Calibrating and validating multi-region multimodal MFD models

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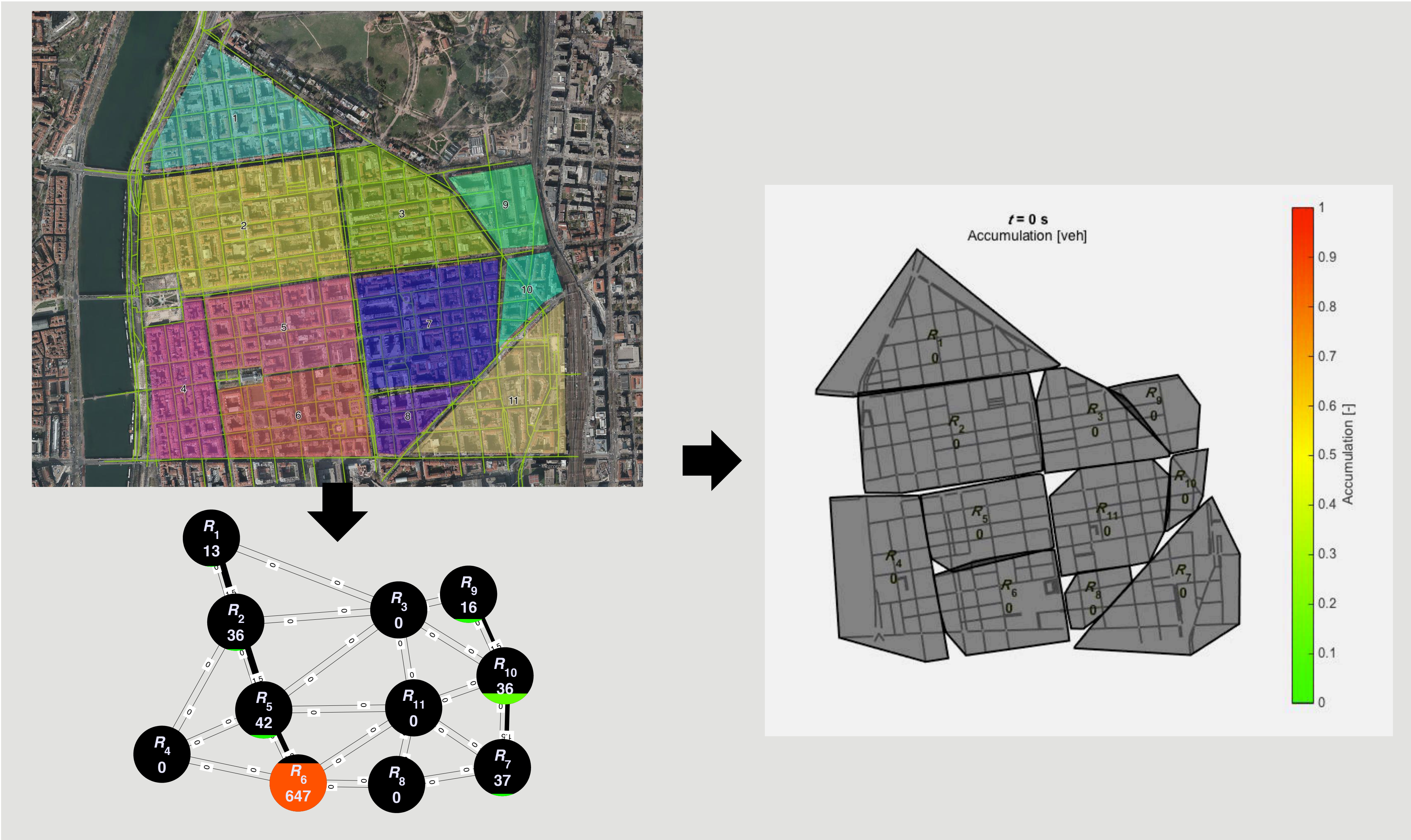
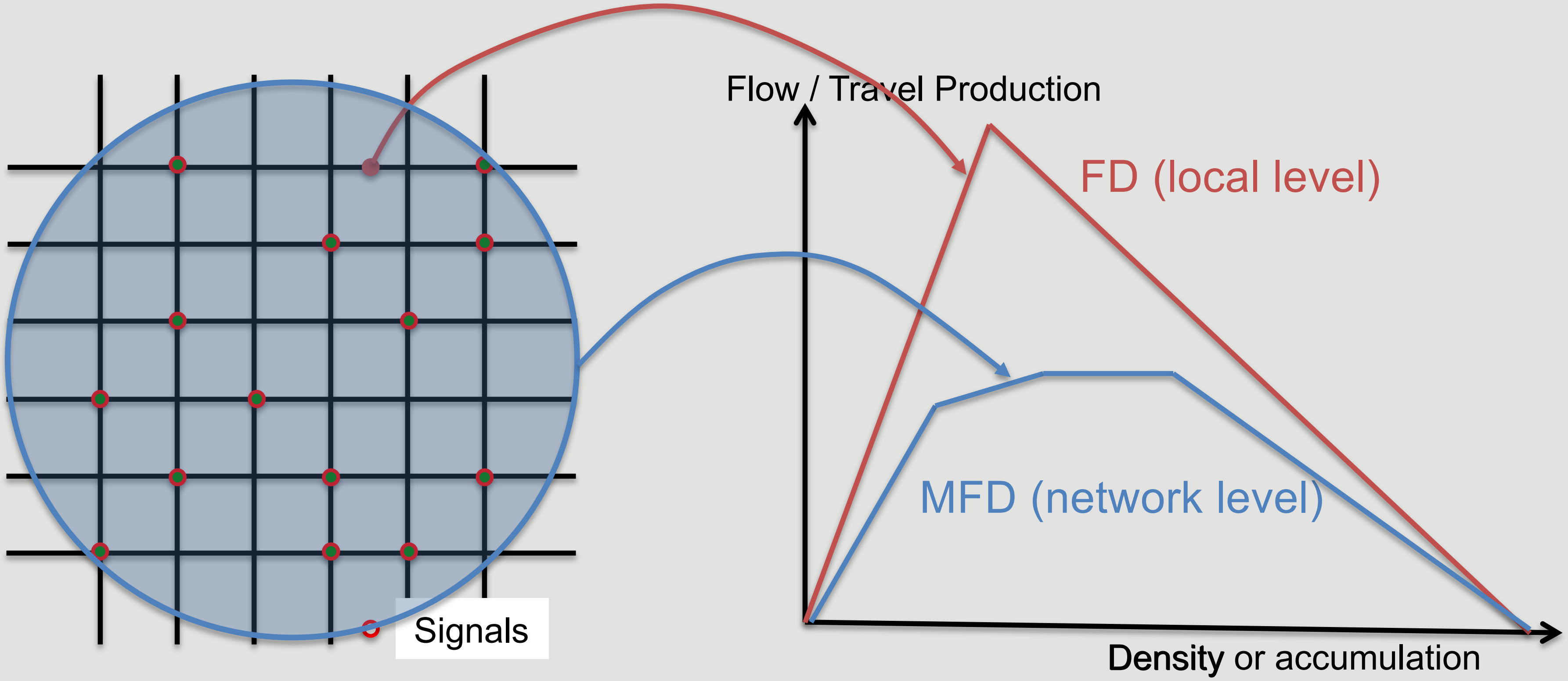
Large-scale dynamic urban simulation



MFD definition



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

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

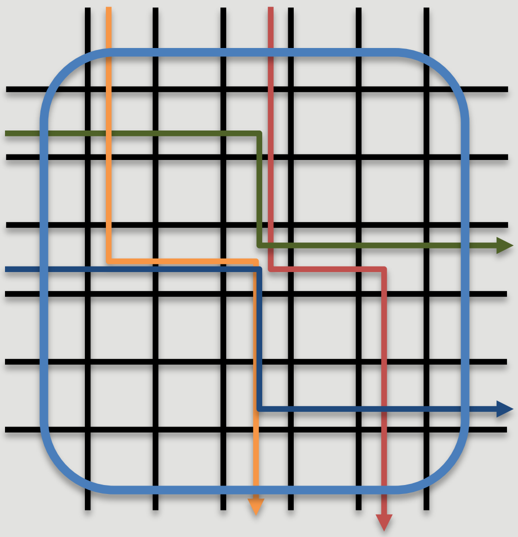
Mean flow Q

Similar in a link

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

But not in a network

Outflow Q_{out}



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

Little's formula
(requires steady-state)

