(t)}{dt} = q_{in,i}(t) - q_{out,i}(t) \ \ with \ q_{out,i}(t) = \frac{n_i}{n}\frac{P(n_i \ldots)}{L_i}$$

- Trip-based version

$$L_{c,r} = \int_{t-\tau_{c,r}(t)}^{t} v_{c,r}(n_{c,r}(s), n_{p,r}(s)) \, \mathrm{d}s,$$

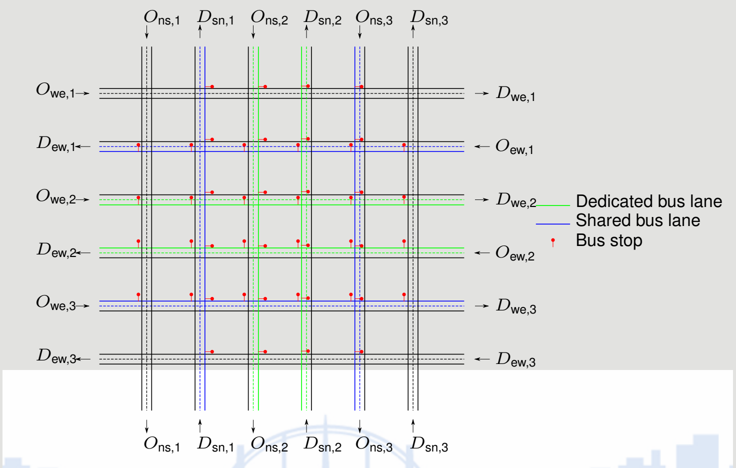
- Accumulation-based version with delay

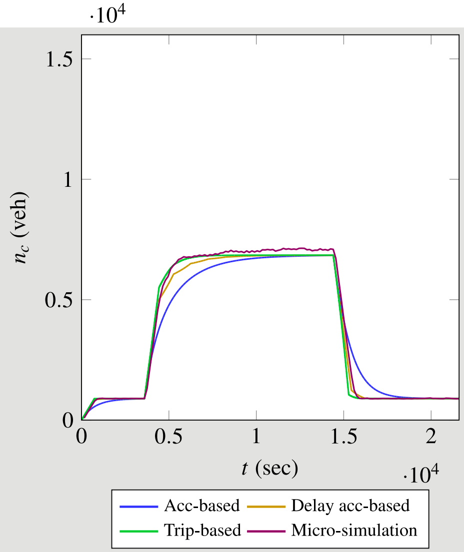
$$\int_{-\infty}^{t} q_{m,\mathrm{in}}(s) \, \mathrm{d}s = \int_{-\infty}^{t+\tau_m(t)} q_{m,\mathrm{out}}(s) \, \mathrm{d}s. \qquad q_{m,\mathrm{out}}(t + \tau_m(t)) = \frac{q_{m,\mathrm{in}}(t)}{1 + \dfrac{\mathrm{d}\tau_m(t)}{\mathrm{d}t}}.$$

It requires stabilization when inflow decreases

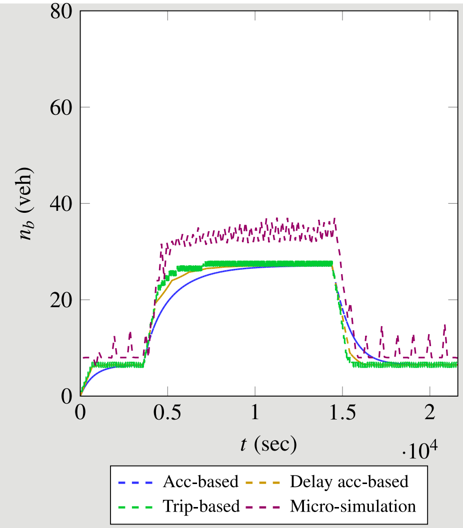
Paipuri, M., Leclercq, L., 2020. Bi-modal Macroscopic Traffic Dynamics in a Single Region. *Transportation Research part-B*,

Comparison of multimodal MFD extensions

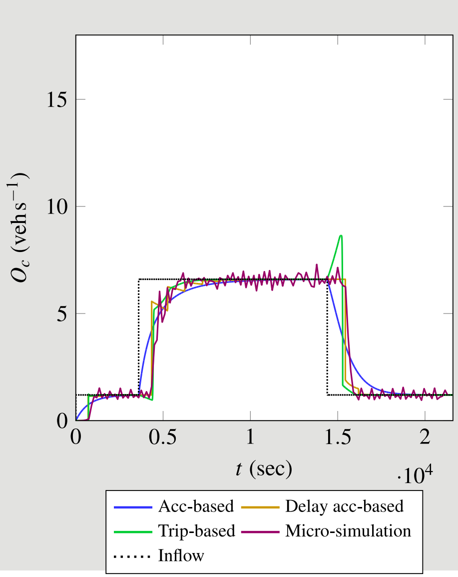




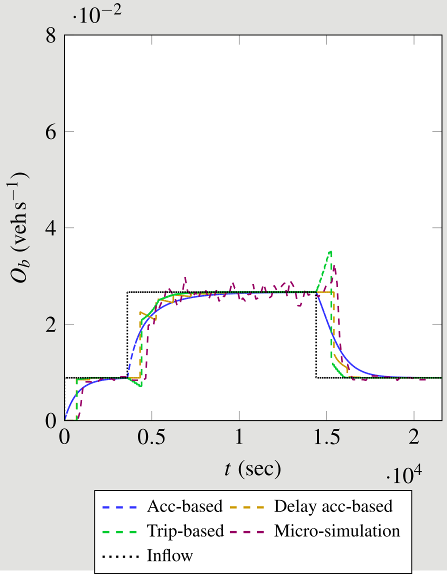
(a) Accumulation *vs.* time for cars.



(b) Accumulation *vs.* time for buses.



(c) Outflow *vs.* time for cars.

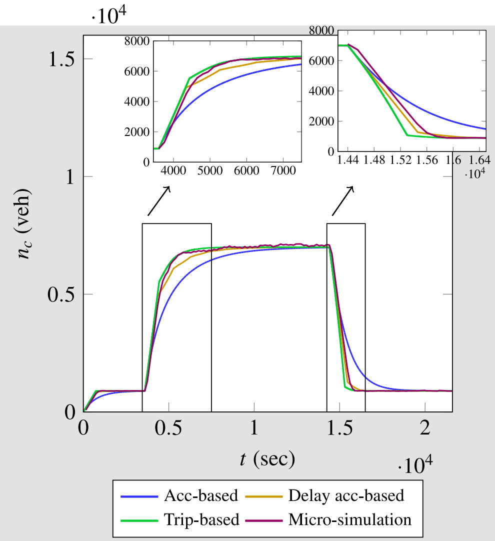


(d) Outflow *vs.* time for buses.

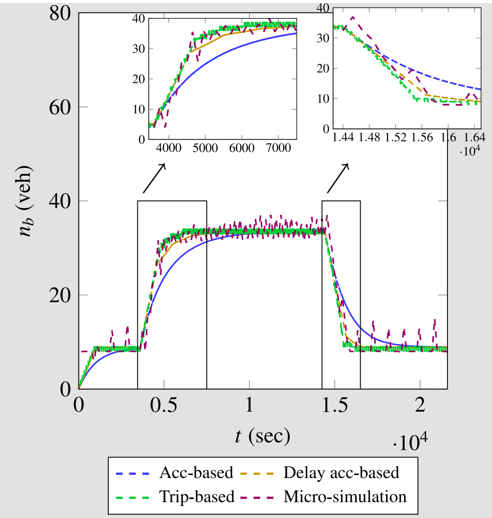
Single 3D MFD

Comparison of multimodal MFD extensions

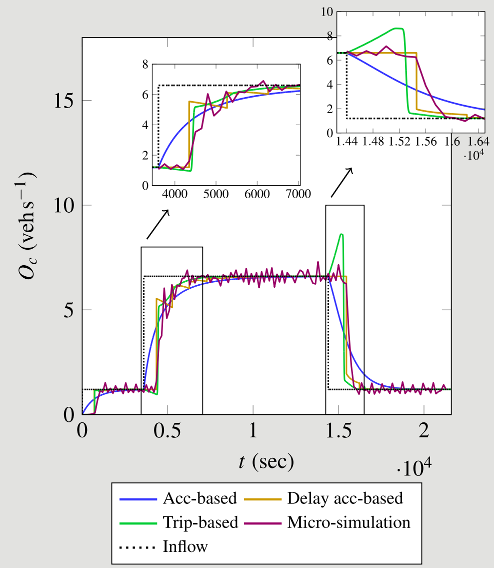
Segragated 3D MFD



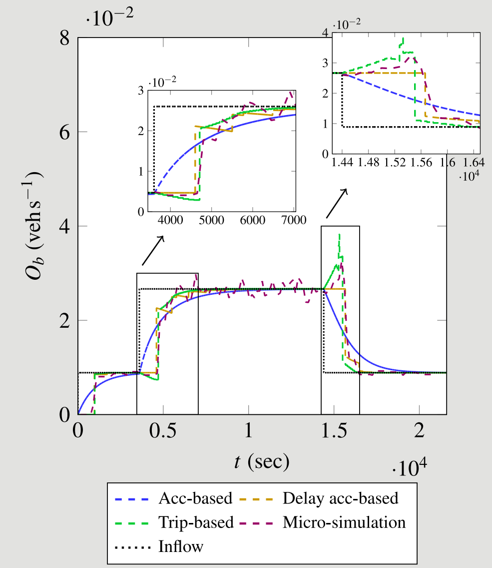
(a) Accumulation *vs.* time for cars.



(b) Accumulation *vs.* time for buses.



(c) Outflow *vs.* time for cars.

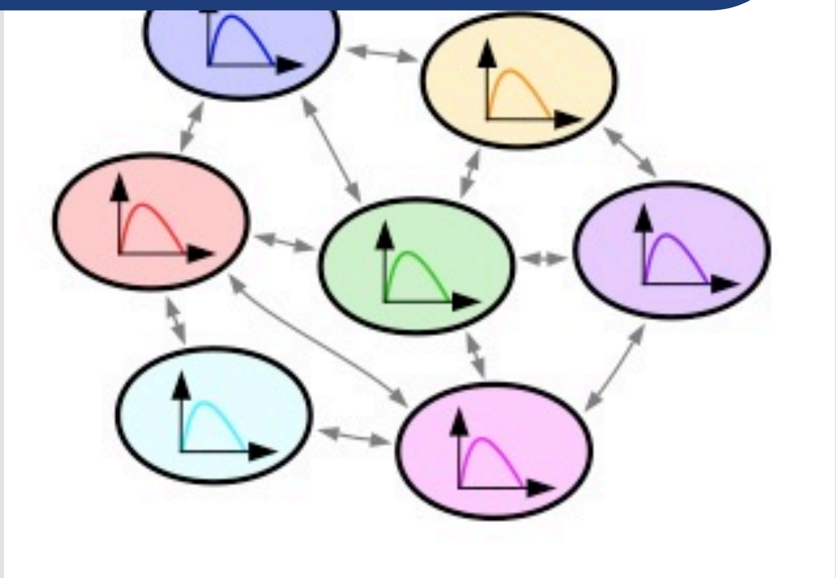


(d) Outflow *vs.* time for buses.

