Macroscopic Fundamental Diagrams: Estimation methods

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ETH, Seminar

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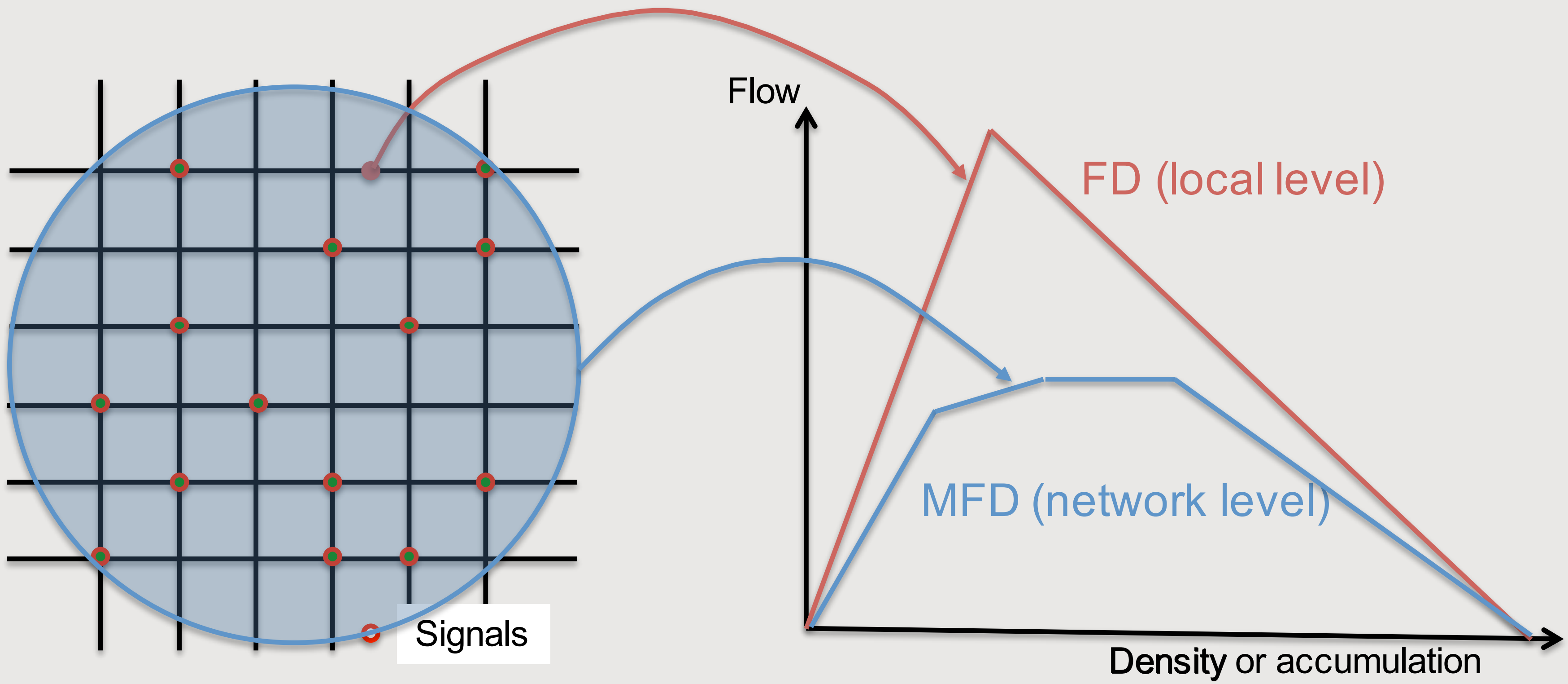
UNIVERSITÉ DE LYON ENTPE IFSTTAR

The LICIT Laboratory

- A joined research unit belonging to IFSTTAR and ENTPE
  – IFSTTAR: French National Research Center on Transportation and Network Management
  – ENTPE: Civil Engineering school with a Transportation Program
- IFSTTAR and ENTPE are members of Université de Lyon
- The LICIT has two research teams dedicated to road transportation system modeling and control :
  – MOMI (data driven approaches) – N.E. El Faouzi (head of the lab)
  – AMMET (model driven approaches) – L. Leclercq

MFD definition



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

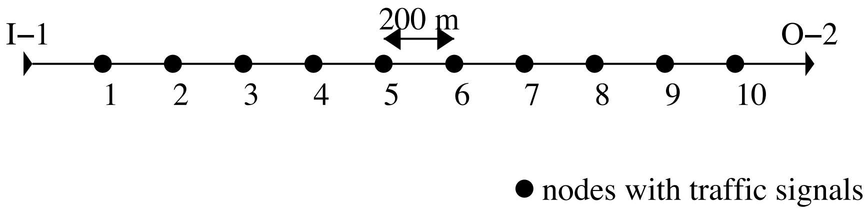
Outline

- Short recap of existing estimation methods for the Macroscopic Fundamental Diagram (MFD)
- Cross-comparison of the different methods for two typical networks (Leclercq, Chiabaut *et al*, part B, 2014)
  - Analytical VS. Edie methods
  - Edie VS. loops methods
  - Loops VS. Probes methods
- Using MFD for simulation purpose (Leclercq, Parzani *et al*, ISTTT21, 2015)
- Conclusion

Cross-comparaison of different methods

Studied Networks

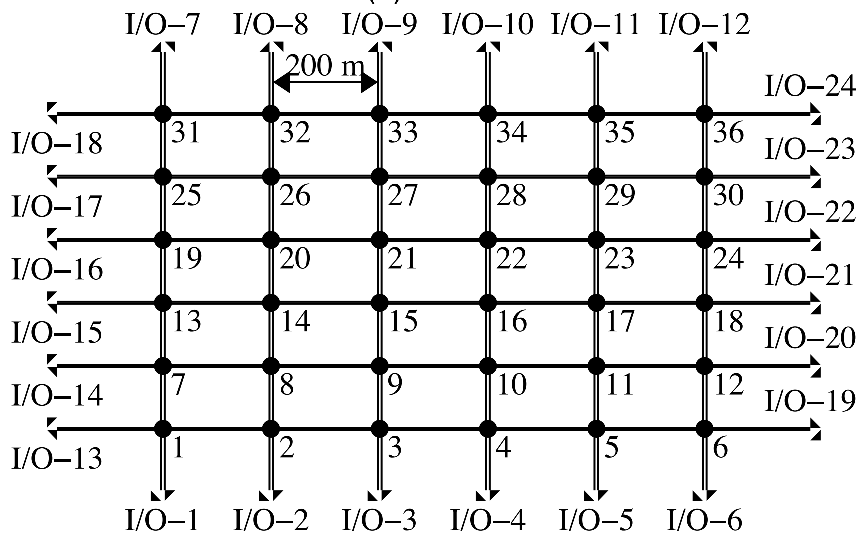
(a) – SC1



A Urban corridor

A square grid network

(b) – SC2



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

We mainly focus on homogeneous loadings (the methodology is presented in the paper)