Estimation from loop detectors

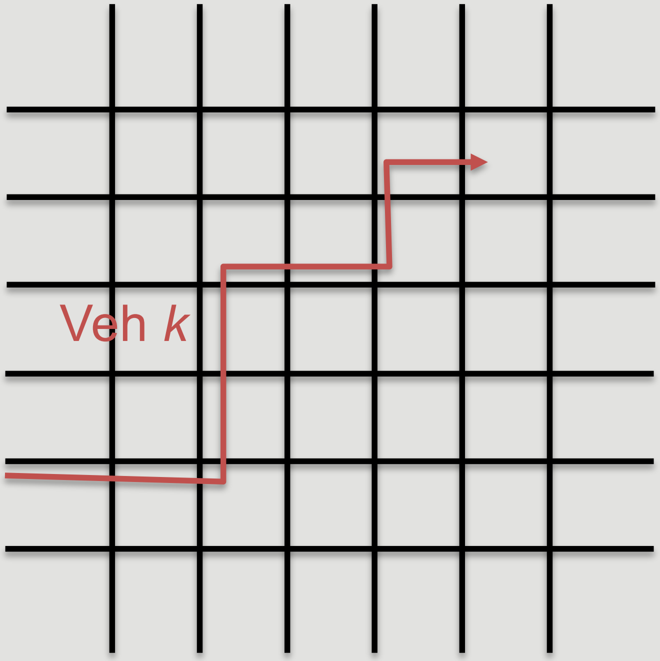
For the equipped network:

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

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

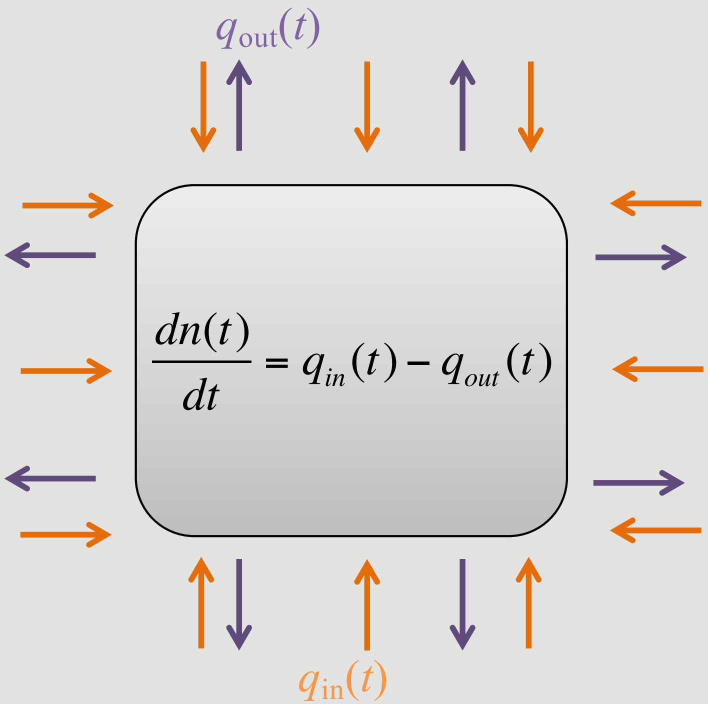
Travel time related to the Δt period

$$P = V^* N$$

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

The existing formulations for NMFD models

The accumulation-based (bathtub) model



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

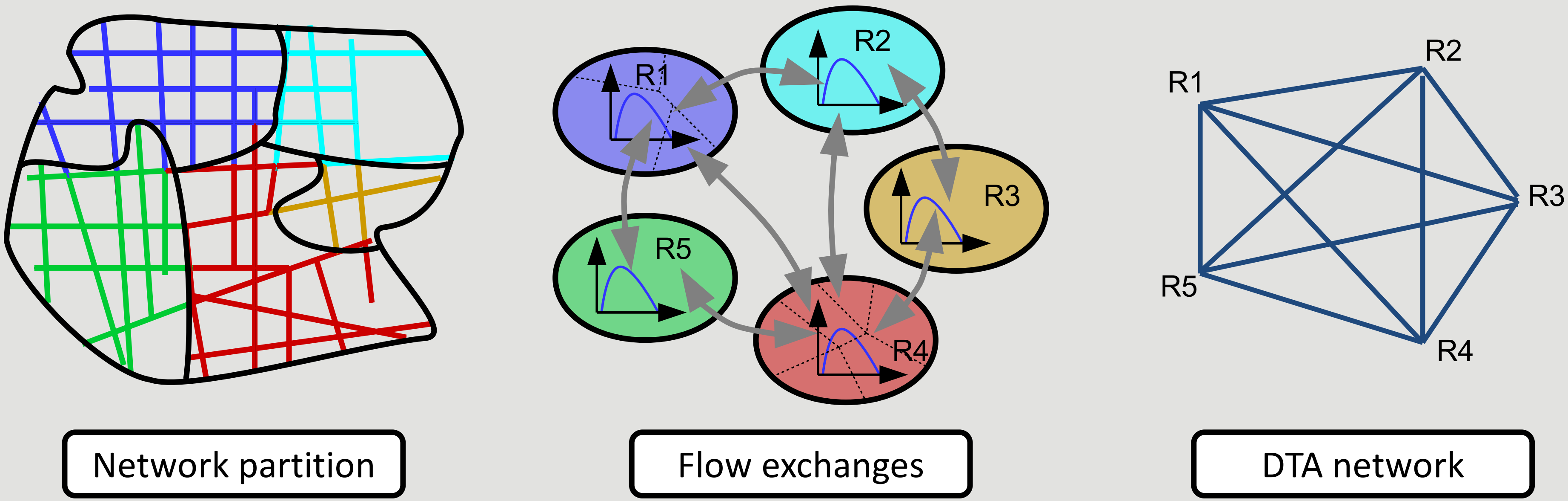
Production-MFD

$$q_{out}(t) = G\big(n(t)\big) = \frac{P(n(t))}{L}$$

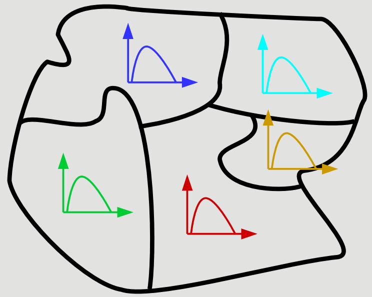
Outflow-MFD

Average trip length

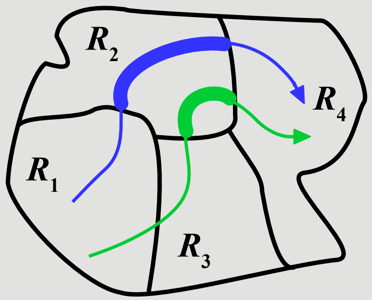
Multi-reservoir systems



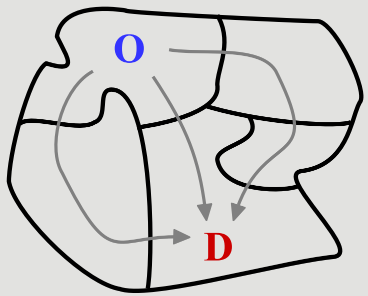
Calibration of multi-reservoir systems



- MFD



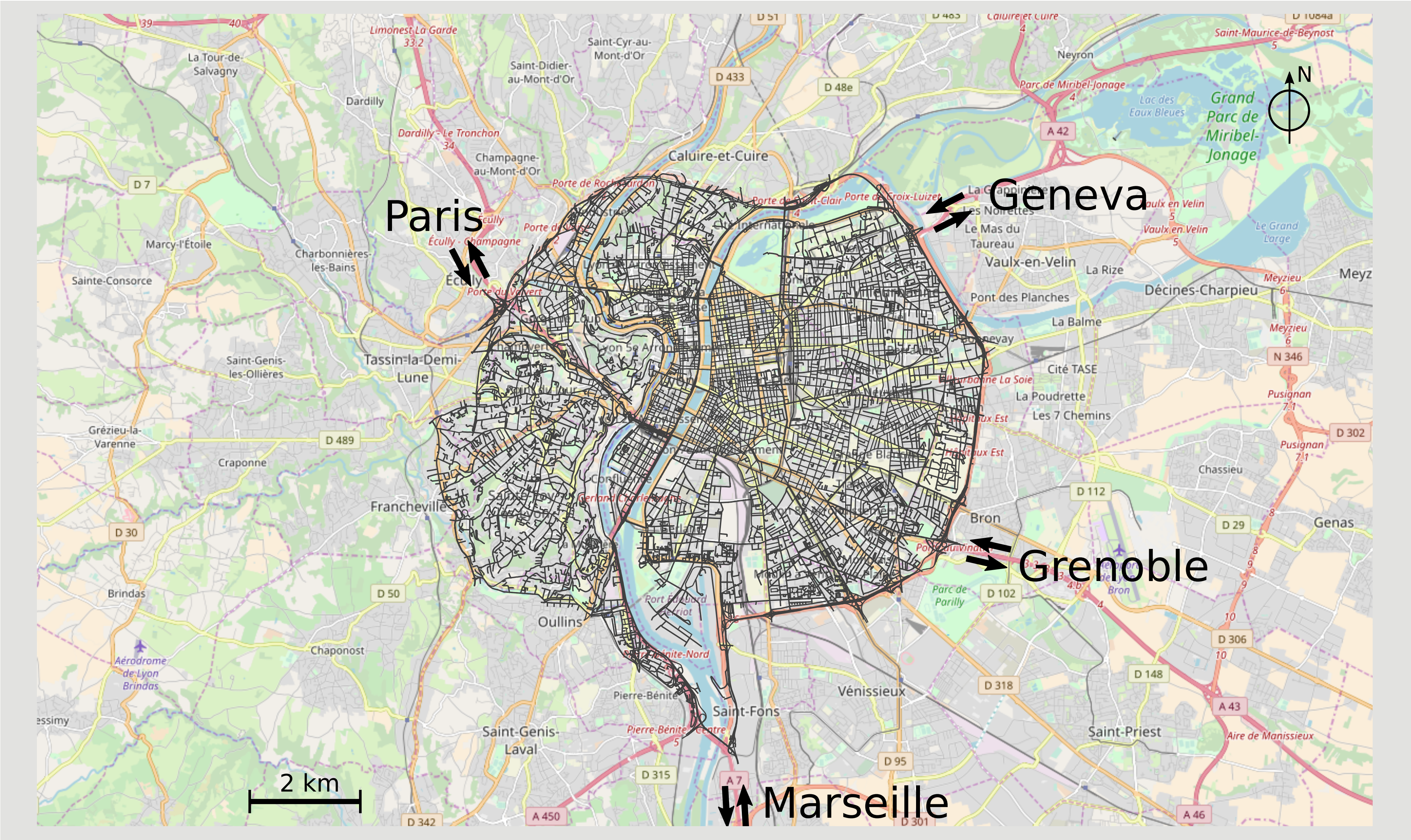
- Trip lengths



- Path flow distributions

Application to the Lyon Metropolis

The Lyon network (1)



The Lyon network (2)

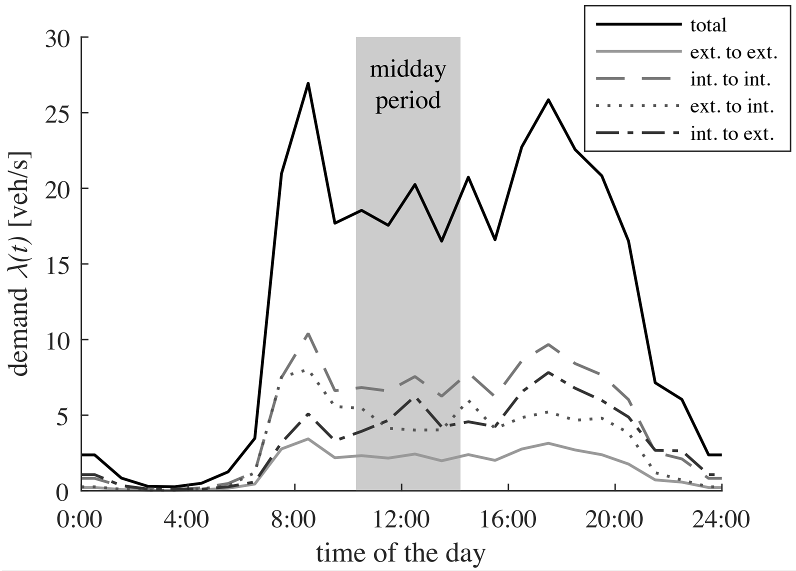
3 clustering case studies:

1-reservoir, whole city 5-reservoir 10-reservoir

Demand estimation

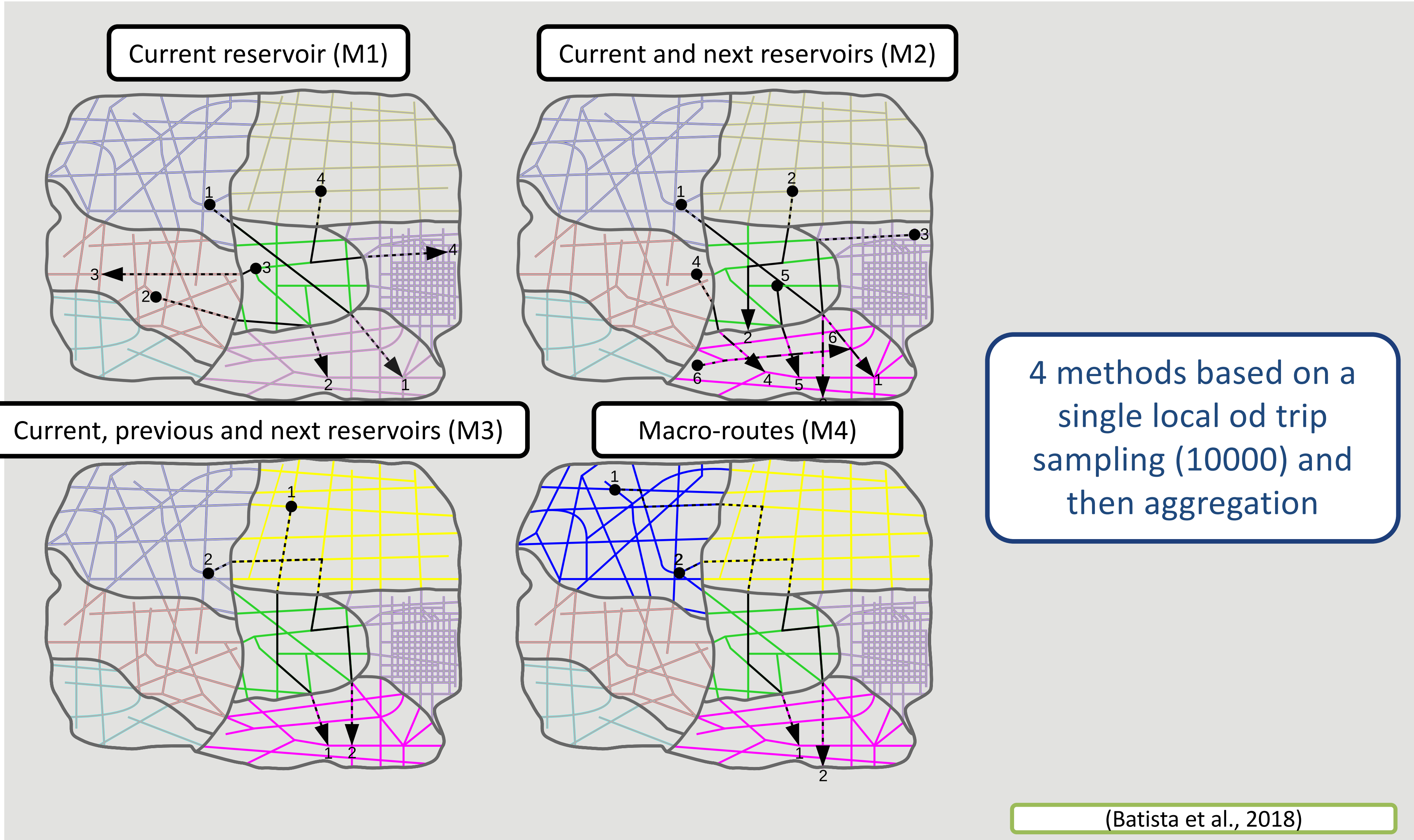
Demographical partitioning of Lyon (IRIS zones)

Smooth demand evolution for the whole city

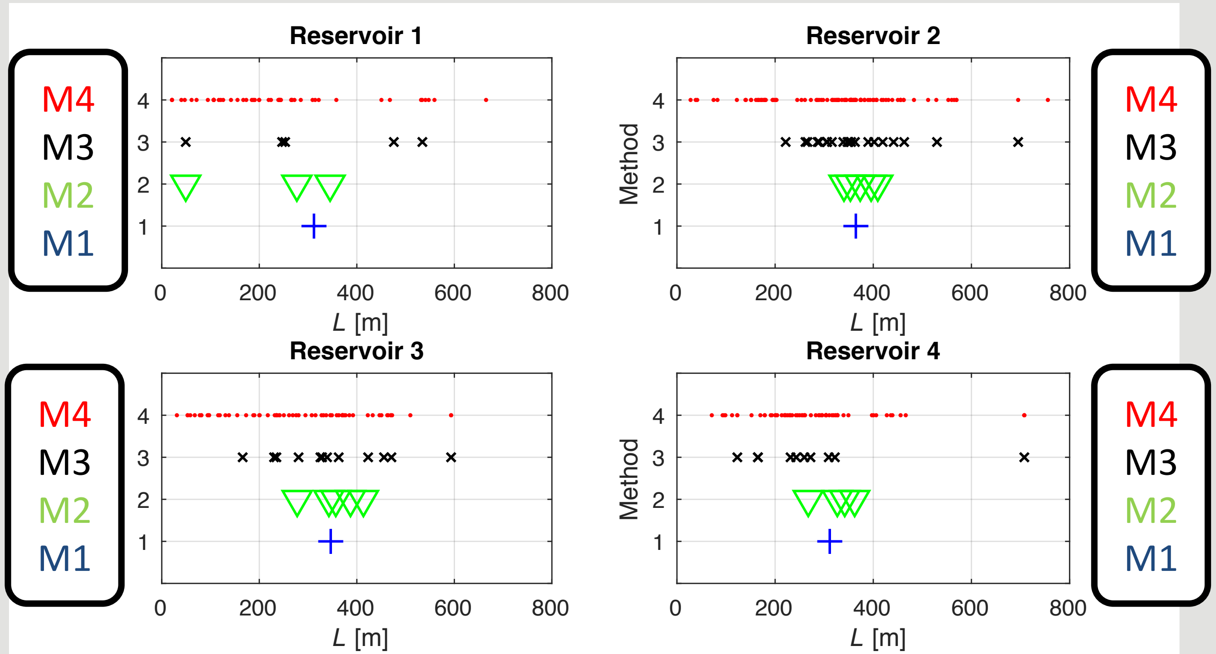


The OD matrix at the level of IRIS zones comes from Lyon authorities (Household survey 2015)