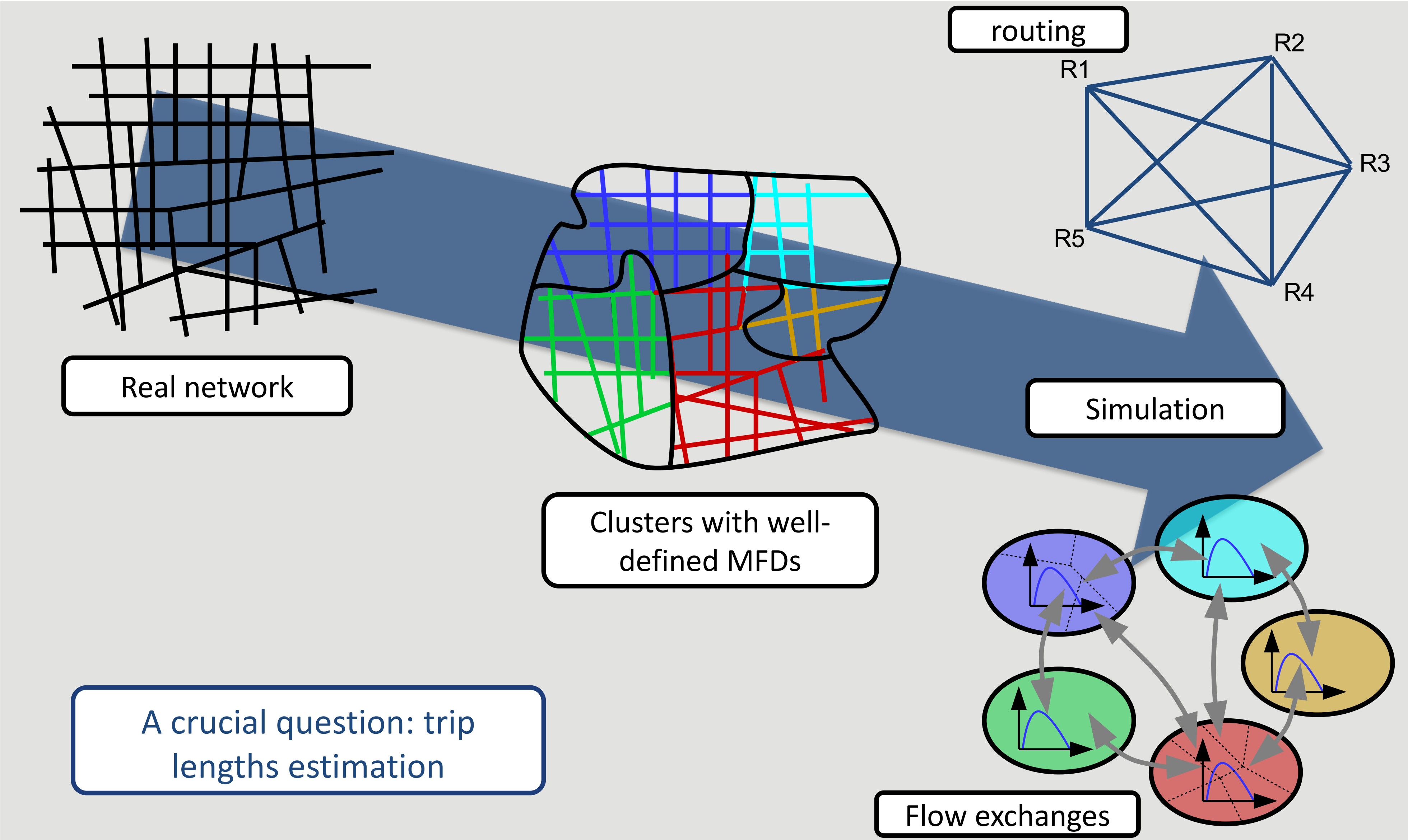
Multi-reservoir systems and traffic assignment

Batista, S., Leclercq, L., Menendez, M., 2021. Dynamic traffic assignment for regional networks with traffic-dependent trip lengths and regional paths. *Transportation Research part C*,

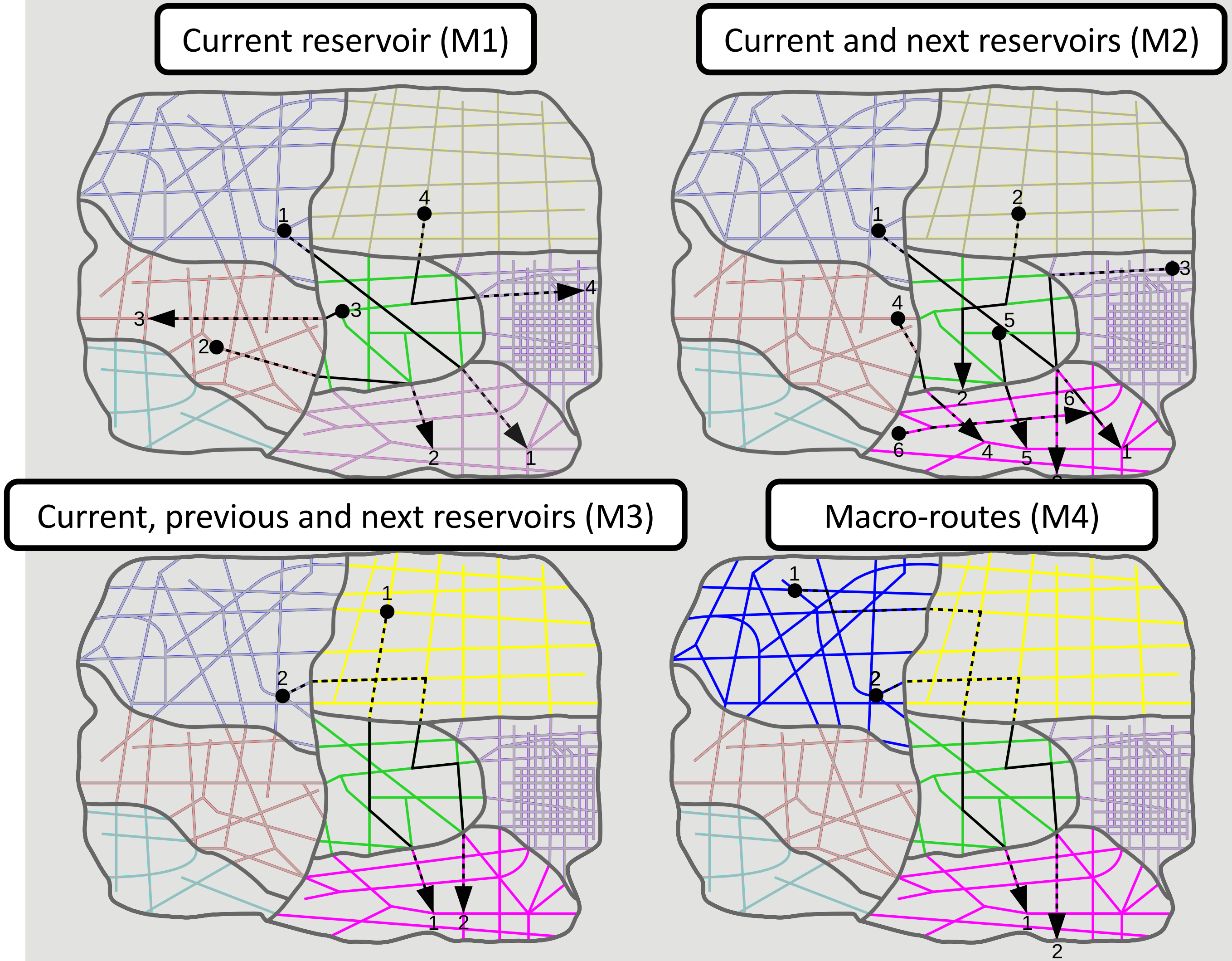
Batista, S.F.A., Leclercq, L., 2019. Regional dynamic traffic assignment framework for MFD multi-regions models. *Transportation Science*,



Multi-reservoir systems



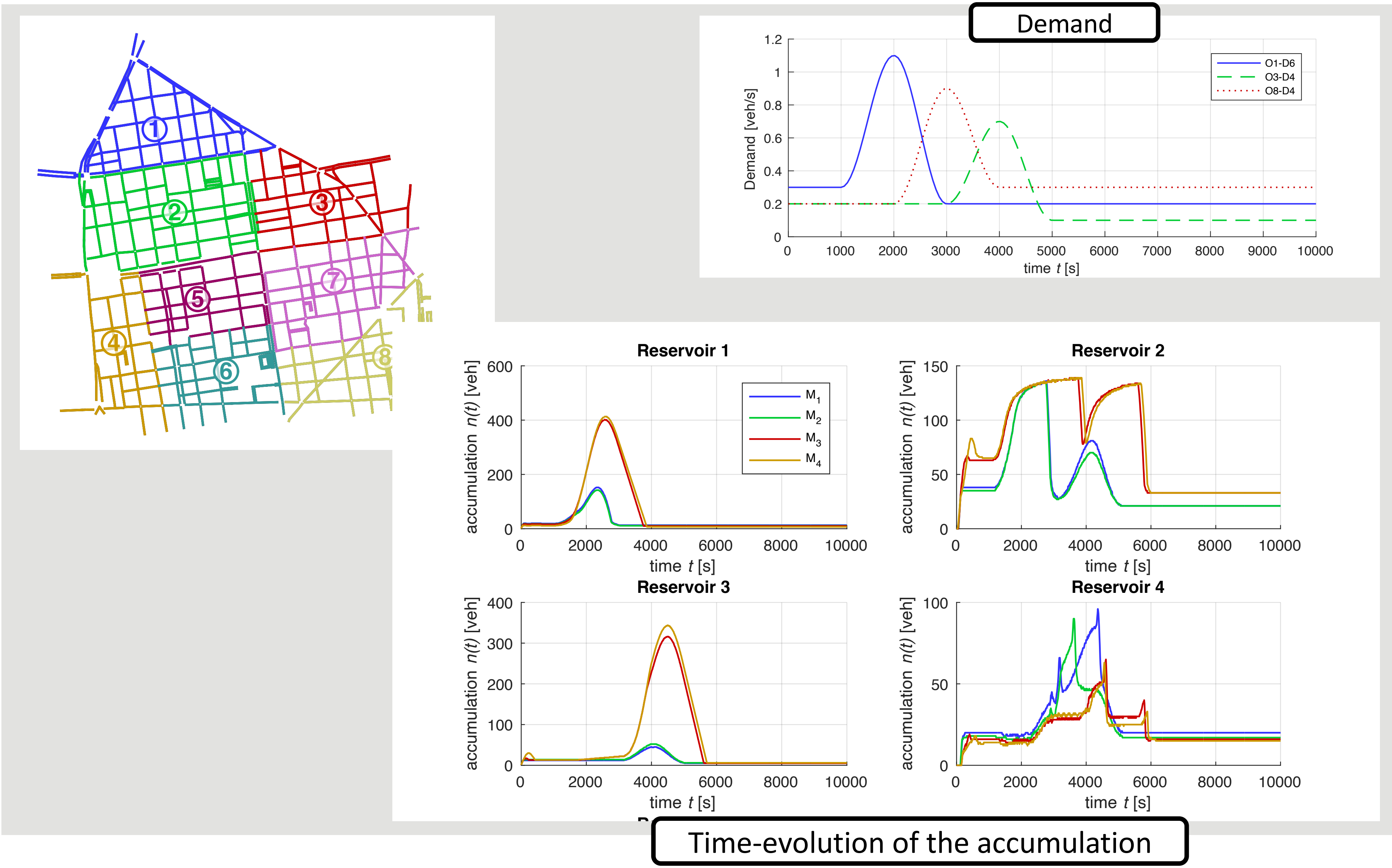
Estimation of the trip lengths



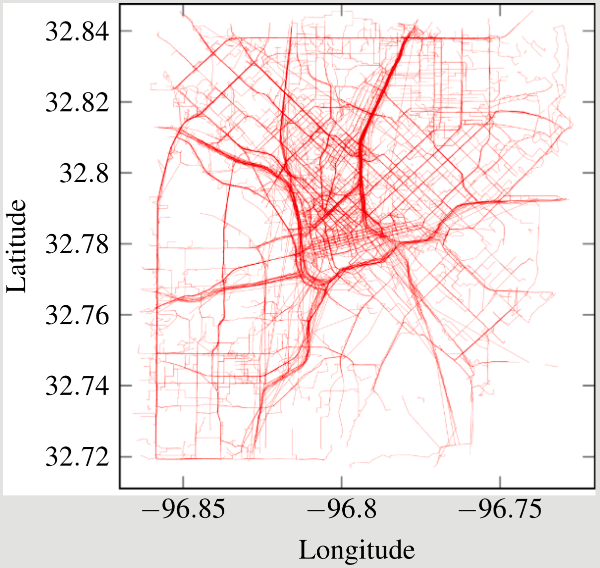
4 methods based on a single local od trip sampling (10000) and then aggregation

(Batista et al., 2018)