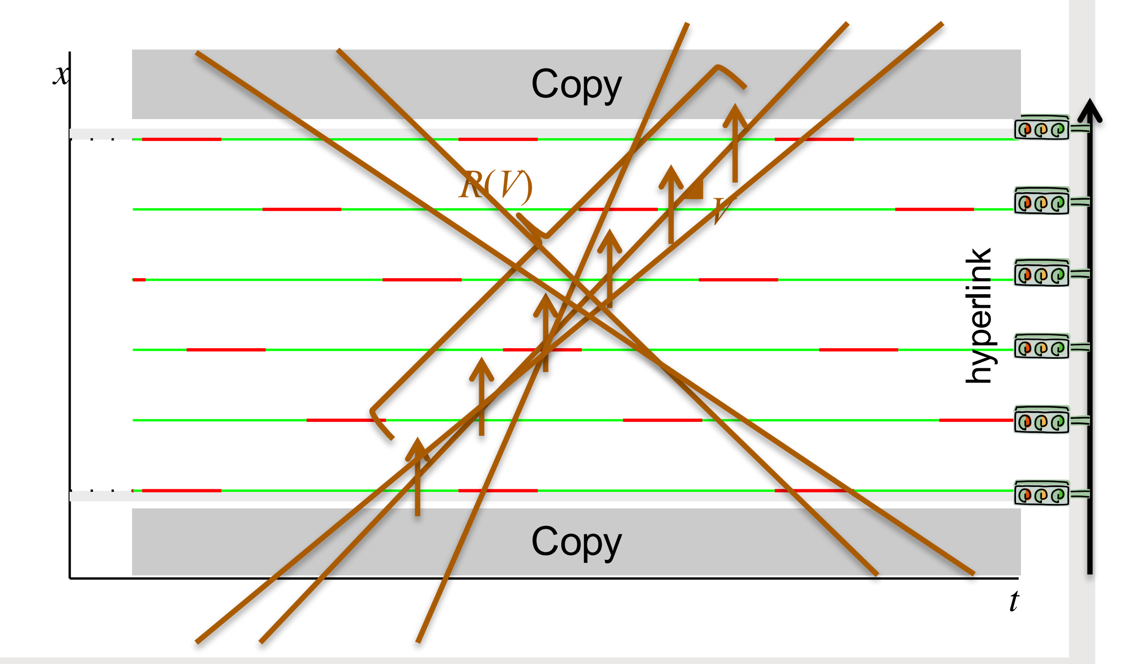
Different estimation methods

Analytical Method (1) – Cuts for a corridor

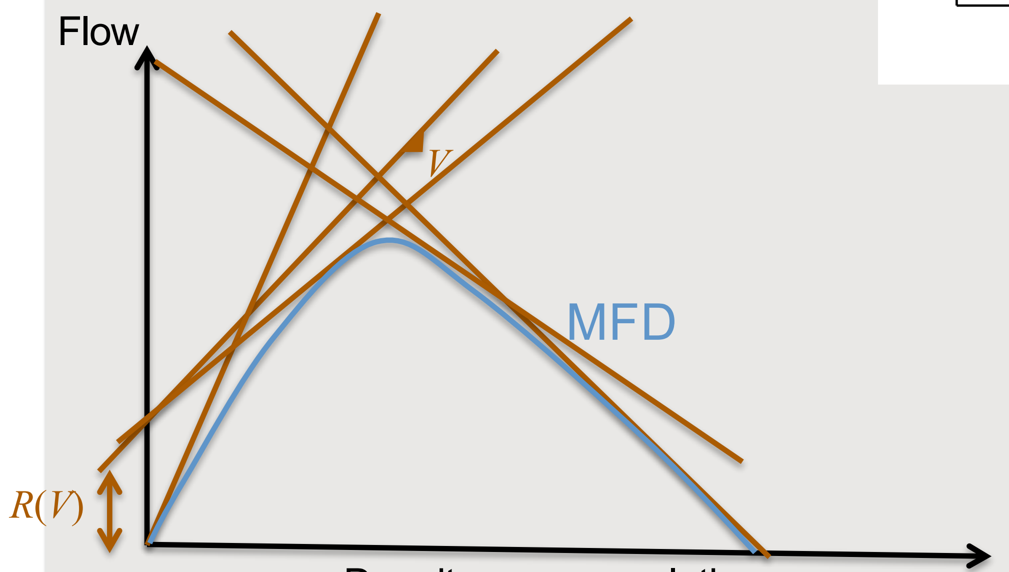
Moving observer (mean speed V)

Minimum overtaking flow $R(V)$

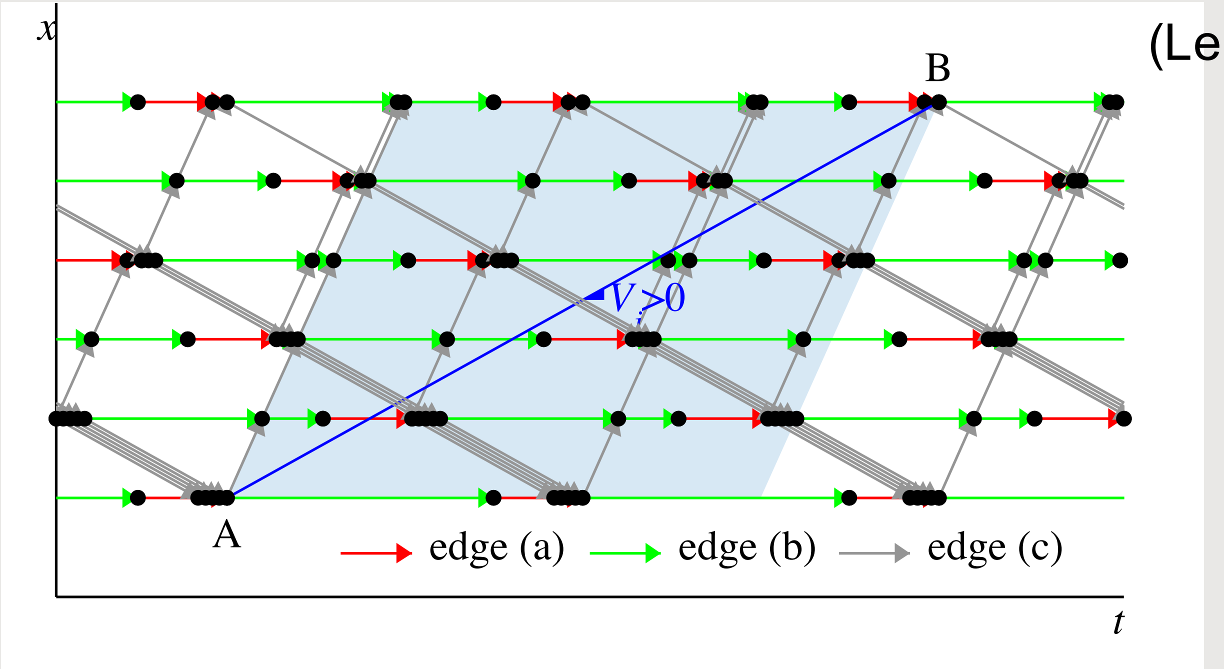
Cut: $Q=\min_V(KV+R(V))$



(Daganzo and Geroliminis, 2008)