Trip lengths estimation (1)

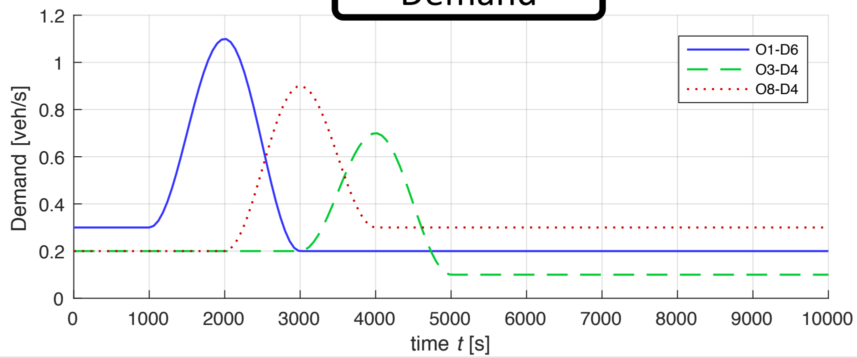


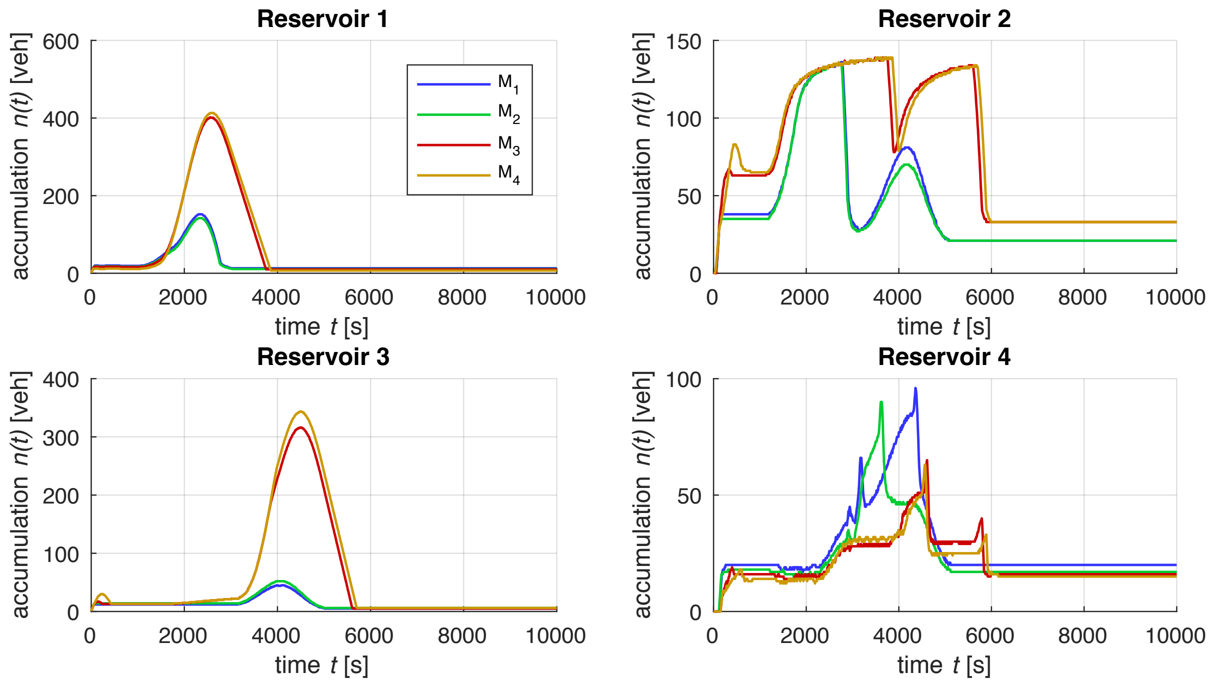
Trip lengths estimation (2)



Trip lengths estimation (3)

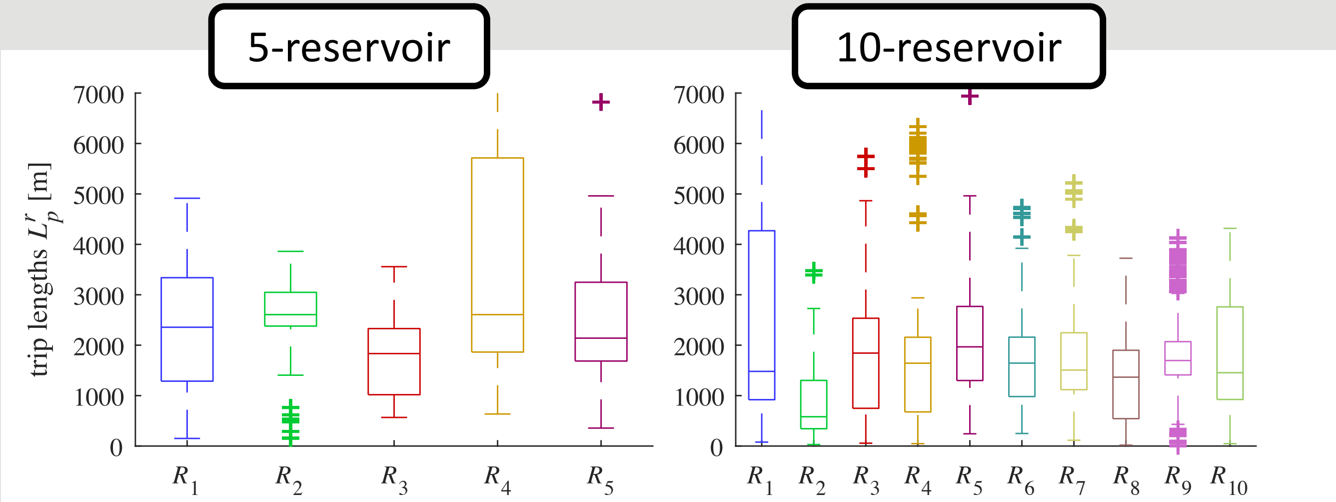
Demand





Time-evolution of the accumulation

Trip length estimation (4)



MFD estimation

Loop detectors (Feb 2011)

> Production in reservoir *r*

$$P_{\Delta t}^{r} = \frac{L_{tot}^{r}}{L_{equip}^{r}} \left(\sum_{\substack{equip \\ link\ i}} l_i . q_{i,loop,\Delta t} \right)$$

Taxi GPS trips (Feb 2011)

> Mean speed in reservoir *r*

$$V_{\Delta t}^{r} = \frac{TTD_{taxi}^{r}}{TTT_{taxi}^{r}}$$

> Accumulation in reservoir *r*

$$n_{\Delta t}^{r} = \frac{P_{\Delta t}^{r}}{V_{\Delta t}^{r}}$$

MFD estimation

Loop detectors (Feb 2011)

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> Accumulation in reservoir *r*

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Calibrating the scaling factor function is trickier than expected!

$$P_{\Delta t}^{r} = \frac{1}{\Gamma^{r}} . \left(\sum_{\substack{equip \\ link\ i}} l_i . q_{i,loop,\Delta t} \right) = \frac{1}{\Gamma^{r}} . P_{\Delta t,equip}^{r}$$

The 1-reservoir case – Scaling factor

Hypothesis:
In free-flow and steady state conditions, the total inflow equals the total demand λ, thus the total production P can be estimated with the mean trip length (L = 4300 m):