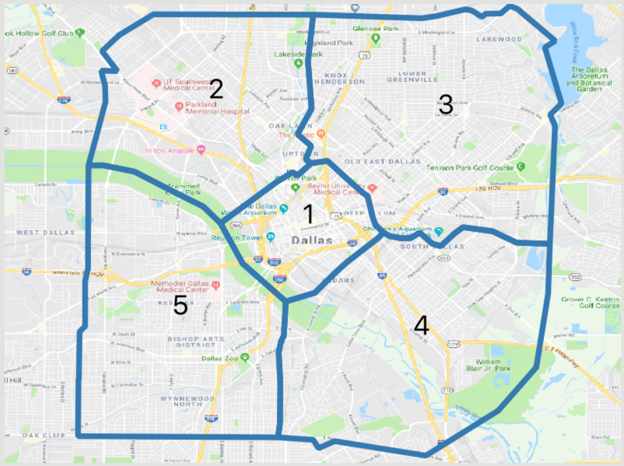
Impacts on the simulation results

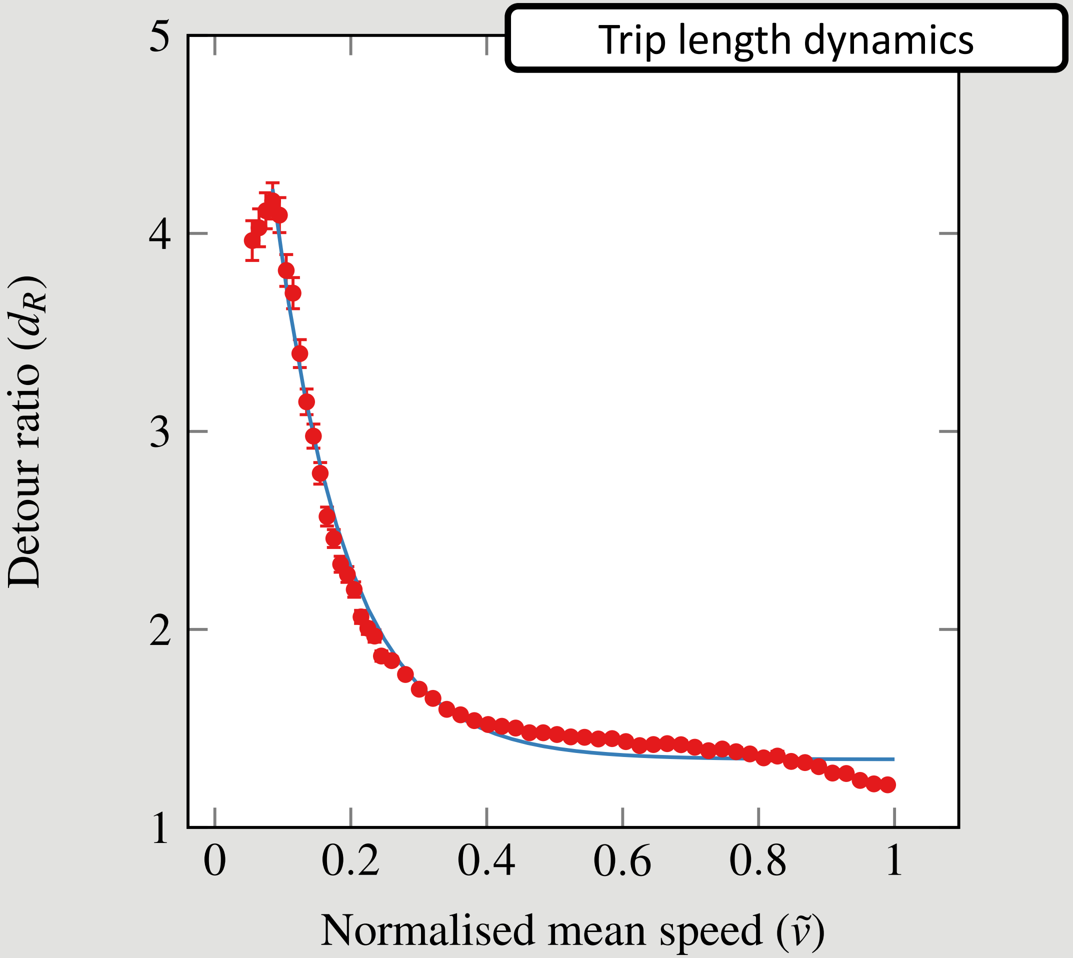


Trip lengths estimation - cellphone data



LBS data over Dallas city (US) – 6 months





Paipuri, M., Xu, Y., Gonzalez, M.C., Leclercq, L., 2020. Estimating MFDs, Trip Lengths and Path Flow Distributions in a Multi-region Setting Using Mobile Phone Data.

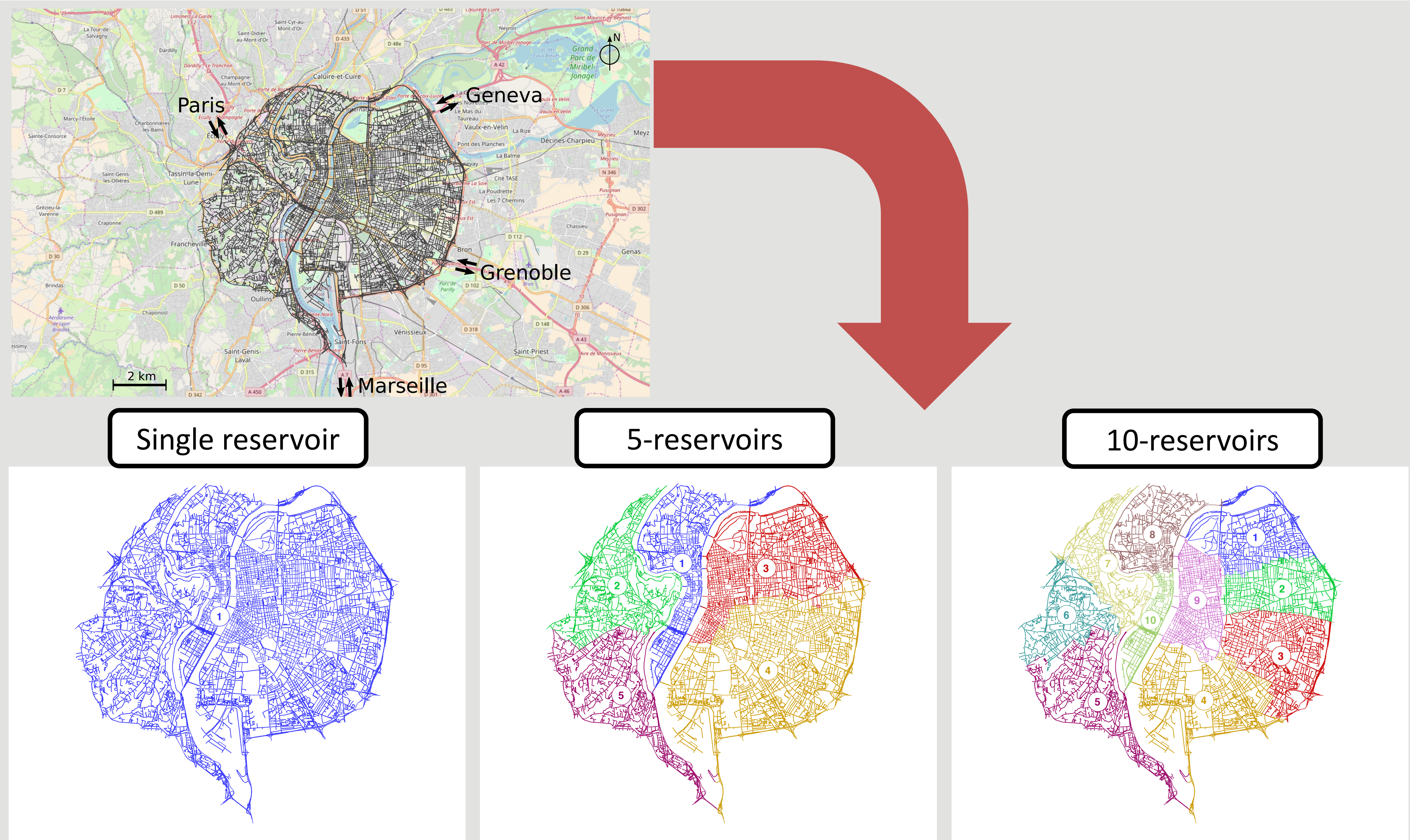
Berkeley UNIVERSITY OF CALIFORNIA

Application to the Lyon Metropolis

Mariotte, G., Leclercq, L., Batista, S.F.A., Krug, J., Paipuri, M., 2020. Calibration and validation of multi-reservoir MFD models: A case study in Lyon. *Transportation Research part B*.

MFDUrbaSim (A python open-source MFD simulator): https://github.com/licit-lab/MFDurbanSim

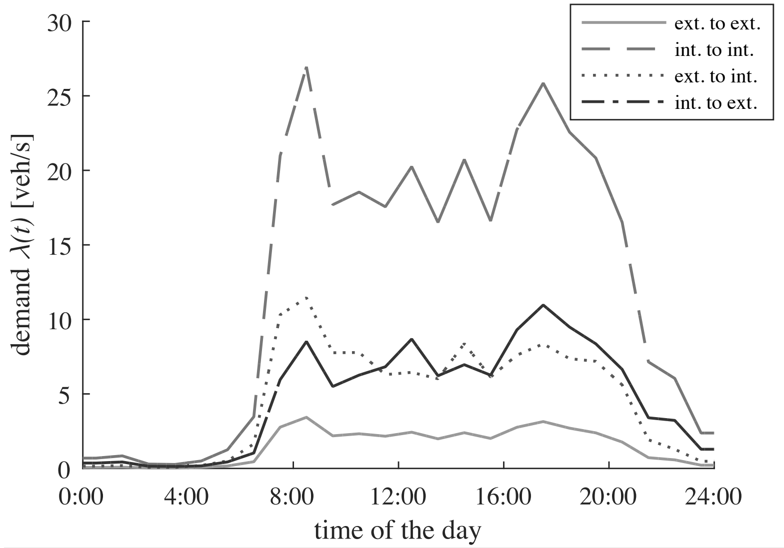
MFD simulation for Lyon metropolis



Demand estimation

Demographical partitioning of Lyon (IRIS zones)

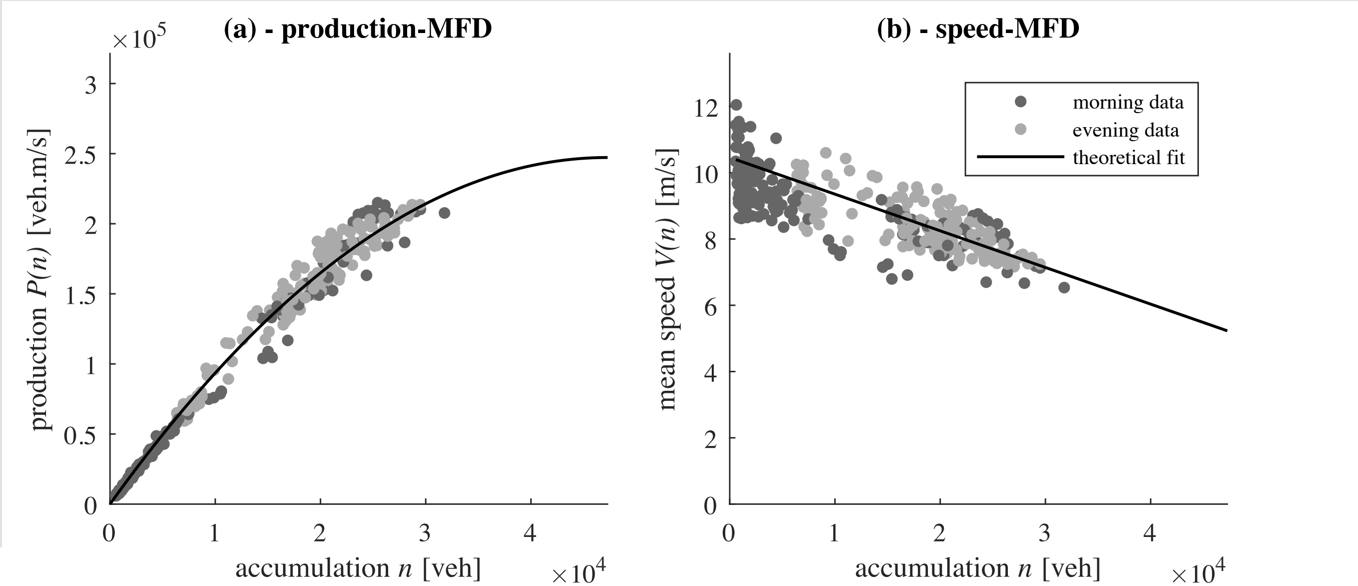
Smooth demand evolution for the whole city