Analytical Method (2) - The sufficient graph



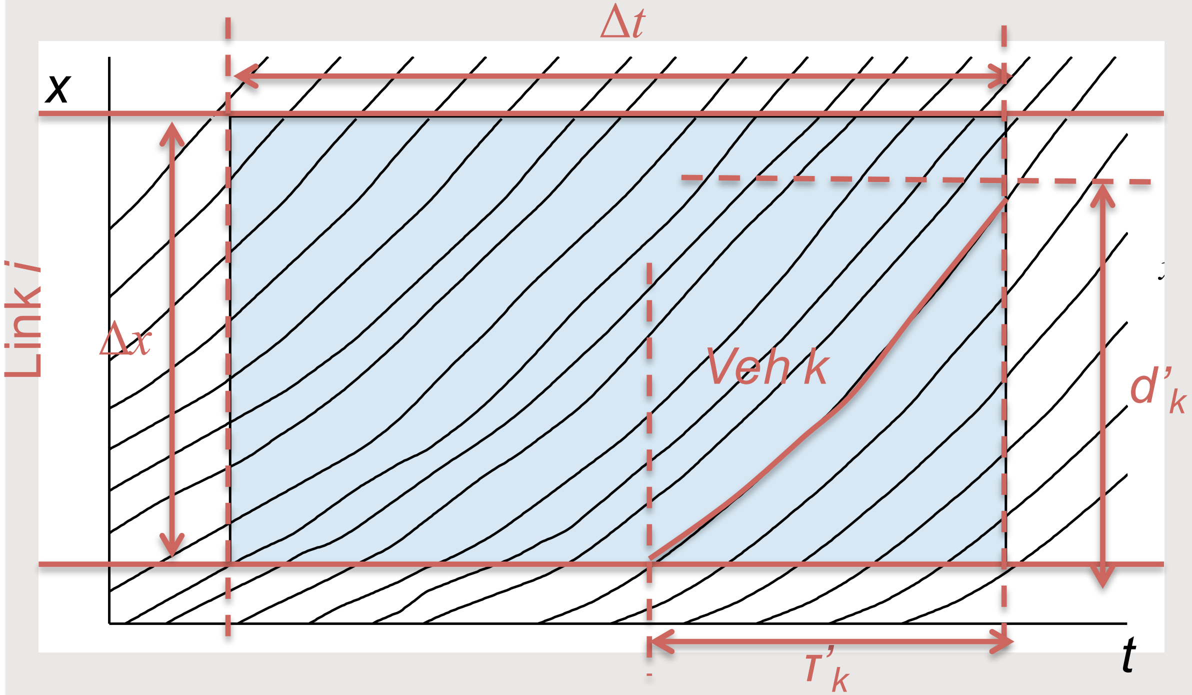
(Leclercq and Geroliminis, 2013)

The cost $R(V)$ for different V can be calculated using a sufficient graph defined by three kinds of edges

The estimation is tight only if the network is homegenously loaded

Numerical Methods (1) - Edie's definitions

For one link:



$$q_i = \frac{\sum_k d'_k}{\Delta x \Delta t}$$

$$k_i = \frac{\sum_k \tau'_k}{\Delta x \Delta t}$$

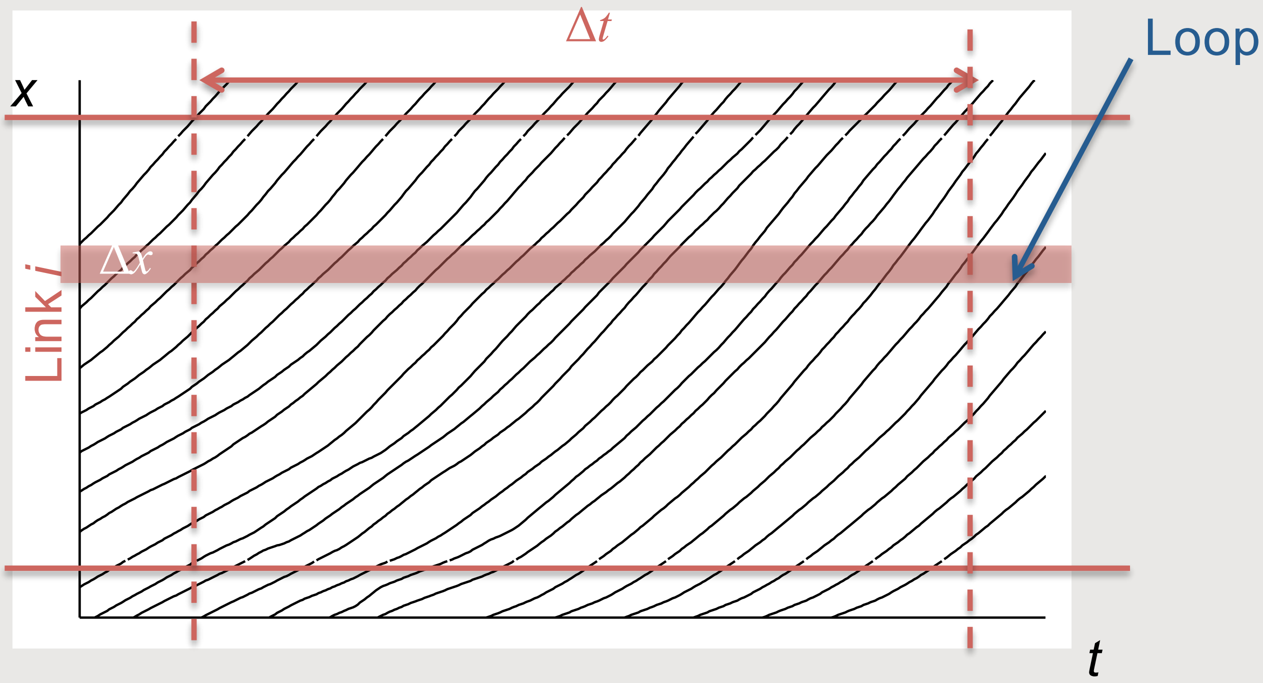
For the whole network:

$$Q = \sum_i l_i Q_i / l \qquad K = \sum_i l_i K_i / l$$

$$V = Q / K$$

Numerical Methods (2) – Loop detectors

For one link:



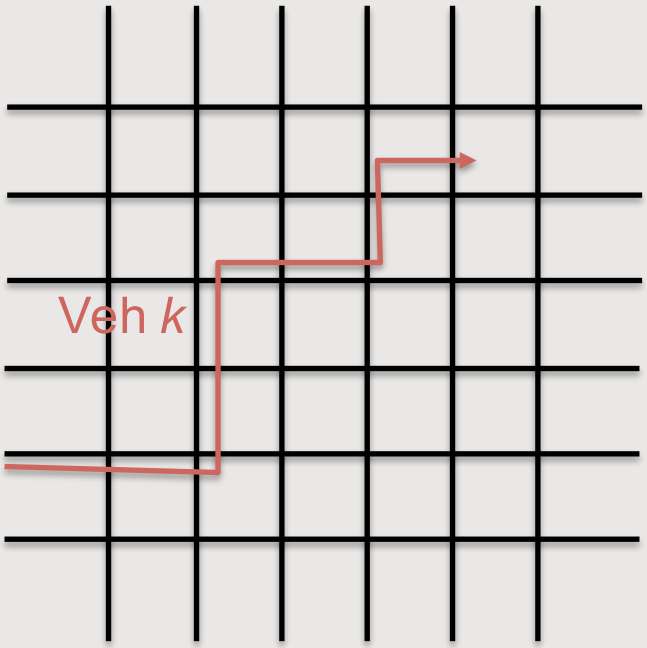
$$q_i = \sum_k d'_k \Big/ \Delta x \Delta t$$

$$k_i = \sum_k \tau'_k \Big/ \Delta x \Delta t$$

For the whole network:

$$Q = \sum_i l_i Q_i / l \qquad K = \sum_i l_i K_i / l$$

Numerical Methods (3) – Probe vehicles



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

Distance traveled

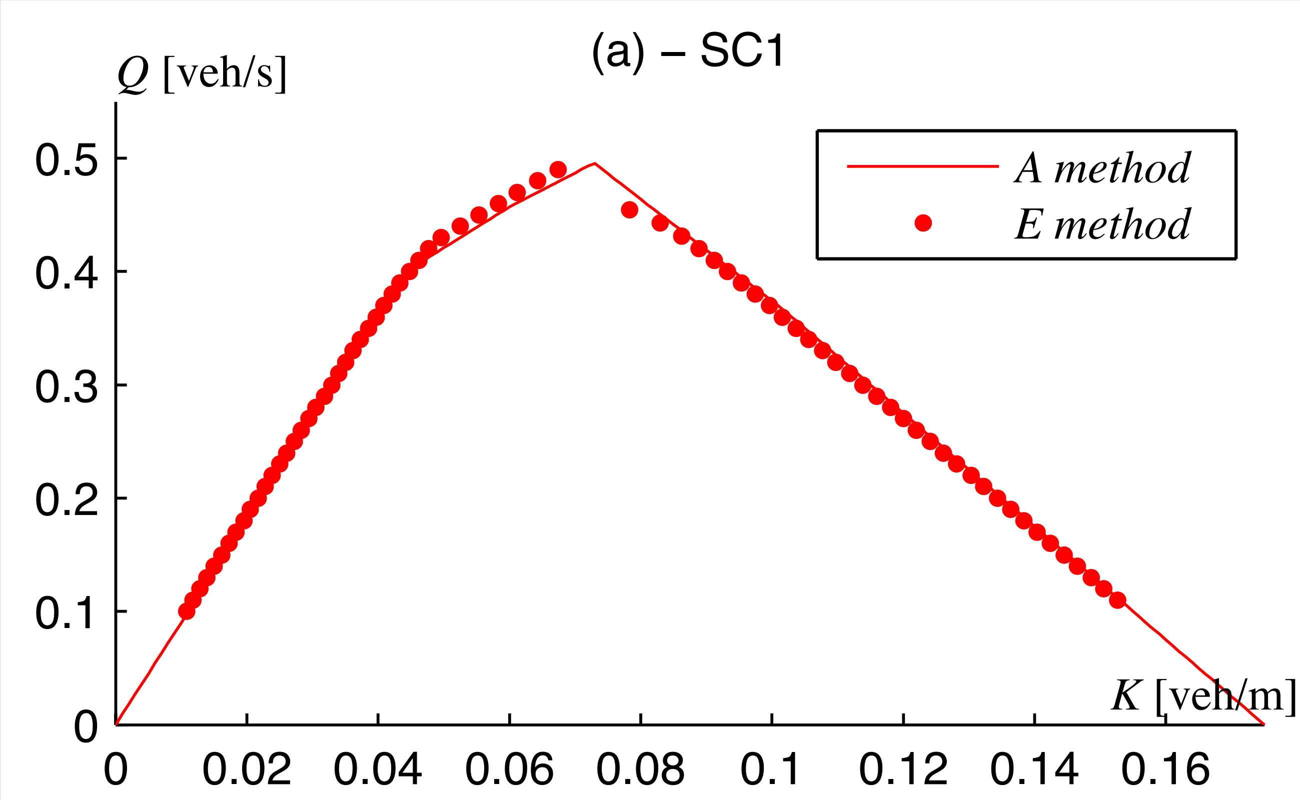
$$V = \sum_{k \in K} d''_k \Big/ \sum_{k \in K} \tau''_k$$

Travel time related to the Δt period

Mean flow *Q* should be determined by another way (loops)

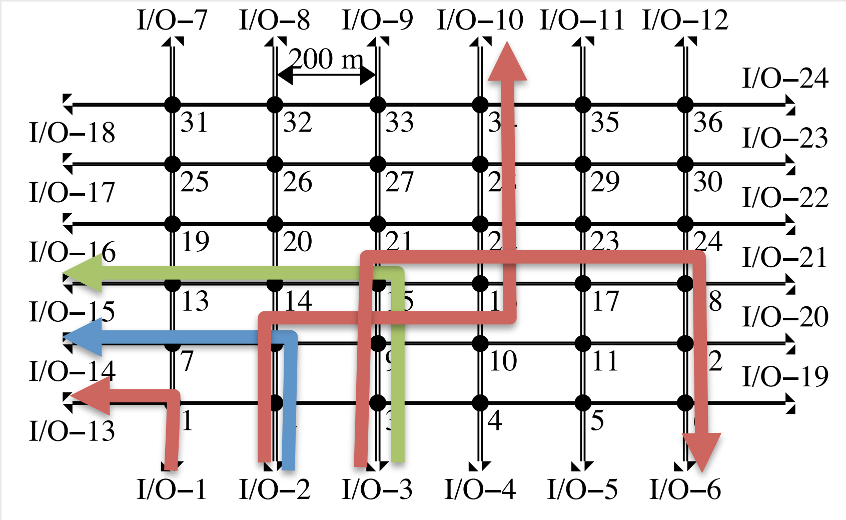
Cross-comparison of the different methods