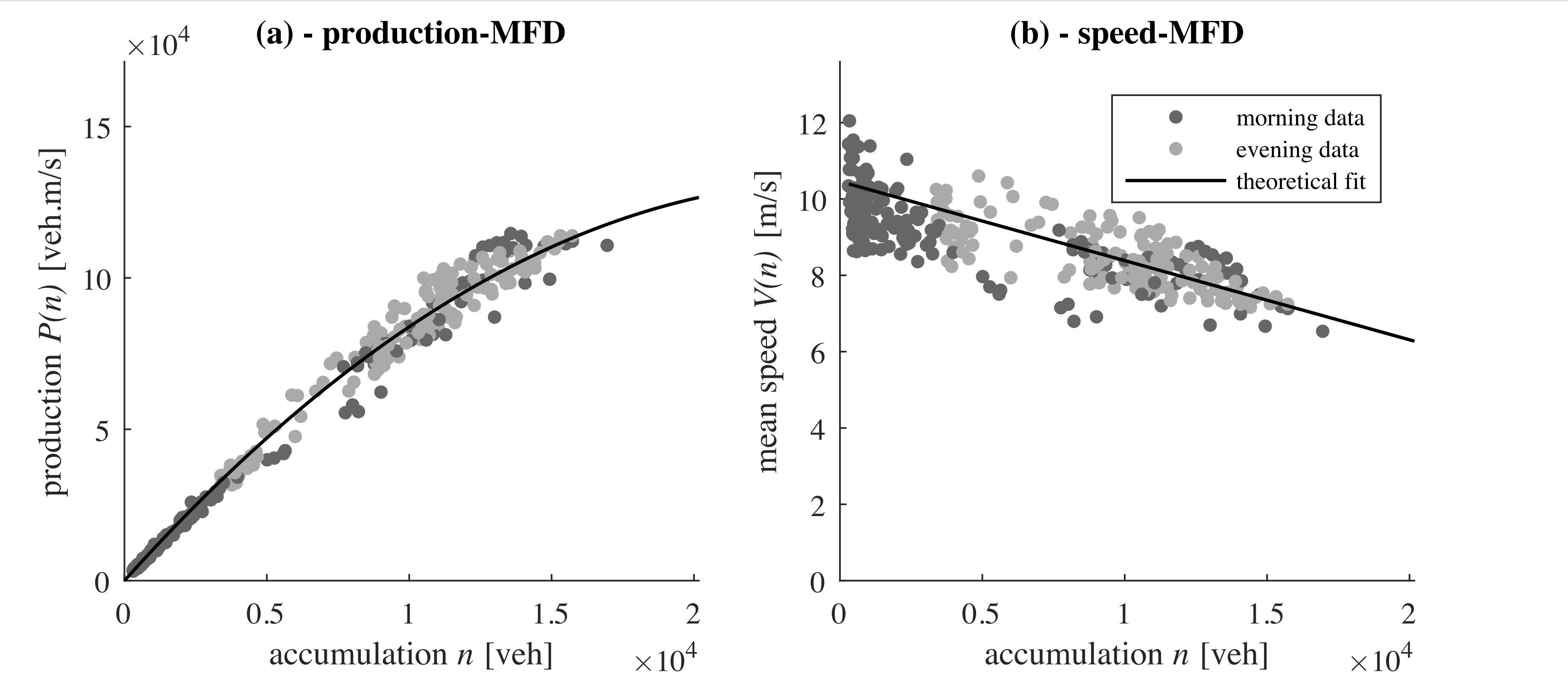
$$P^{midday} = L.\lambda^{midday} = \frac{1}{\Gamma}.P_{equip}^{midday}$$

Hence, the scaling factor is estimated one for all at noon as:

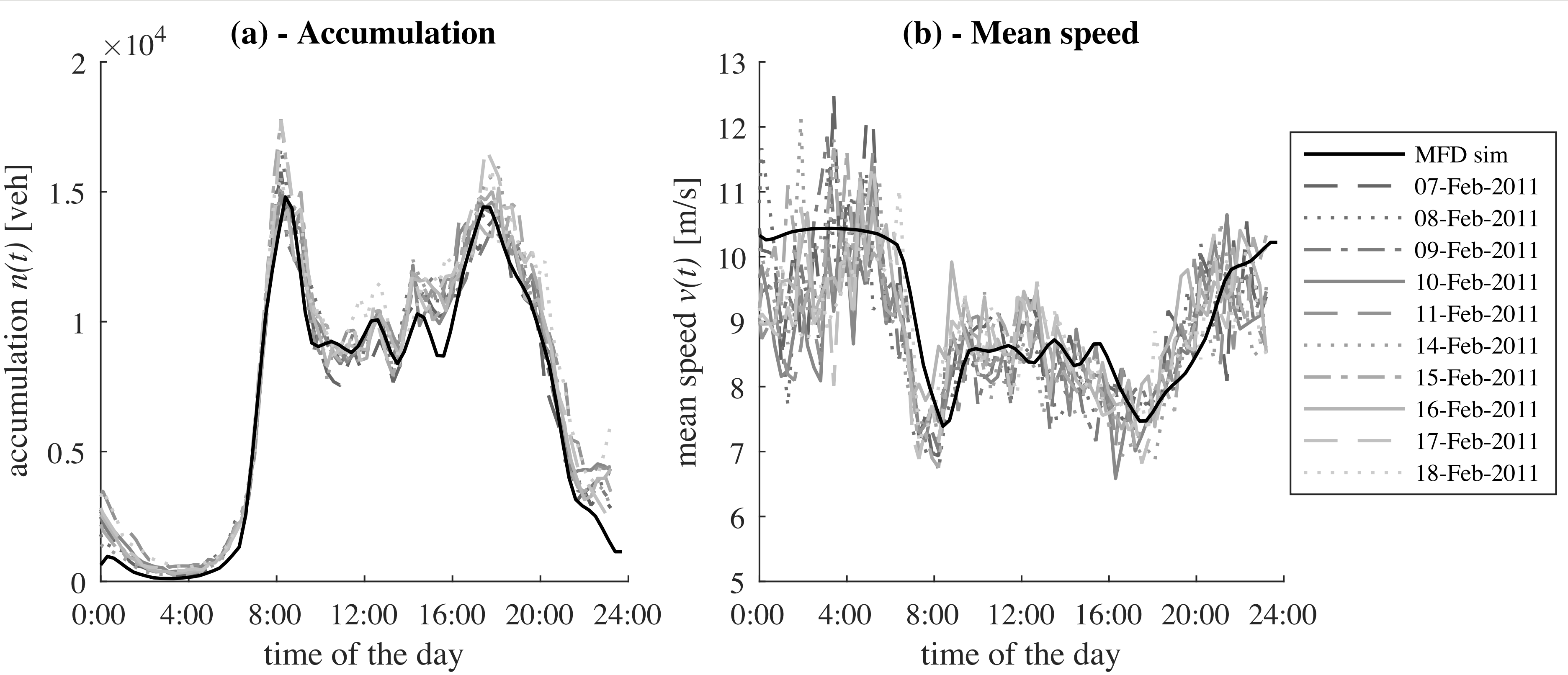
$$\Gamma = \frac{P_{equip}^{midday}}{L.\lambda^{midday}} = 0.065$$

The 1-reservoir case – MFD

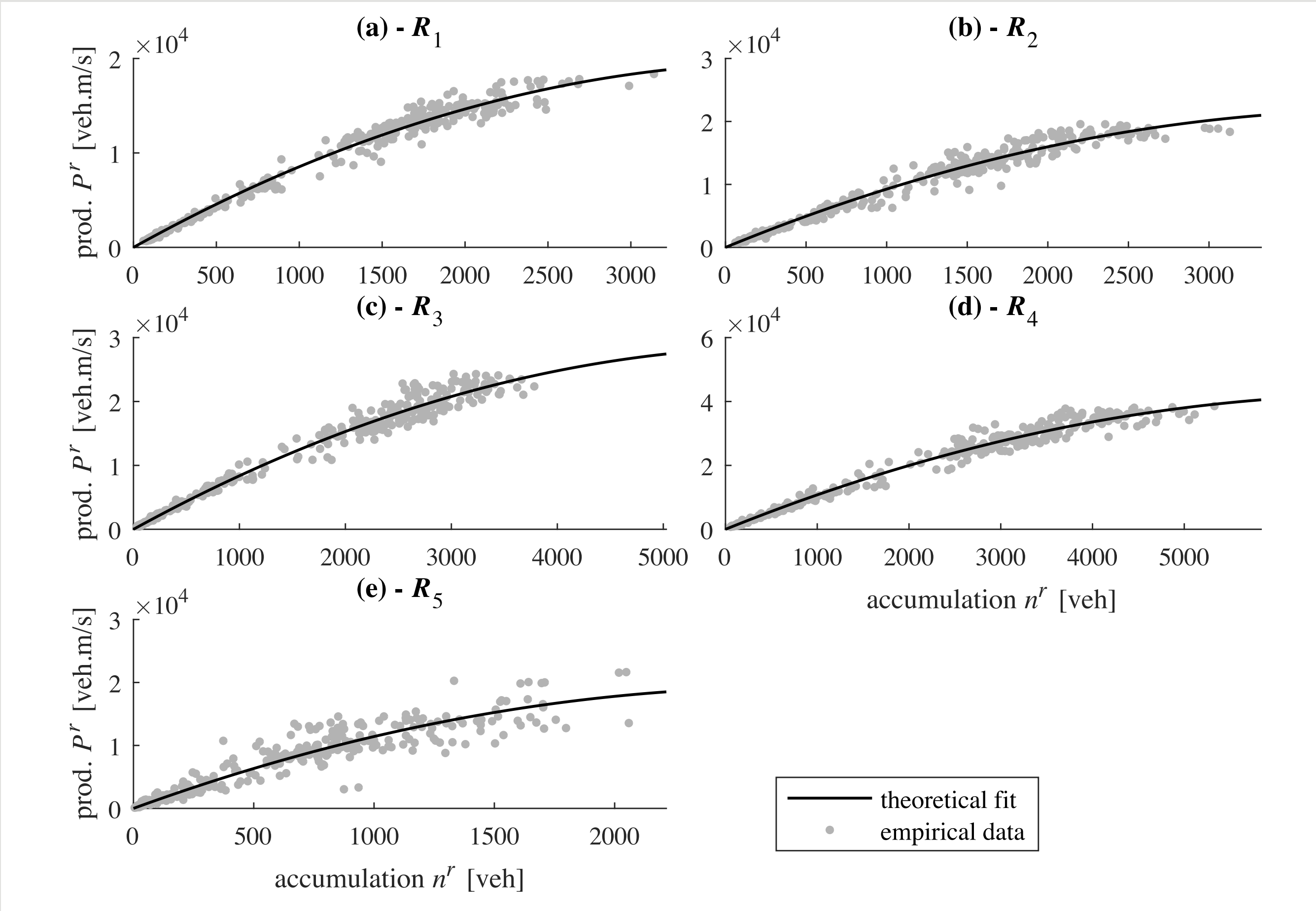
MFD fit with data from Feb, 1 to Feb, 4, 2011