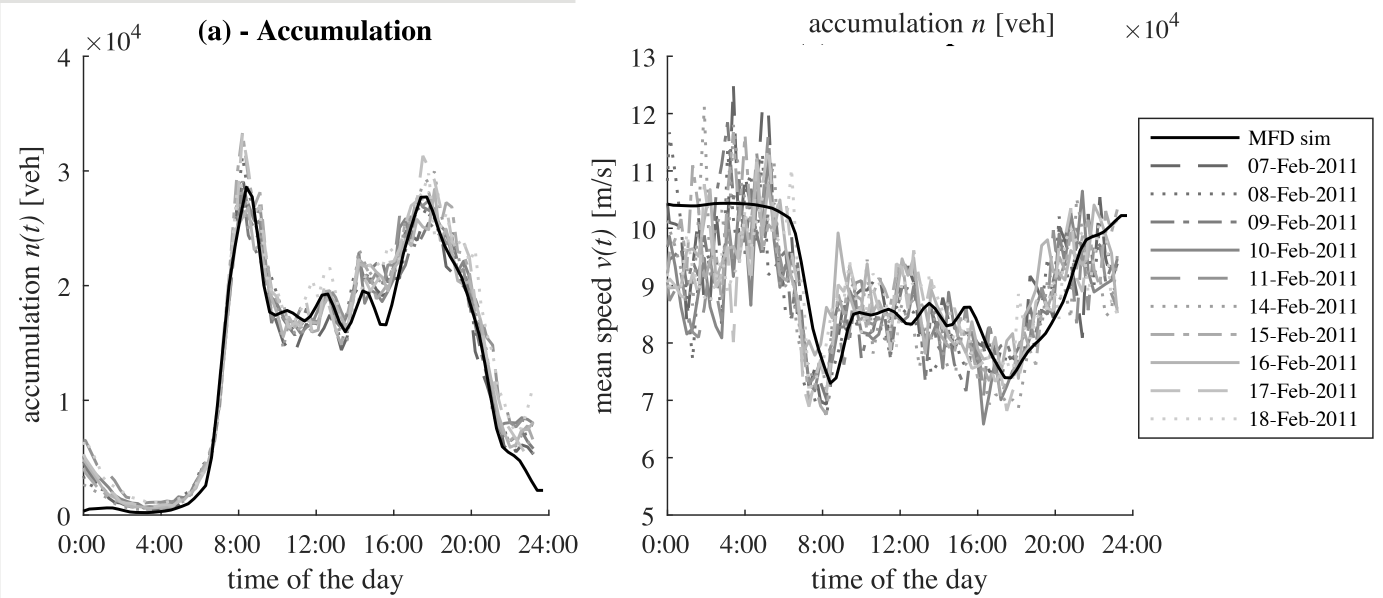


The OD matrix at the level of IRIS zones comes from Lyon authorities (Household survey 2015)