Analytical VS. Edie methods (1) – SC1

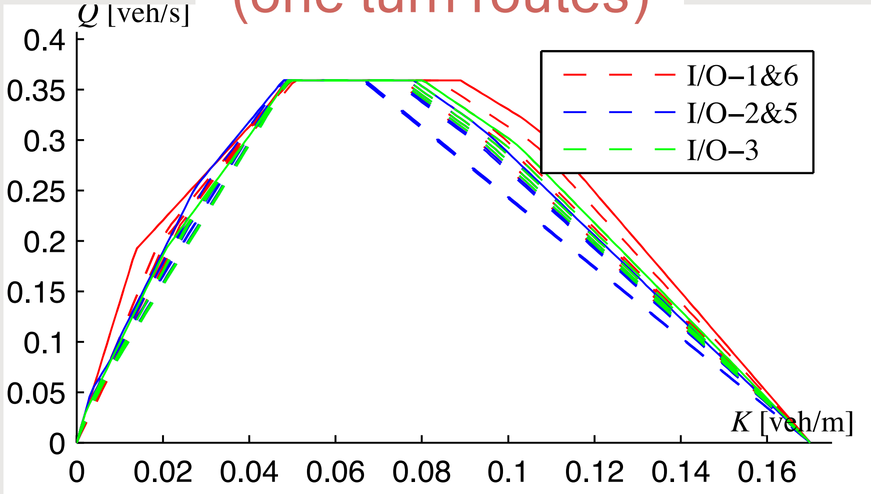


Unsurprisingly, cuts match with the simulation results

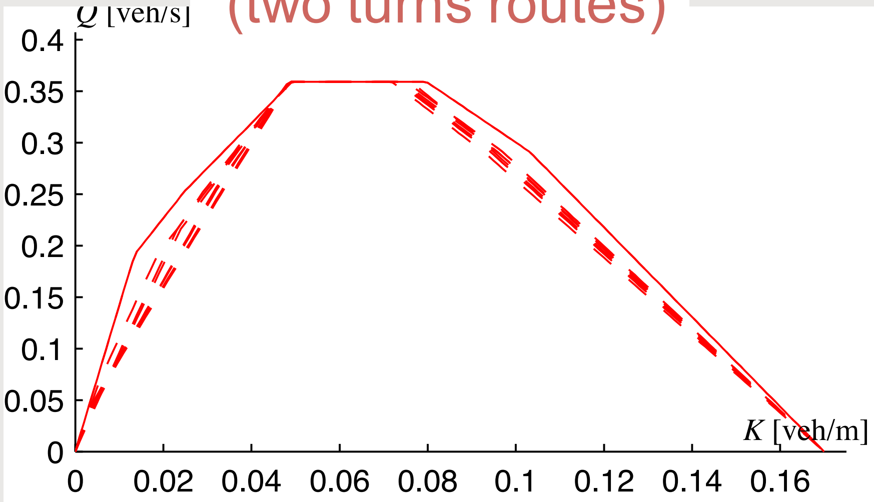
Analytical VS. Edie methods (2) – SC2



Analytical method
(one turn routes)



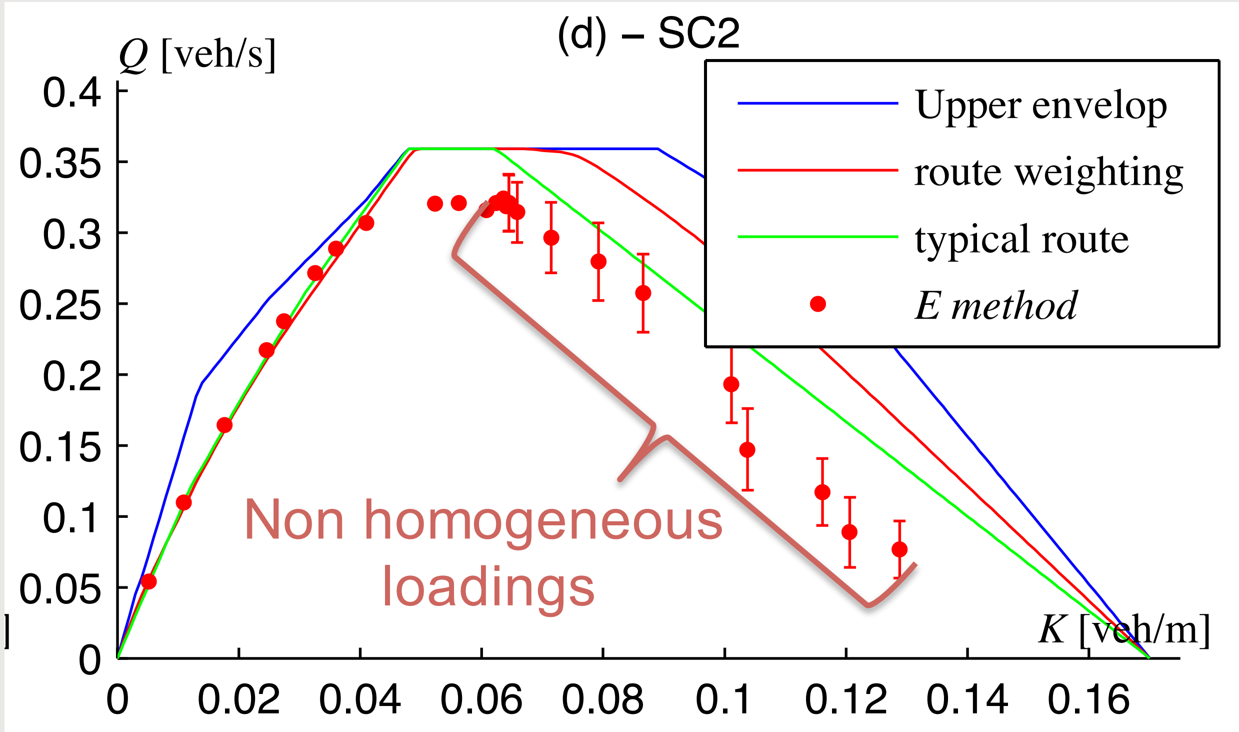
Analytical method
(two turns routes)