The 1-reservoir case – Simulation



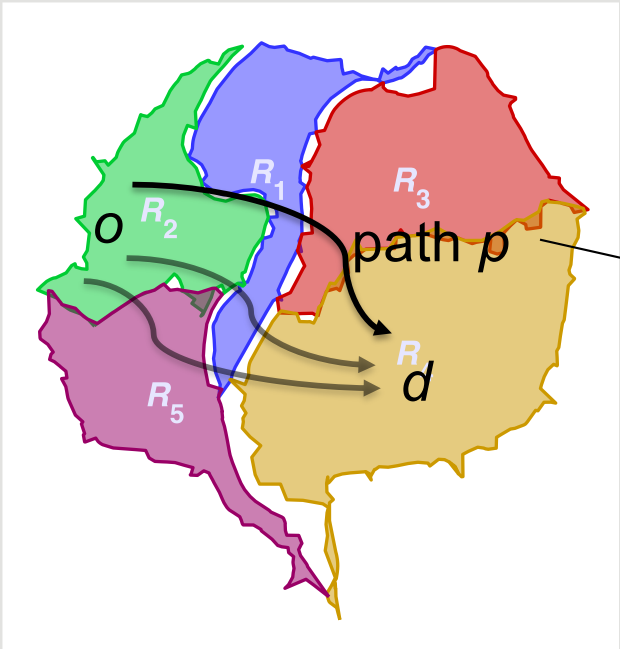
The 5-reservoir case – Scaling factor



Scaling factor? adjusted with the penetration rate of loop detectors for each reservoir

The 5-reservoir case – Path flows (1)

Path flow distribution?



$$\alpha_p = \frac{\lambda_p^{od}}{\lambda^{od}} = ?$$

$$Gap = \sum_{od} Gap^{od} = \sum_{od} \sum_{p \in od} \alpha_p . \frac{TT_p - \min_{p' \in od} TT_{p'}}{\min_{p' \in od} TT_{p'}}$$

measures how far users are complying with Wardrop's principle (Sbayti et al., 2007)

The 5-reservoir case – Path flows (2)

Two ways to estimate the path flow distribution:

- Relying on a well-known network equilibrium principle (UE)
- Optimizing the flow distribution to match the data

Optimization method:

To avoid running the whole simulation and save computational time, the total production is compared to data only at noon in assuming steady state conditions:

$$\min \sum_{r} \left(P^{r}_{equip} - P^{r}_{sim}\right)^{2} \quad \text{where: } P^{r}_{sim} = \Gamma^{r} \sum_{p \in r} L^{r}_{p} \, . \, \alpha_{p} \, . \, \lambda^{od} \text{ (in steady state)}$$

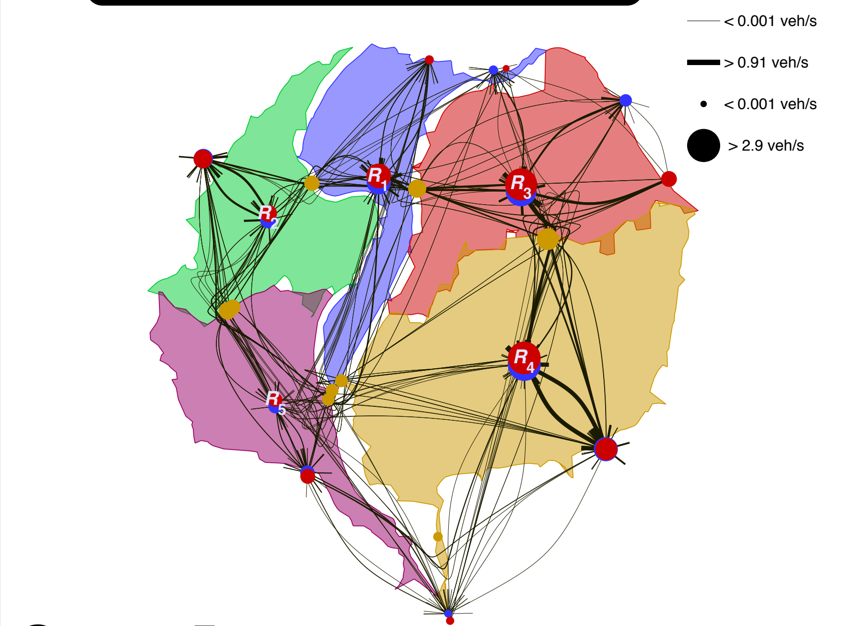
$$\text{s.t.} \quad \forall p, \quad 0 \leq \alpha_{p} \leq 1$$

$$\forall od, \quad \sum_{p \in od} \alpha_{p} = 1 \qquad \Gamma - \epsilon \leq \frac{\sum_{r} P^{r}_{sim}}{\sum_{r} \Gamma^{r} . P^{r}_{sim}} \leq \Gamma + \epsilon, \qquad \Gamma = 0.065$$

The 5-reservoir case – Simulations

Two simulations with different path flow calculations:

Wadrop flow assignment

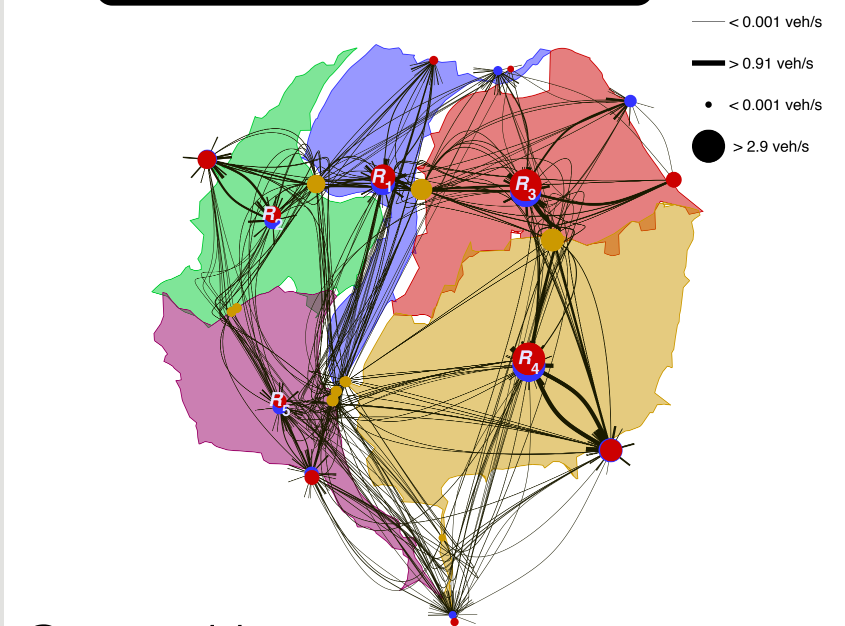


Gap = 5

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

$$\Gamma^r = \{0.8\ 0.8\ 0.8, 0.8, 2\}\frac{L^r_{tot}}{L^r_{equip}}$$

Flow optimization method

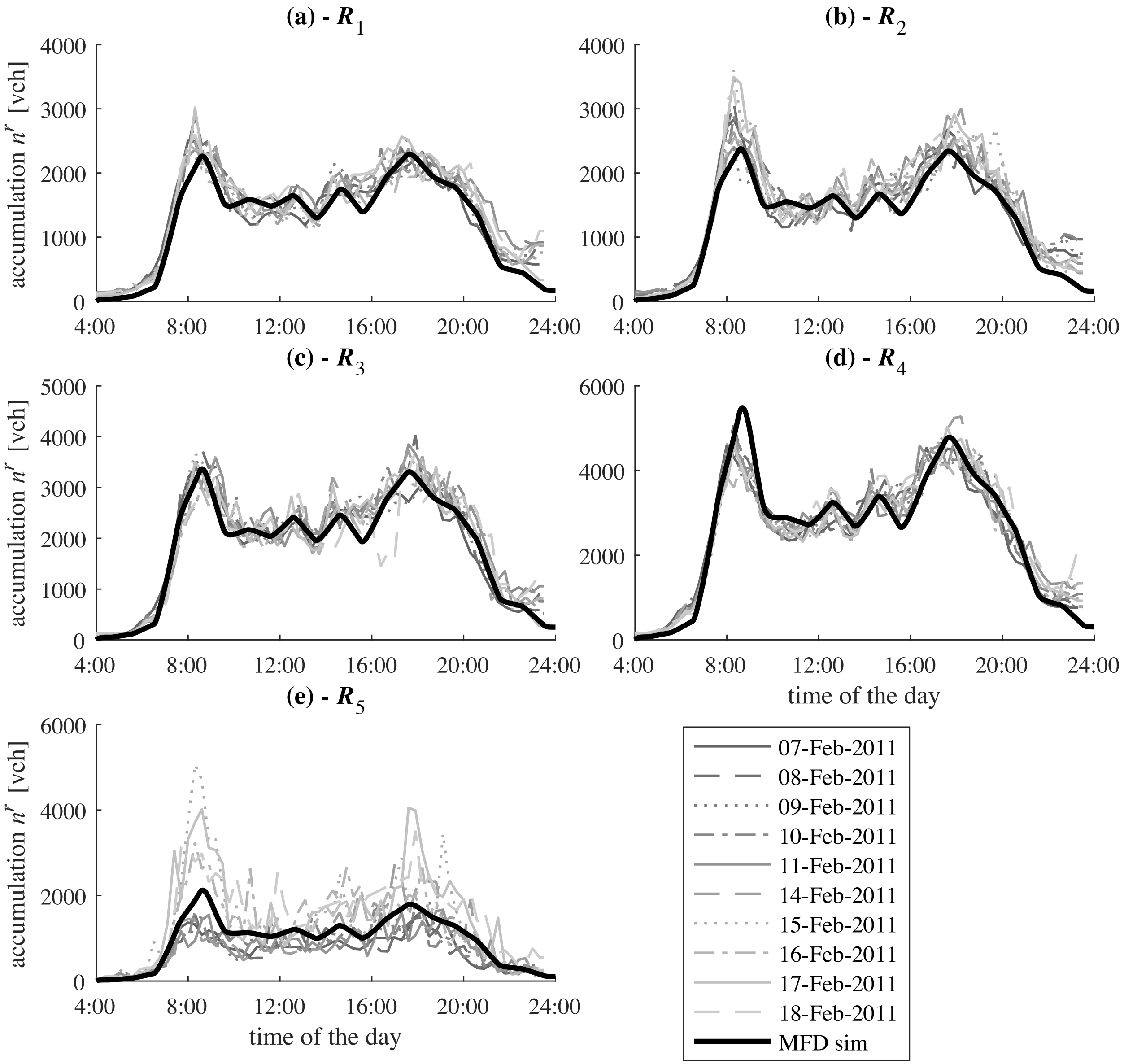


Gap = 11

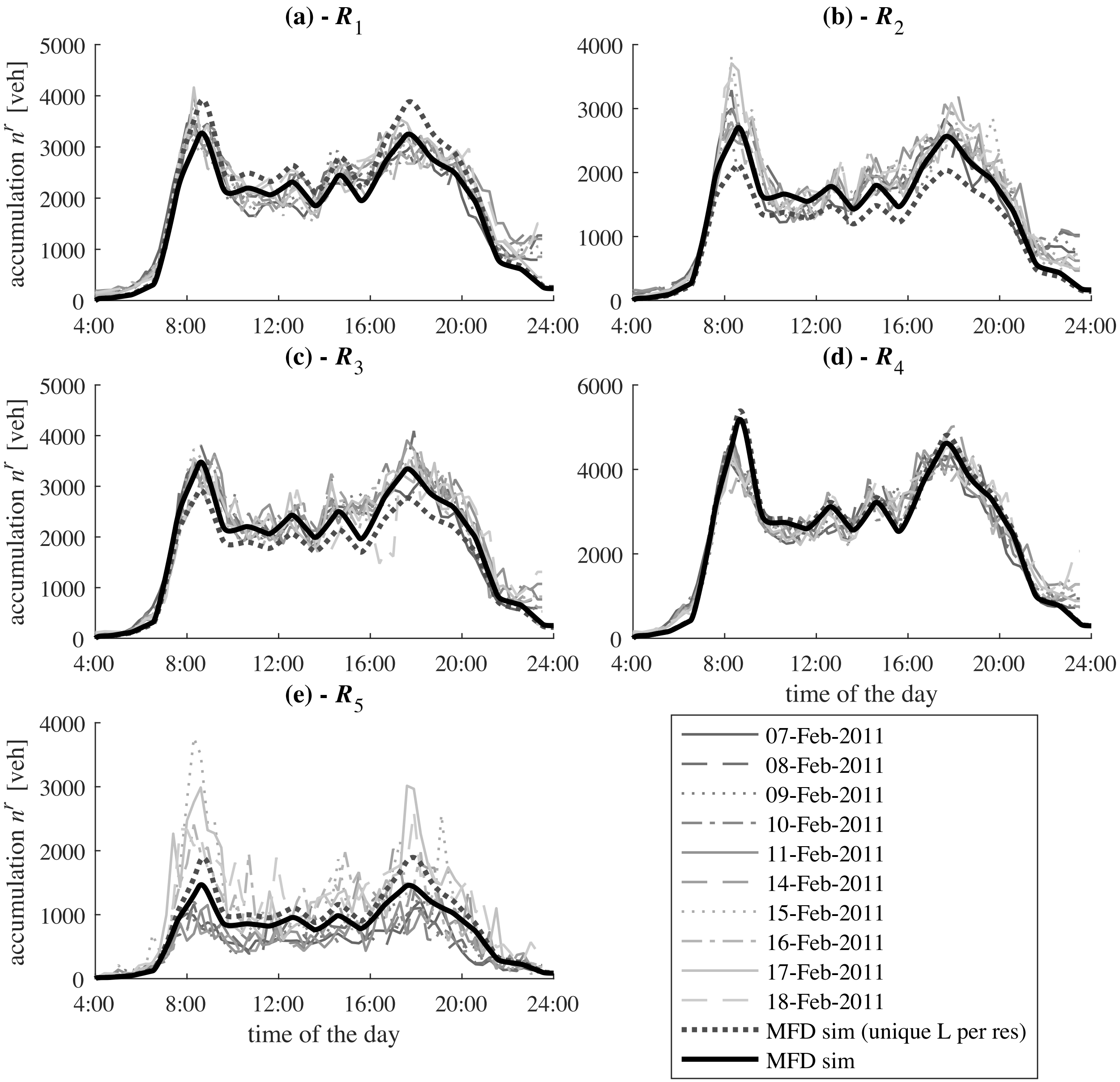
19 % of OD with a Gap^{od} > 0.2

$$\Gamma^r = \{0.7, 1, 0.8, 0.7, 1.3\}\frac{L^r_{tot}}{L^r_{equip}}$$

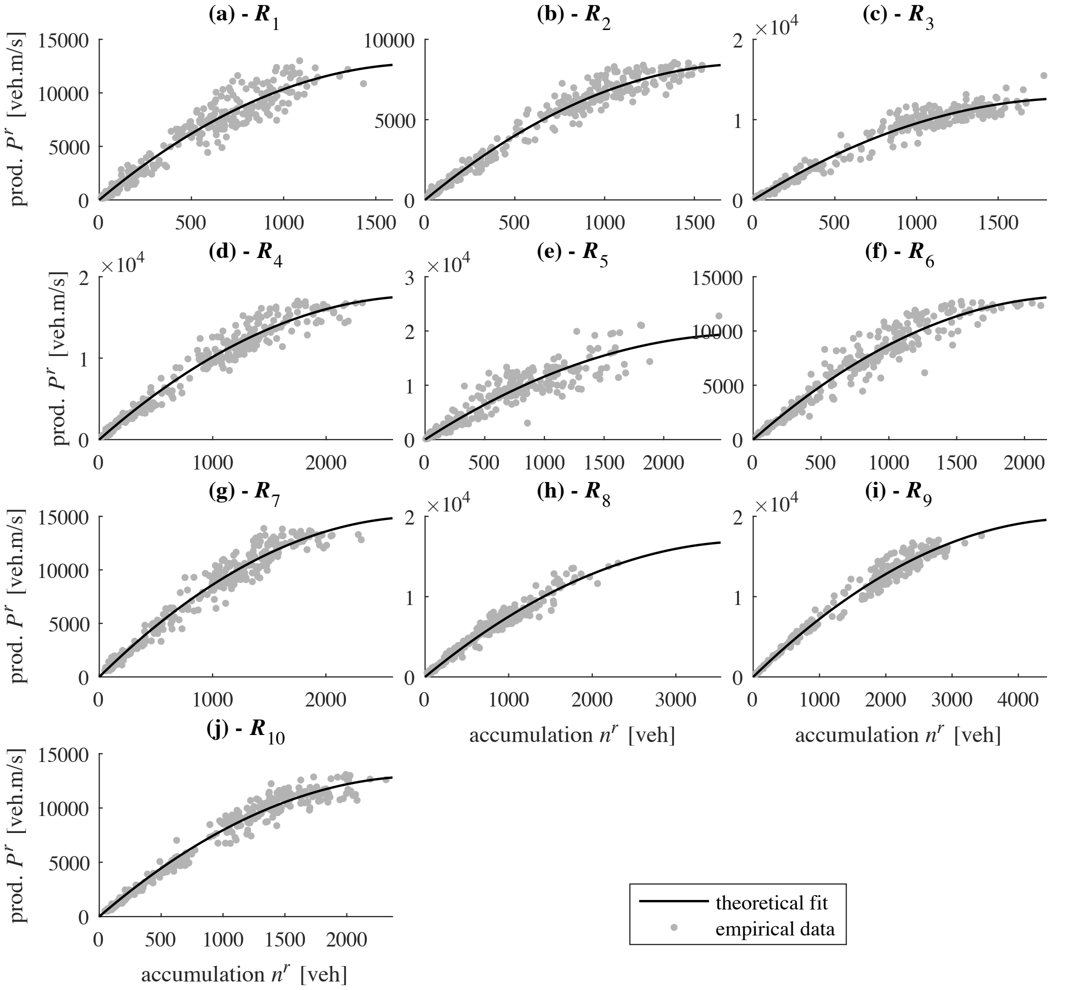
The 5-reservoir case – Wardrop



The 5-reservoir case – Flow optimization



The 10-reservoir case – Scaling factor



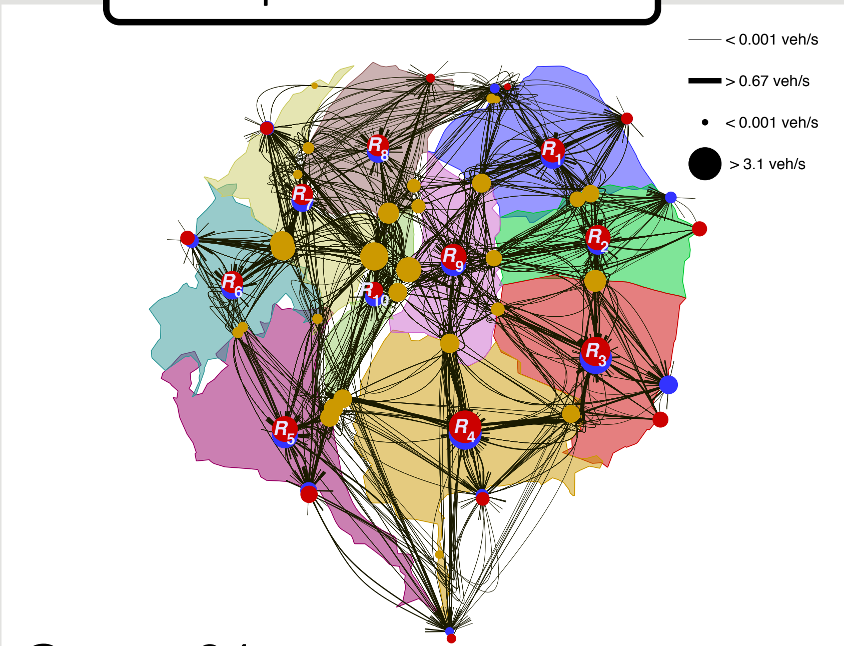
Scaling factor adjusted with the penetration rate of loop detectors for each reservoir:

$$\Gamma^r = \{0.064, 0.055, 0.052, 0.087, 0.003, 0.025, 0.063, 0.026, 0.11, 0.072\}$$

The 10-reservoir case – Simulation