The 1-reservoir case

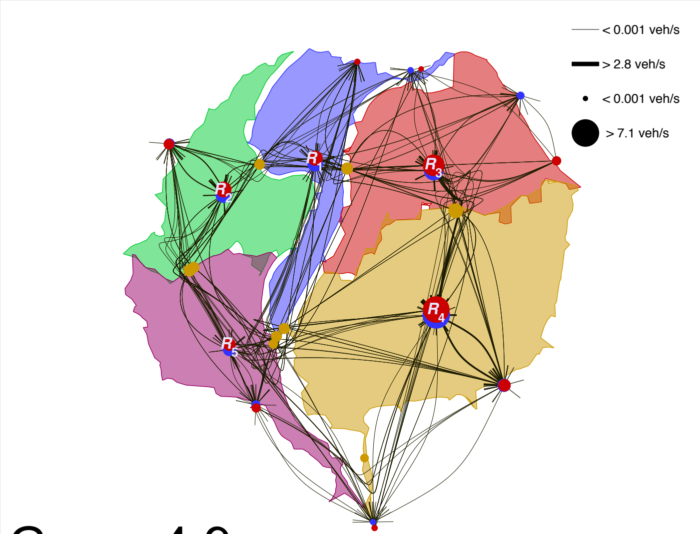
MFD calibration





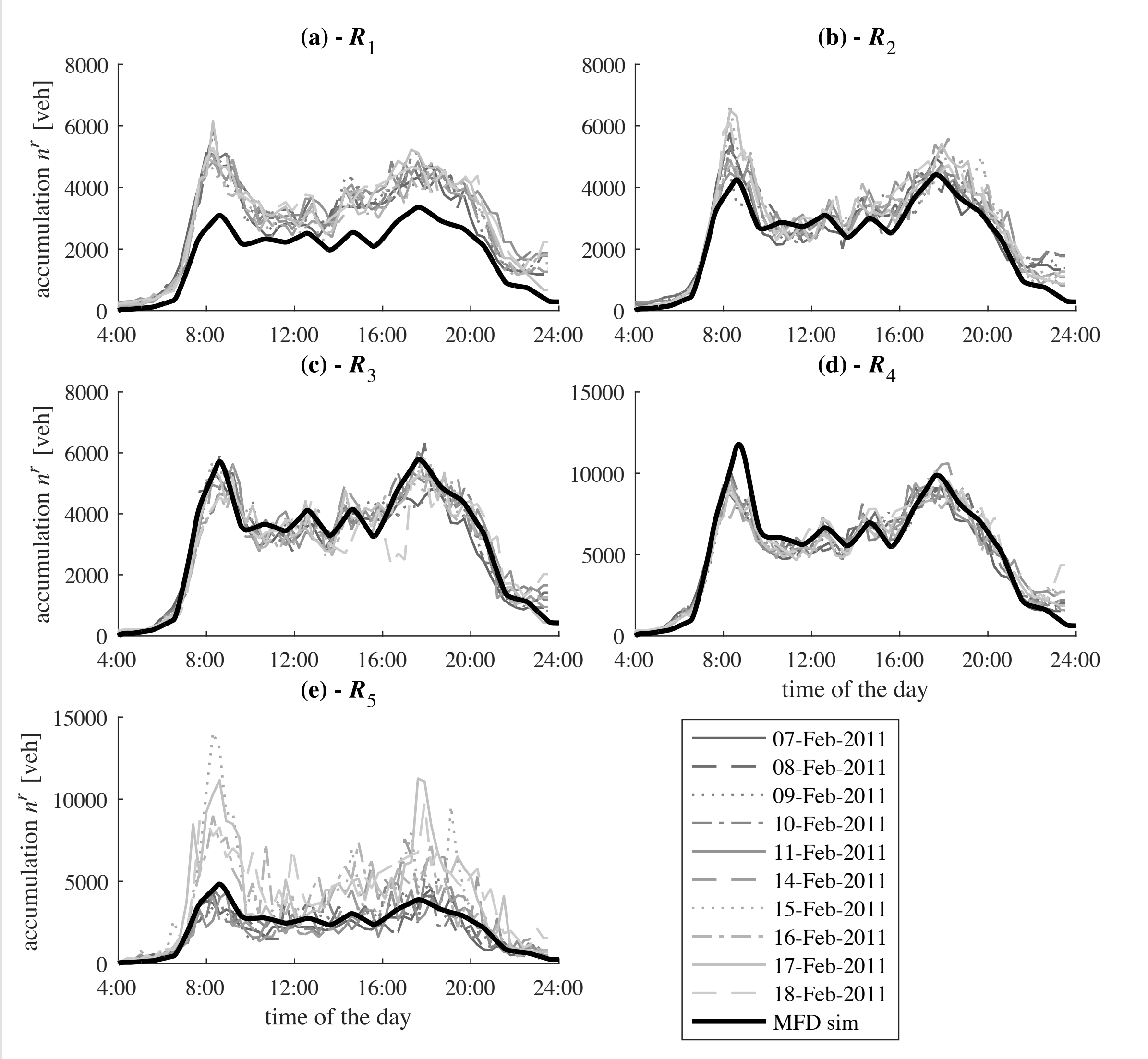
Simulation results

The 5-reservoir case – user equilibrium

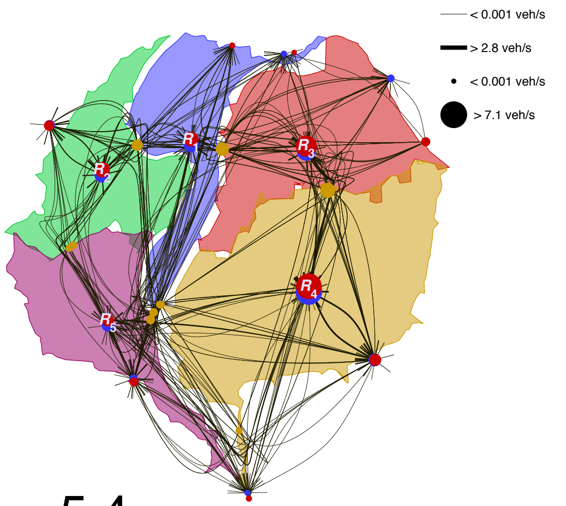


Gap = 4.9

3 % of OD with a Gap^{od} > 0.2

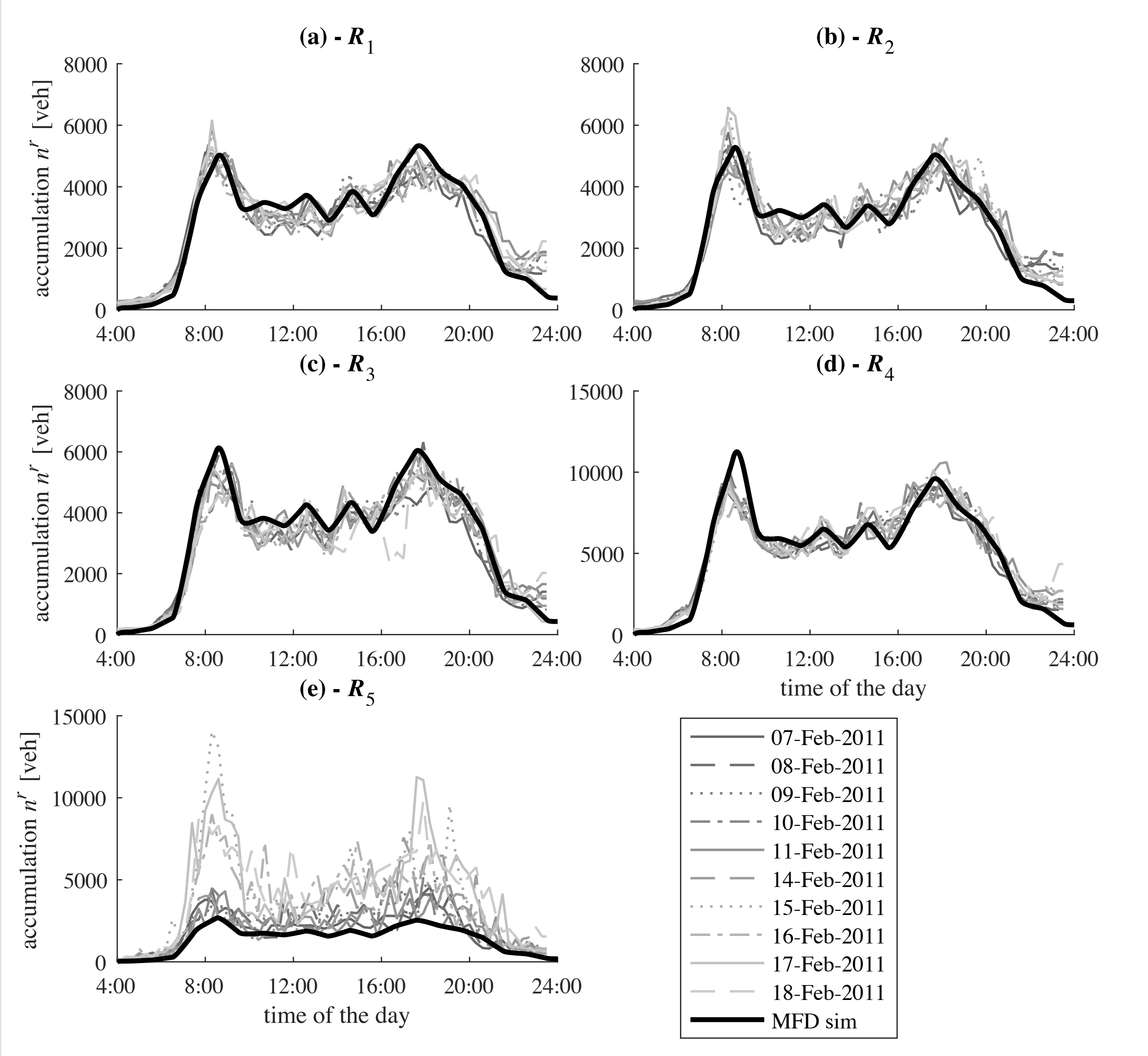


The 5-reservoir case – best fit

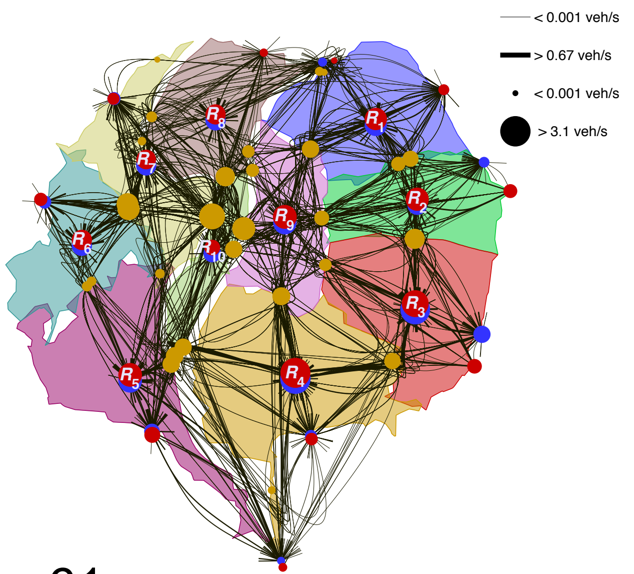


Gap = 5.4

7 % of OD with a Gap^{od} > 0.2

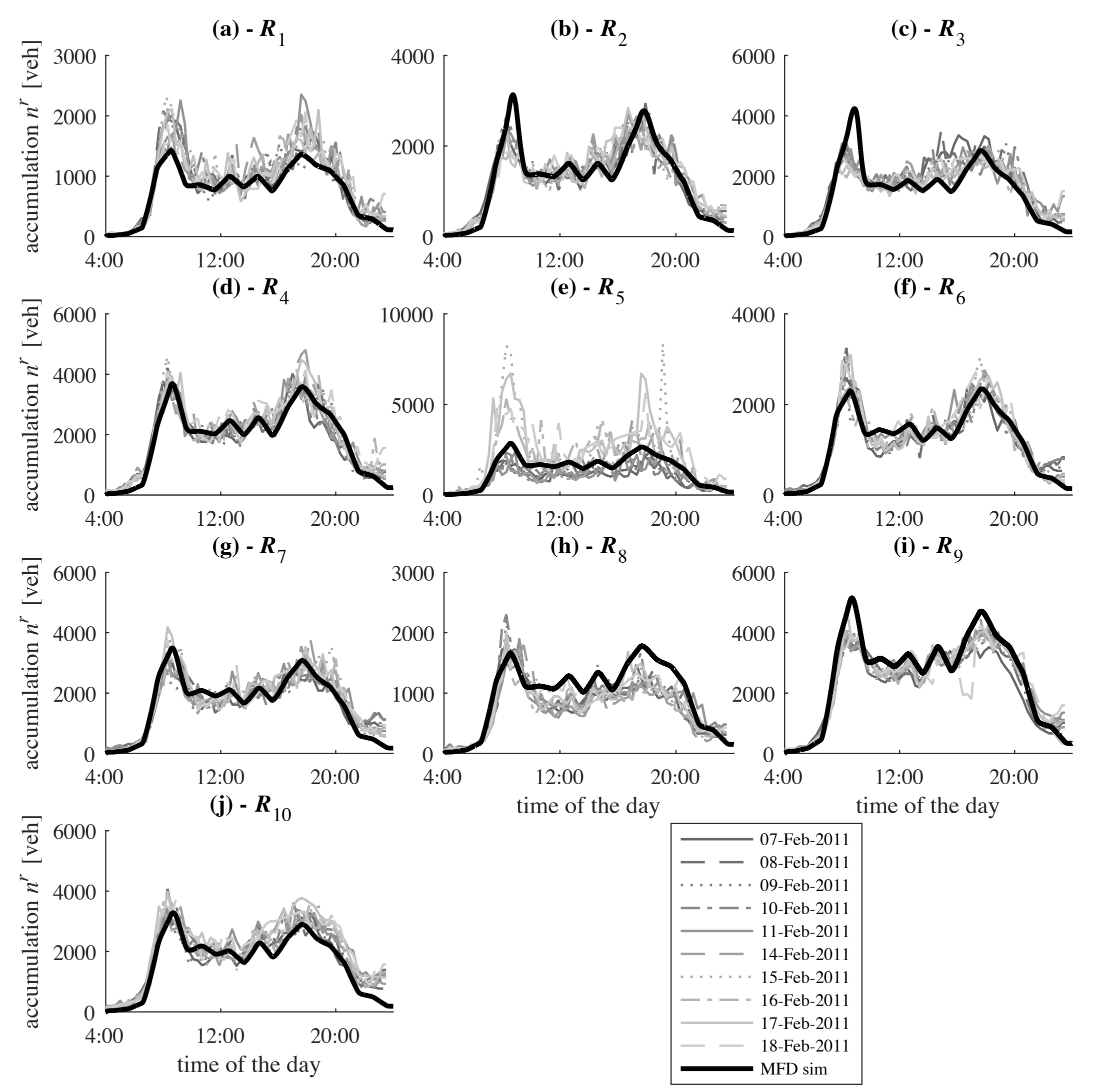


The 10-reservoir case – best fit



Gap = 61

31 % of OD with a Gap^{od} > 0.2



Assessing ride-sharing services

Alisoltani, N., Leclercq, L., Zargayouna, M., 2021. Can dynamic ride-sharing reduce traffic congestion? *Transportation Research part B.*

Test Case – Northern Lyon

Test cases

Lyon 6 + Villeurbanne

Scale of 25 km^2

62450 requests

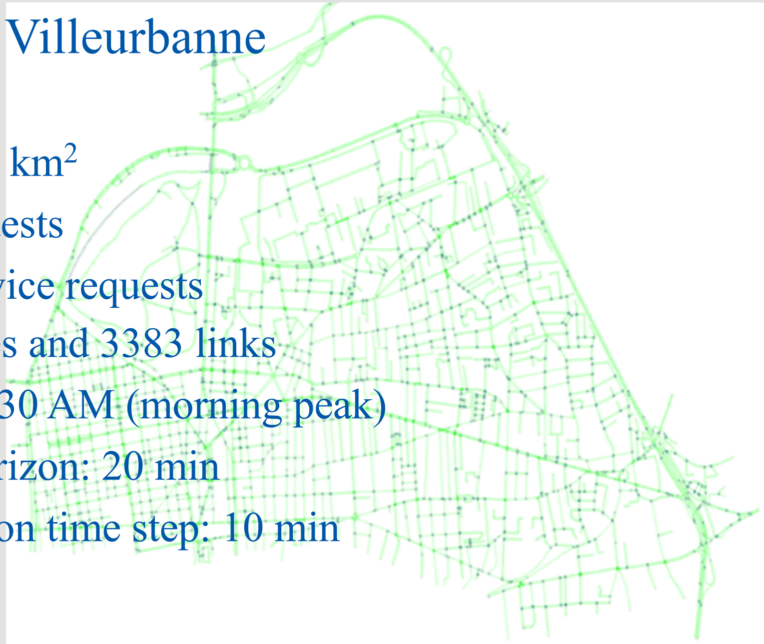
11235 Service requests

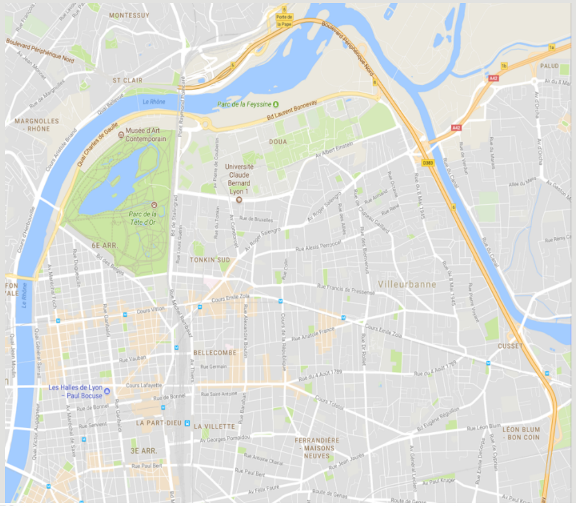
1,883 nodes and 3383 links

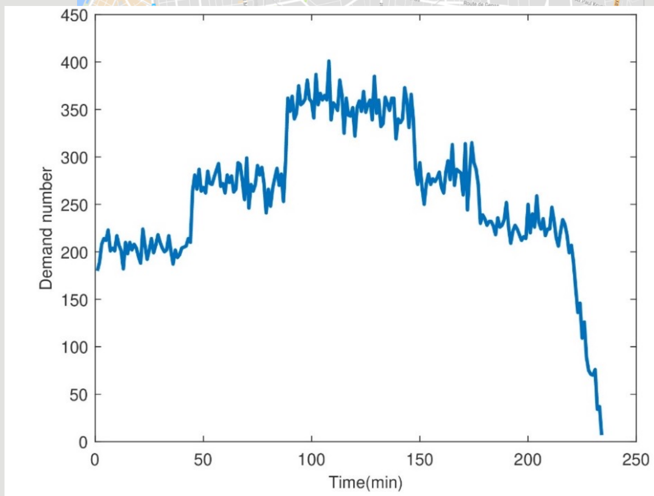
6:30 to 10:30 AM (morning peak)