The analytical method is only applicable for routes not for the global network

Analytical VS. Edie methods (3) – SC2

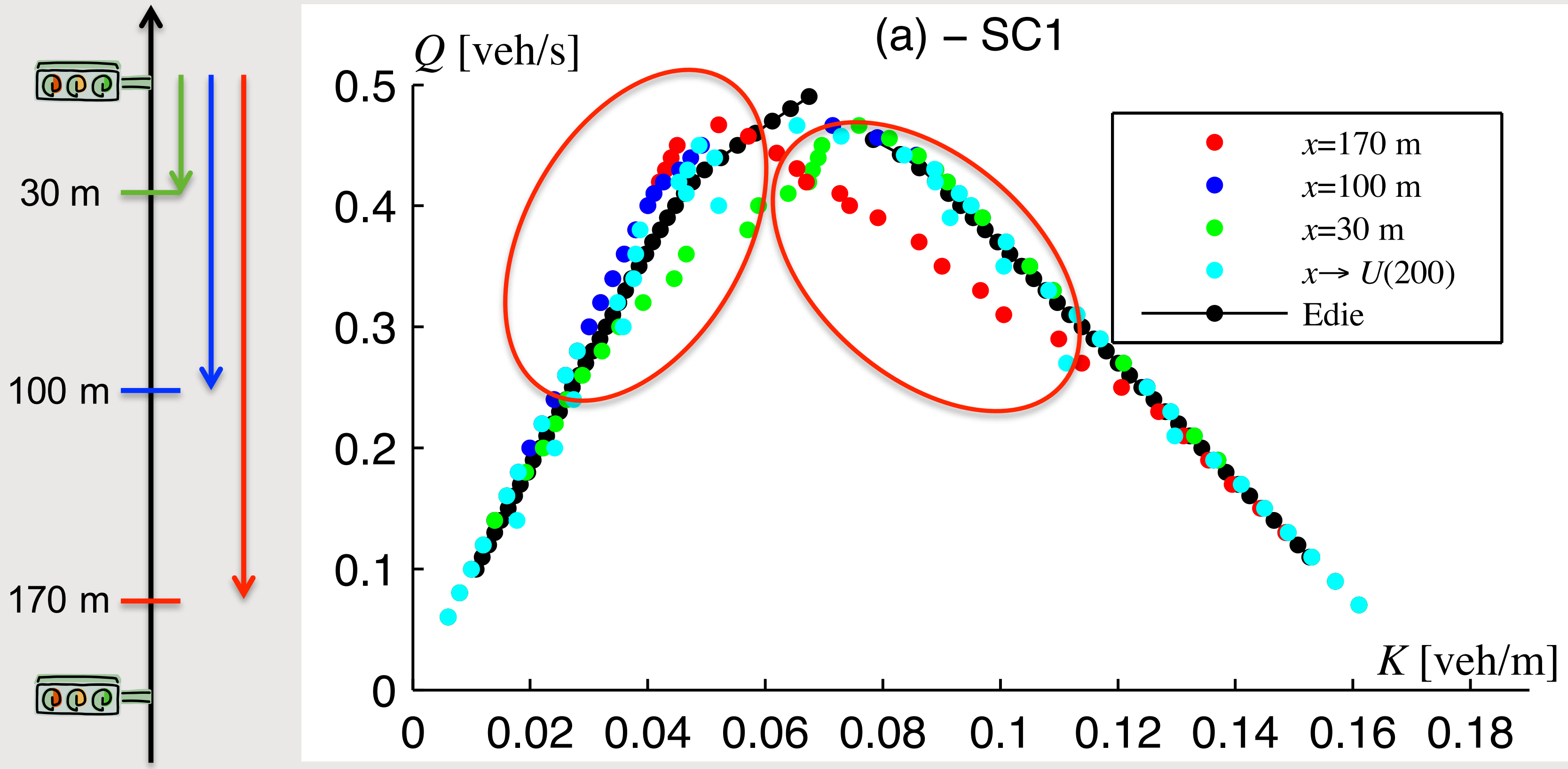
Different ways to estimate the global MFD



The global capacity is reduced in simulation because only an integer number of vehicle can pass the green at each signal cycle

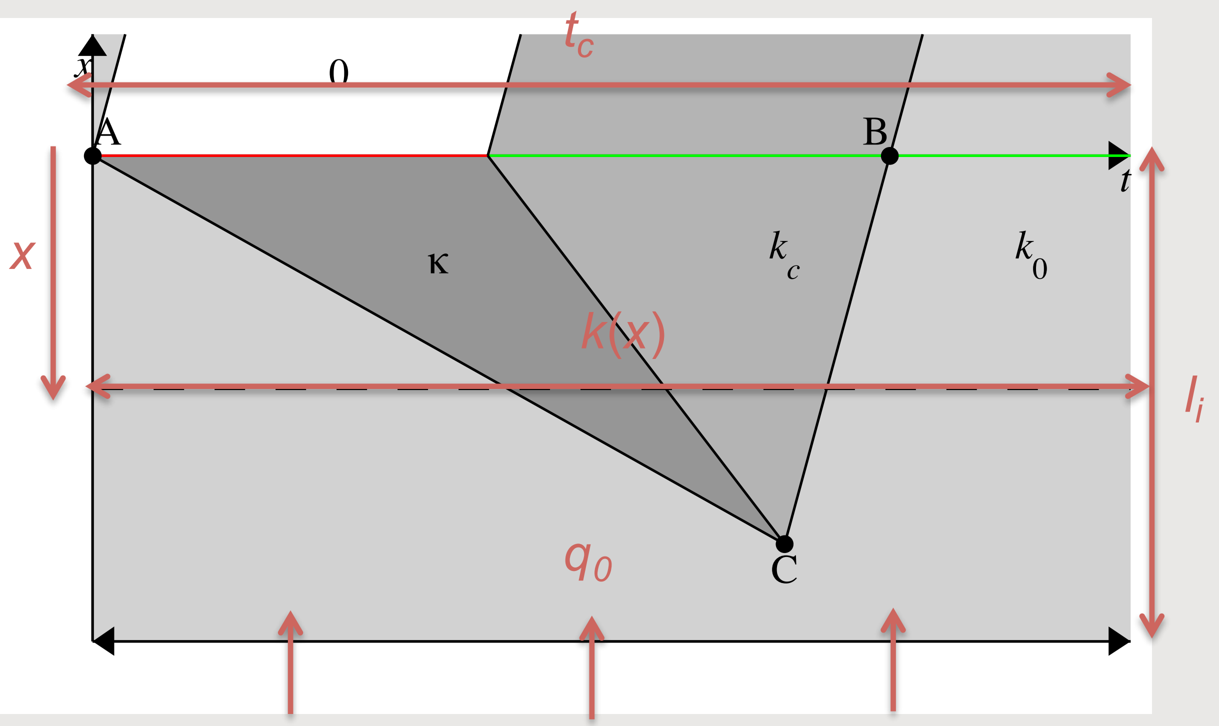
The typical route method appears to provide the closest results compared to simulations

Loops VS. Edie methods (1)