Only one simulation using the flow optimization method, as the global equilibrium hardly complies with Wardrop's principle

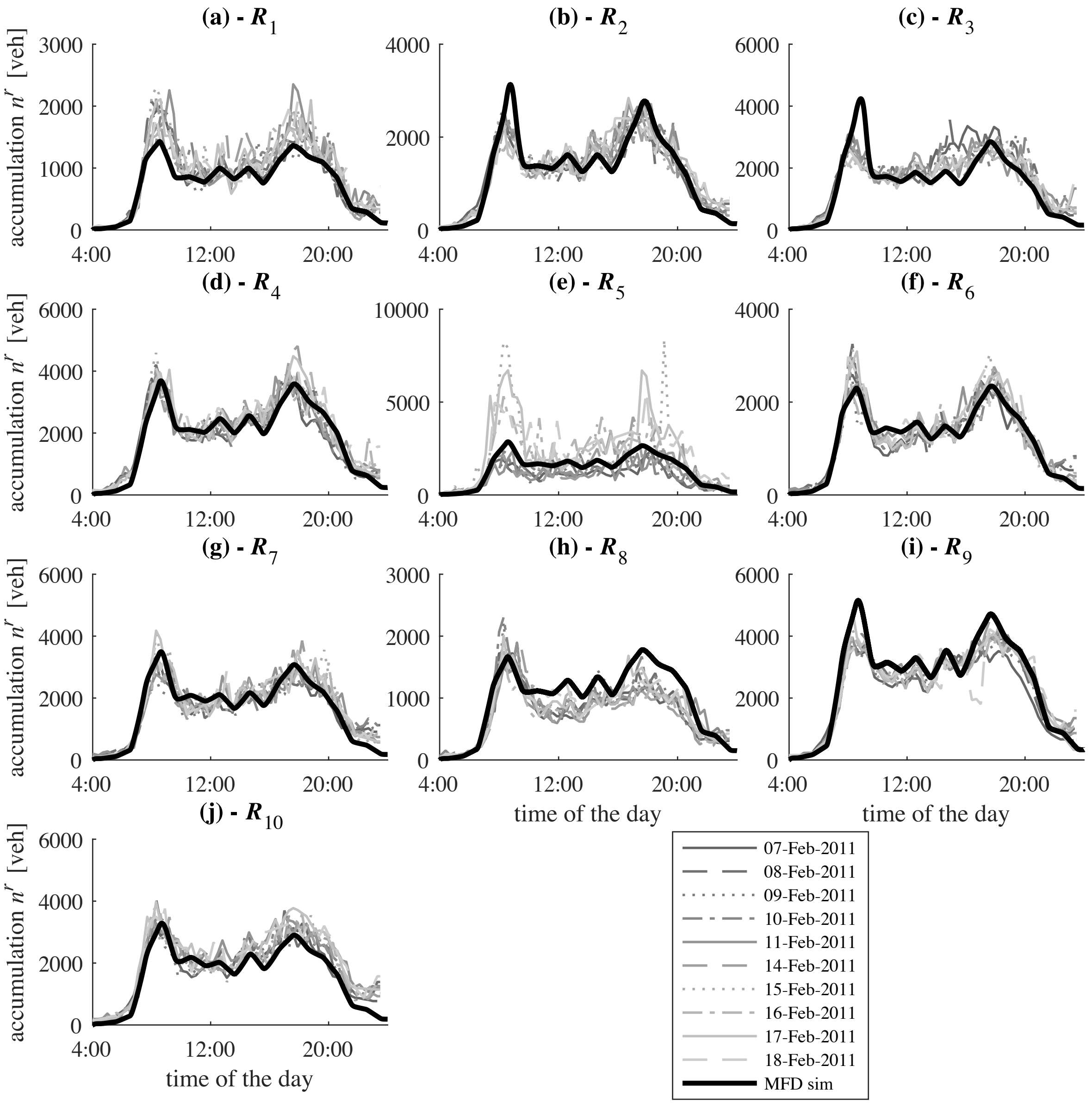
Flow optimization method



Gap = 61

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

The 10-reservoir case – Flow optimization



Conclusion

Conclusion

- **Good match** between MFD simulation and data thanks to the estimation of **scaling factors** that accounts for missing Eulerian observations (links with no loop detector)
- **Reliable network equilibrium** can be achieved using **Wardrop**'s principle to assign OD flows to regional paths when the number of reservoir is low (5-reservoir case)
- **Path flow distribution** estimation is critical with a higher number of reservoirs (10-reservoir case), no clear equilibrium principle

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Thank you for your attention

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