Rolling horizon: 20 min

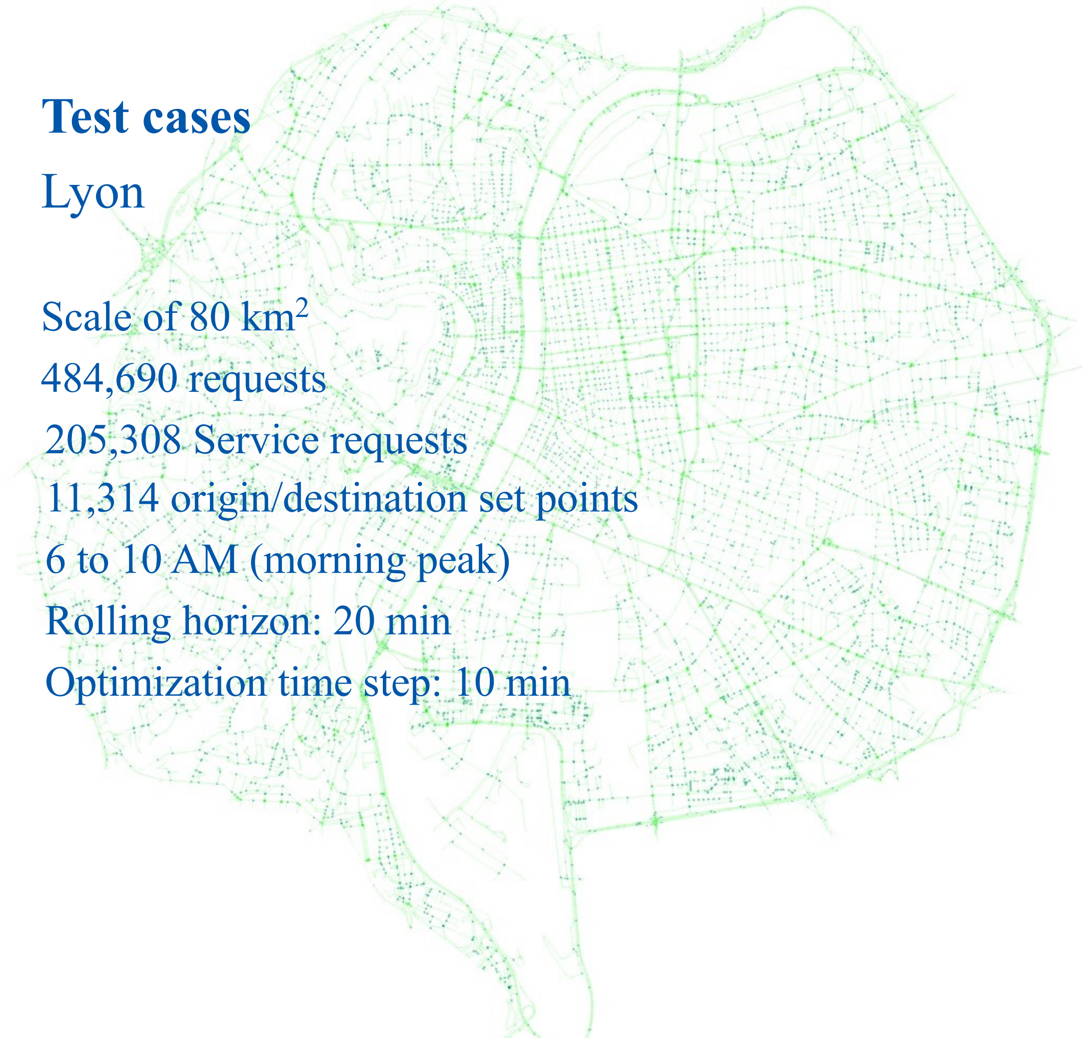
Optimization time step: 10 min







Test case – Full Lyon



Test cases

Lyon

Scale of 80 km^2

484,690 requests

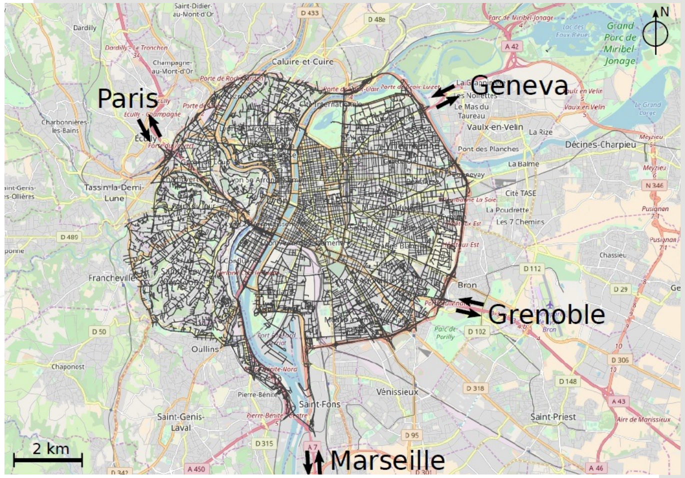
205,308 Service requests

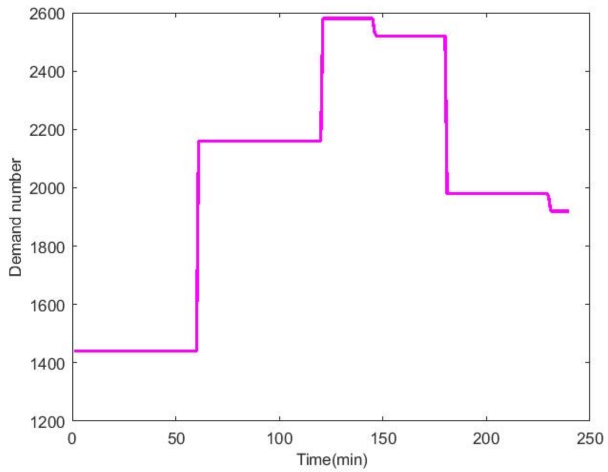
11,314 origin/destination set points

6 to 10 AM (morning peak)