Loops are not able to capture the spatial dynamics within links

A correction method for loops observations

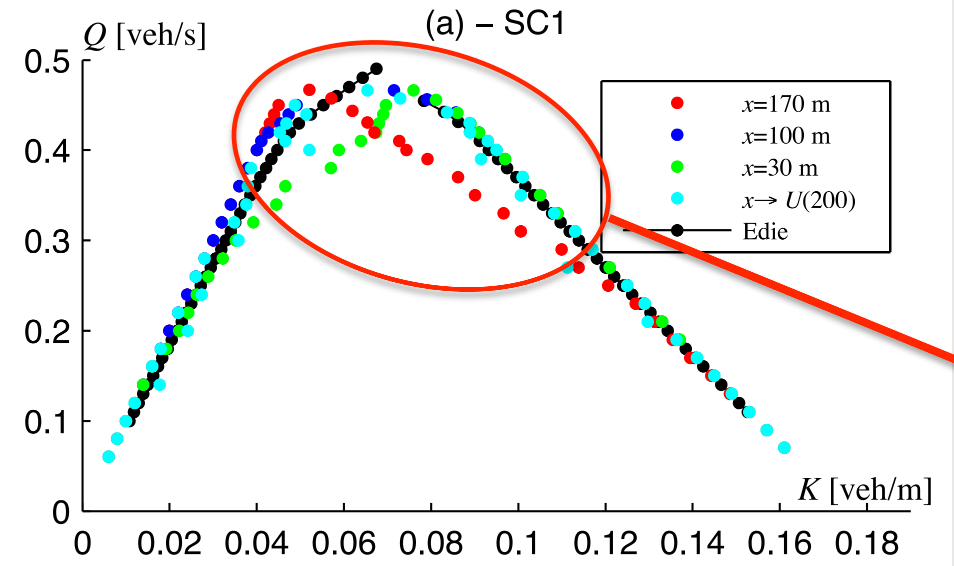


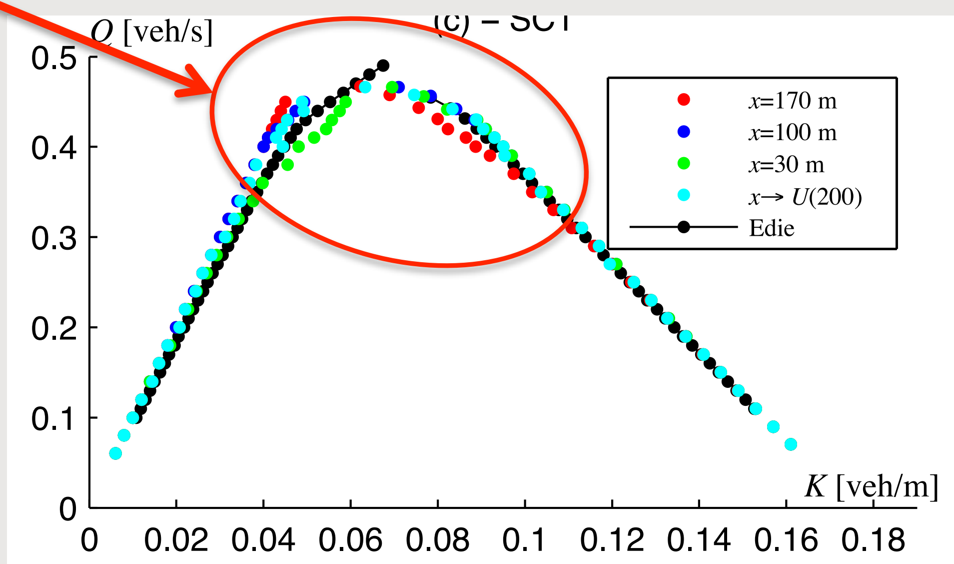
The mean spatial density can be derived from the observations at *x*

$$K = \frac{q_0}{u} + \left(\kappa - \frac{q_0}{w} - \frac{q_0}{u}\right)\frac{q_0}{2\kappa l_i t_C}\left(\tau(x) + \frac{x\kappa}{q_0}\right)$$

$$\tau(x) = \frac{t_C\left(k(x) - q_0/u\right)}{\kappa - q_0/w - q_0/u}$$

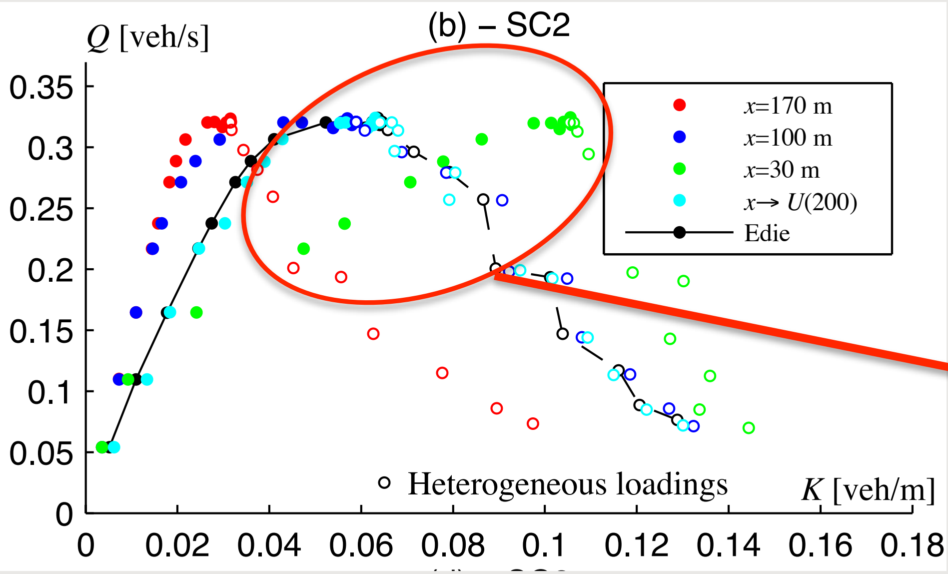
Loops (corrected) VS. Edie methods – SC1