Rolling horizon: 20 min

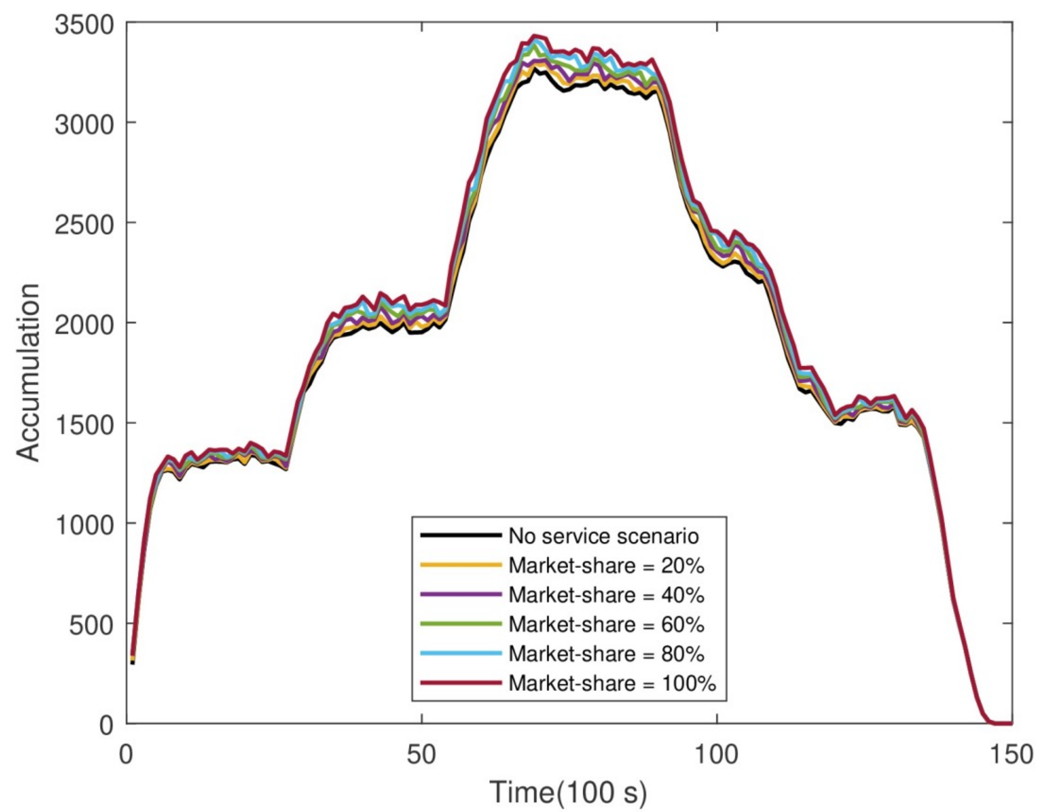
Optimization time step: 10 min





Traffic dynamics for different market share

Northern Lyon



Traffic situation for the number of sharing 0 with different market-shares

Increase in travel time

Market-share 100%: 5.5%

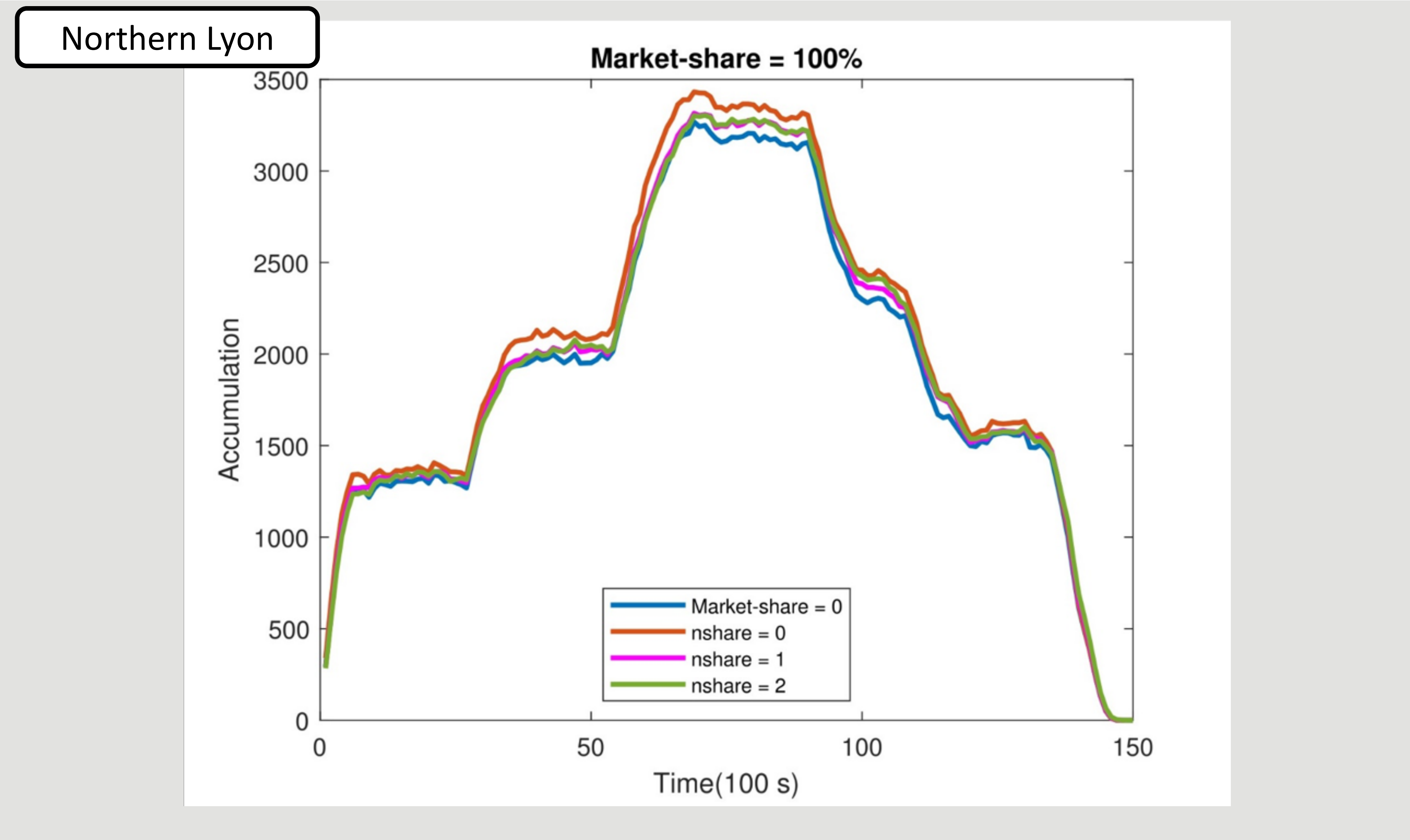
Market-share 80%: 4.4%

Market-share 60%: 3.3%

Market-share 40%: 2.3%

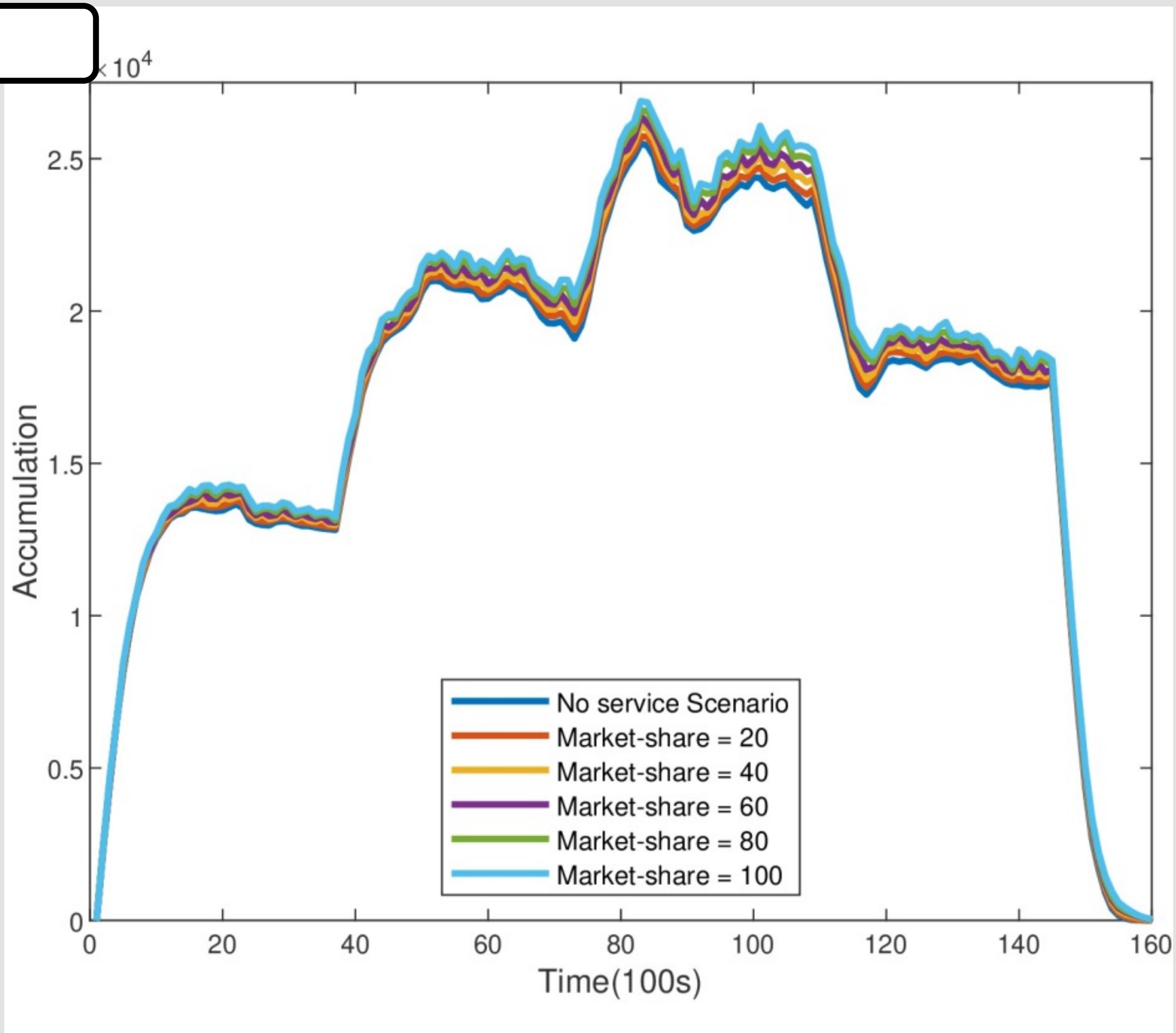
Market-share 20%: 1.1%

Traffic dynamics for different sharing level



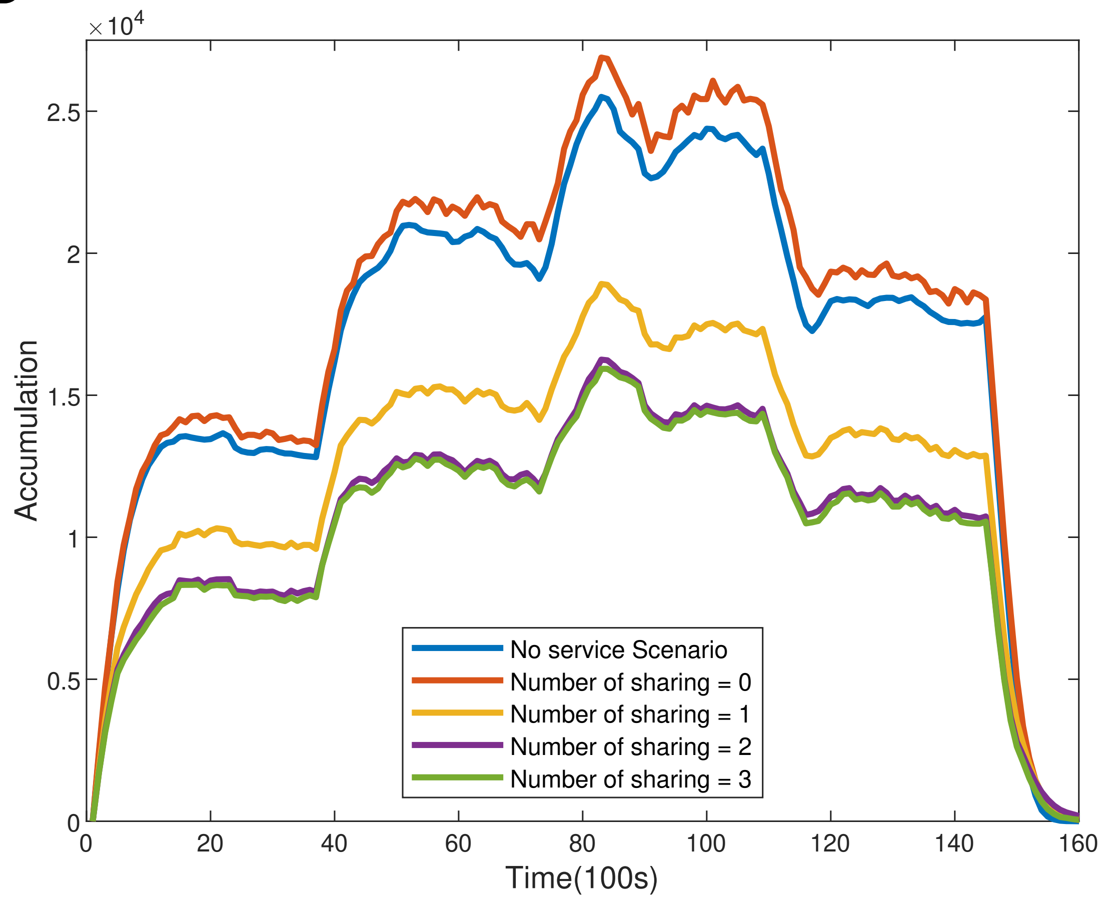
Application to full Lyon Metropolis (1)

Full Lyon



Application to full Lyon Metropolis (2)

Full Lyon

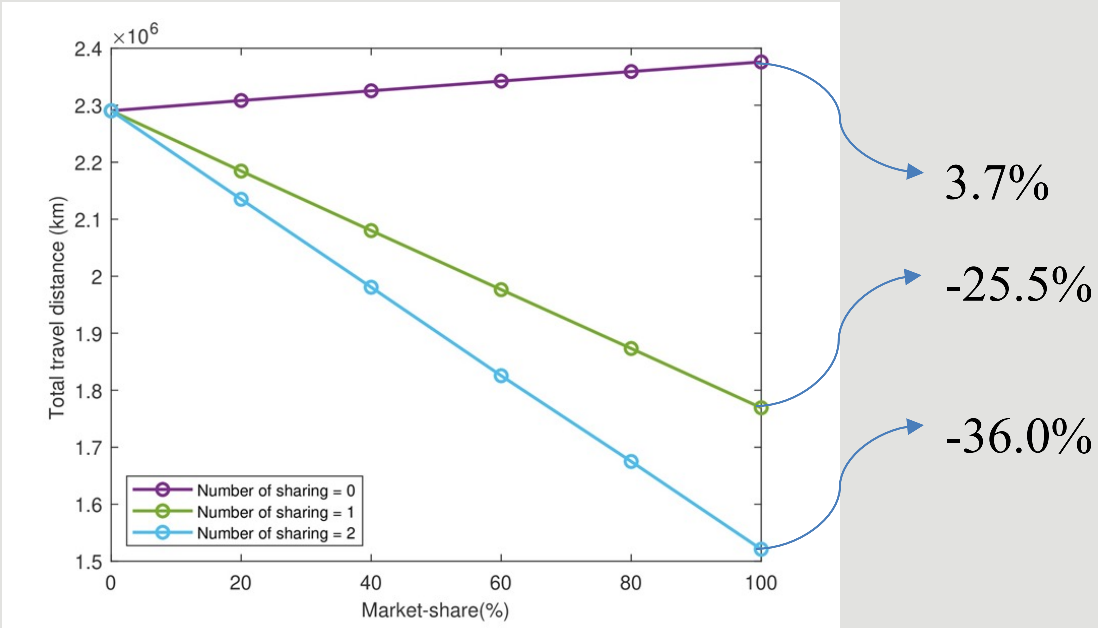


Application to full Lyon Metropolis (3)

Number of sharing	Number of trips	Number of cars
0	205124	17102
1	105745	9489
2	72160	6826
3	69790	6595

Impact of dynamic ride-sharing on large-scale network

Market-share



Total travel distance for all the cars for the number of sharing 0, 1 and 2 with different market-shares

Impact of dynamic ride-sharing on large-scale network

Capacity of vehicles

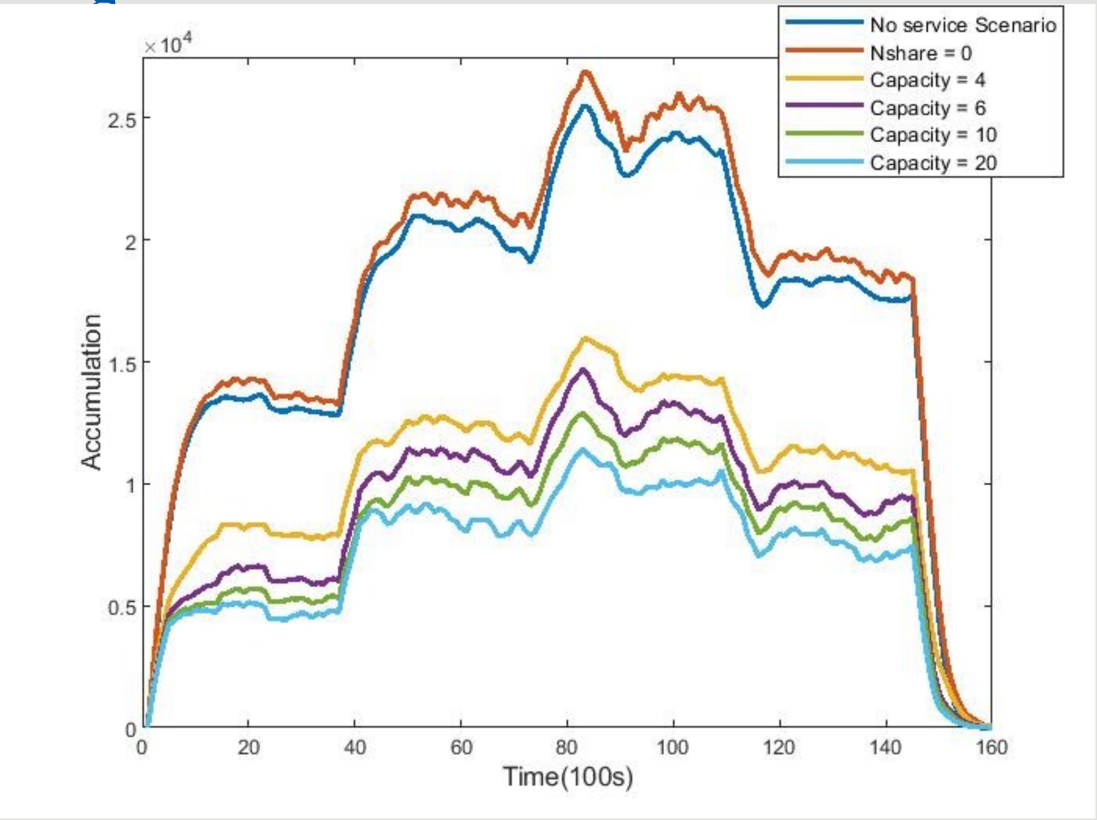
Regular vehicle: capacity = 4, nshare = 3

Big vehicle: capacity = 6, nshare = 5

Van-pooling: capacity = 10, nshare = 9

Shuttle-sharing: capacity = 20, nshare = 19

Configuration	Shared vehicles	
	Number of trips	Number of cars
MS: 100%		
Capacity = 4	69790	6595
Capacity = 6	63304	5714
Capacity = 10	46448	4253
Capacity = 20	30004	2785

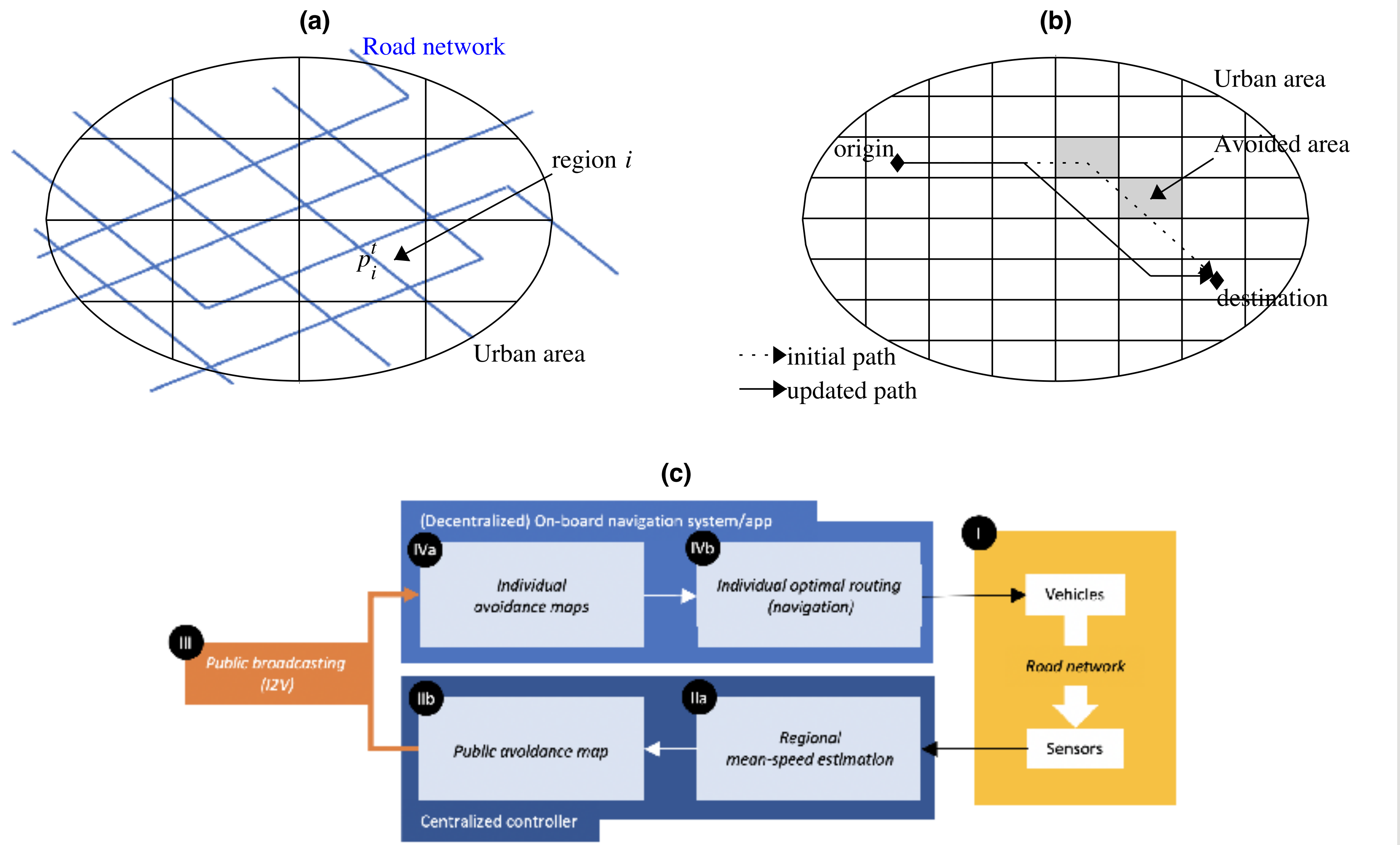


Traffic situation for different vehicle capacity (market-share = 100%)

An optimal route guidance strategy based on avoidance maps

(Leclercq, L., Ladino, A., Becarie, C., 2021. Enforcing Optimal Routing Through Dynamic Avoidance Maps. *Transportation Research part B*,)

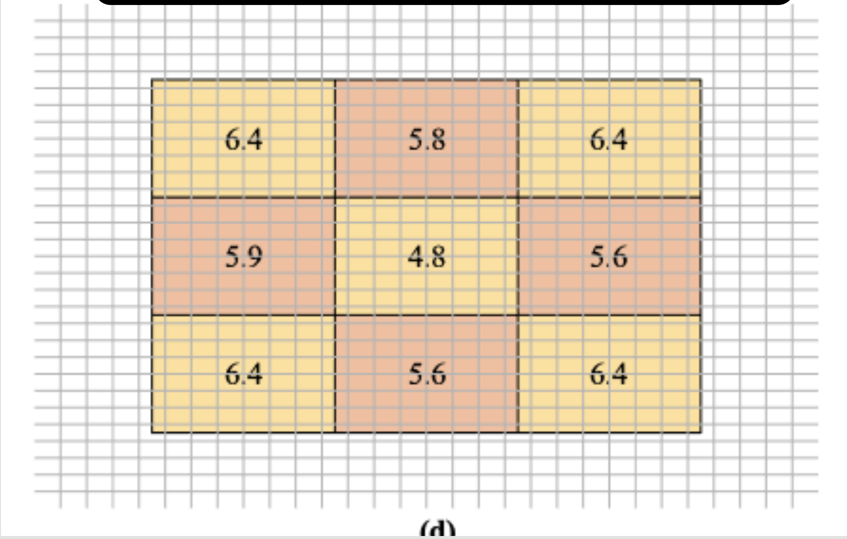
Route guidance based on avoidance maps



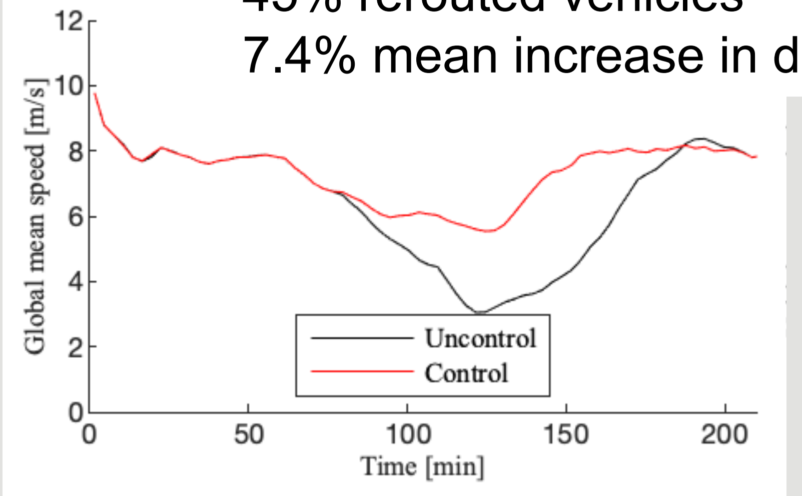
Patent filing under review

Assessment on a toy network

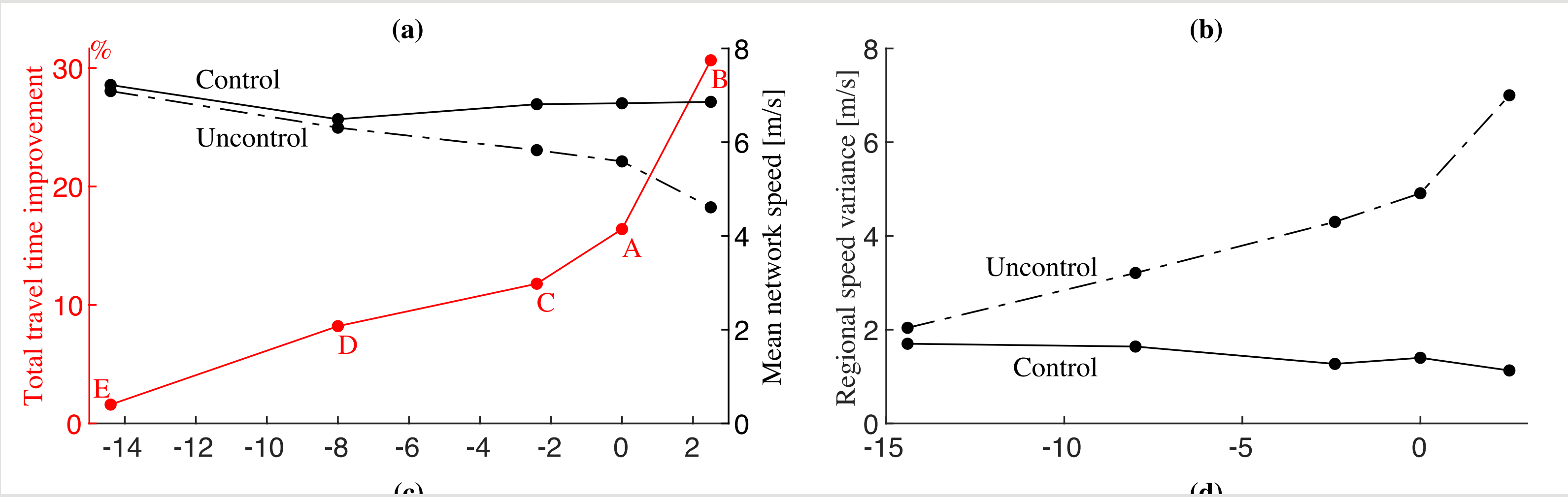
Manhattan network



45% rerouted vehicles
7.4% mean increase in distance

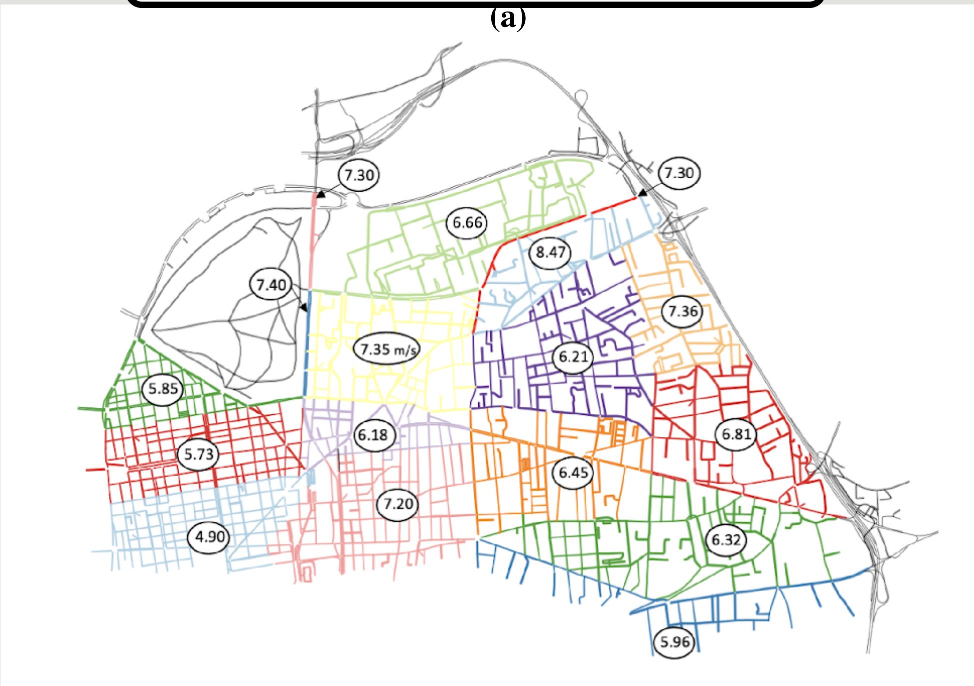


Control efficiency

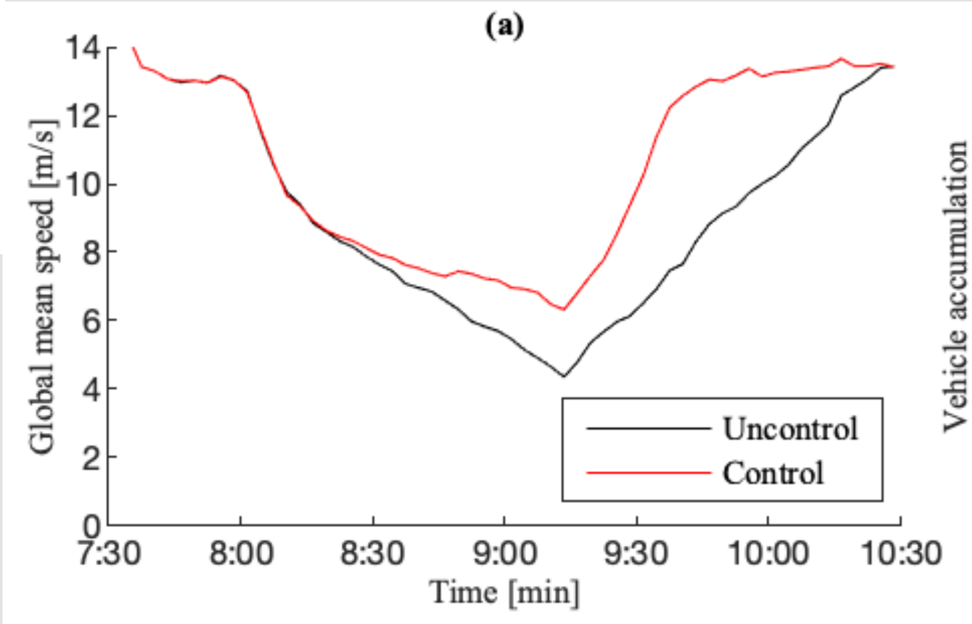


Assessment on a real network

Northern Lyon network



ERC PoC MAGnUM+
(prototype and first field tests)



Special thanks to the MAGnUM team!

European Commission

MAGnUM

European Research Council

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

Thank you for your attention

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@erc_magnum