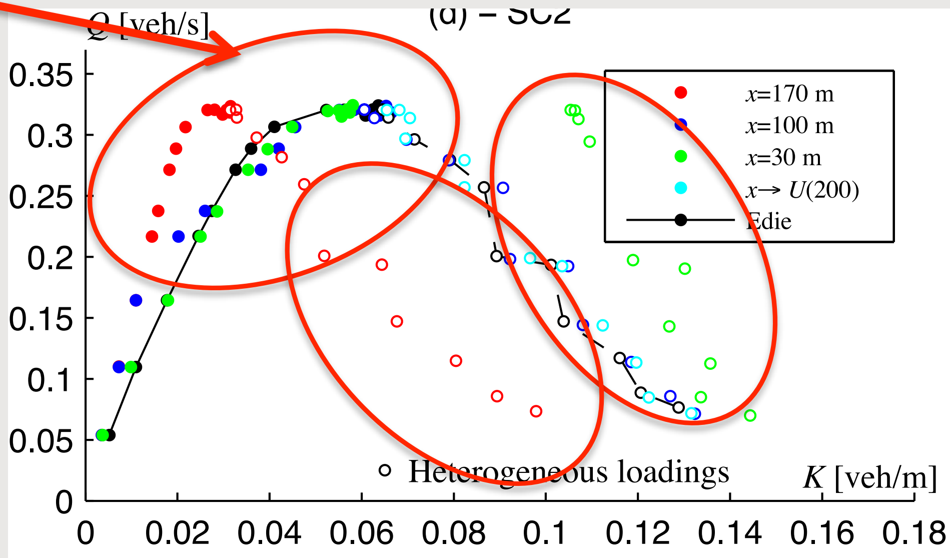


Urban corridor

Loops (corrected) VS. Edie methods – SC2

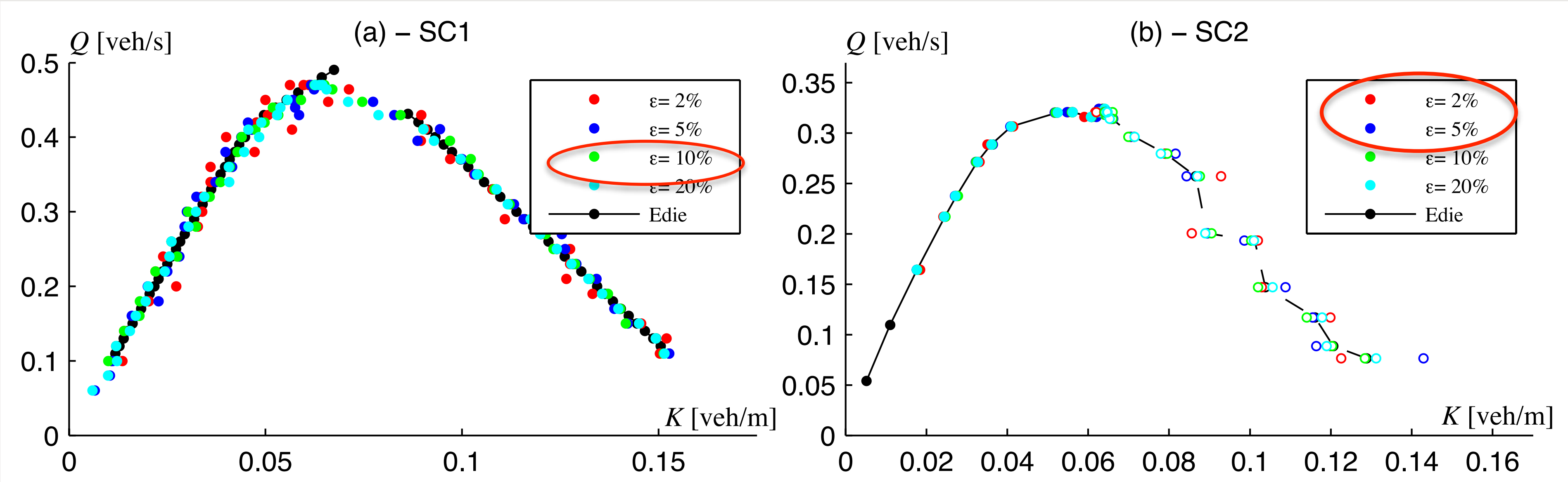


Grid network



The correction method provides few improvements in congestion for such a network

Probes VS Edie methods (1)



Low penetration rates provide accurate estimation for the mean speed

Loops are still needed to capture the mean flow

Conclusion (1)

- The Edie method:
  - always provides the exact estimation of the MFD but requires all the trajectories
- The analytical method:
  - the analytical method leads to a tight estimation for a homogeneously loaded urban corridor
  - For a grid network, the main question is how to scale up the route MFDs to a global MFD.
  - The typical route method provides a appealing balance between simplicity and accuracy

Conclusion (2)

- The loops method:
  - Not relevant for estimating MFD except if loops are numerous and uniformly distributed
  - A correction method can be proposed to reduce the discrepancies due to local observations
- The probes method:
  - Probes provide a accurate estimation of the network mean speed even for low penetration rate (<20%)
  - Loops are still needed for estimating the mean flow

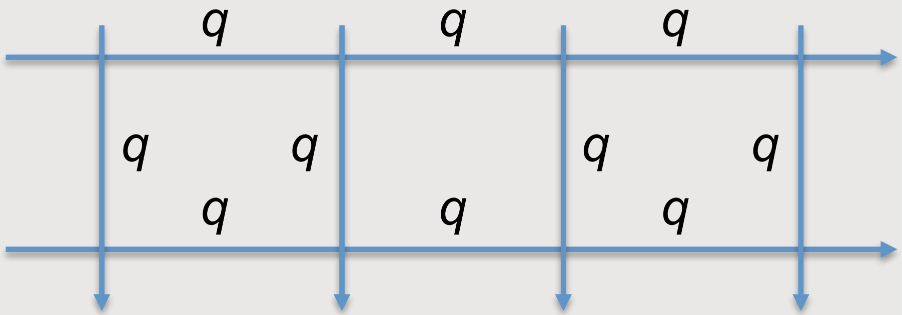
Conclusion (3)

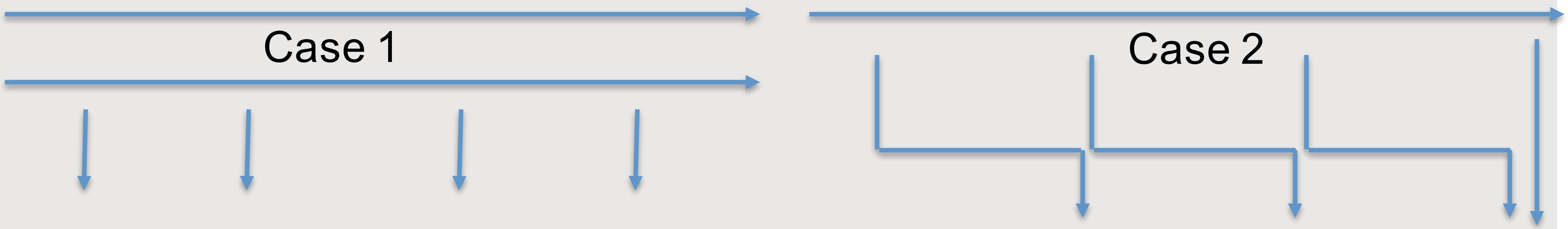
- In this paper we only focus on stationary situations
- The question of filtering stationary states at a network level is very challenging and needs to be investigated

Using MFD for simulation purpose

The macroscopic traffic variables

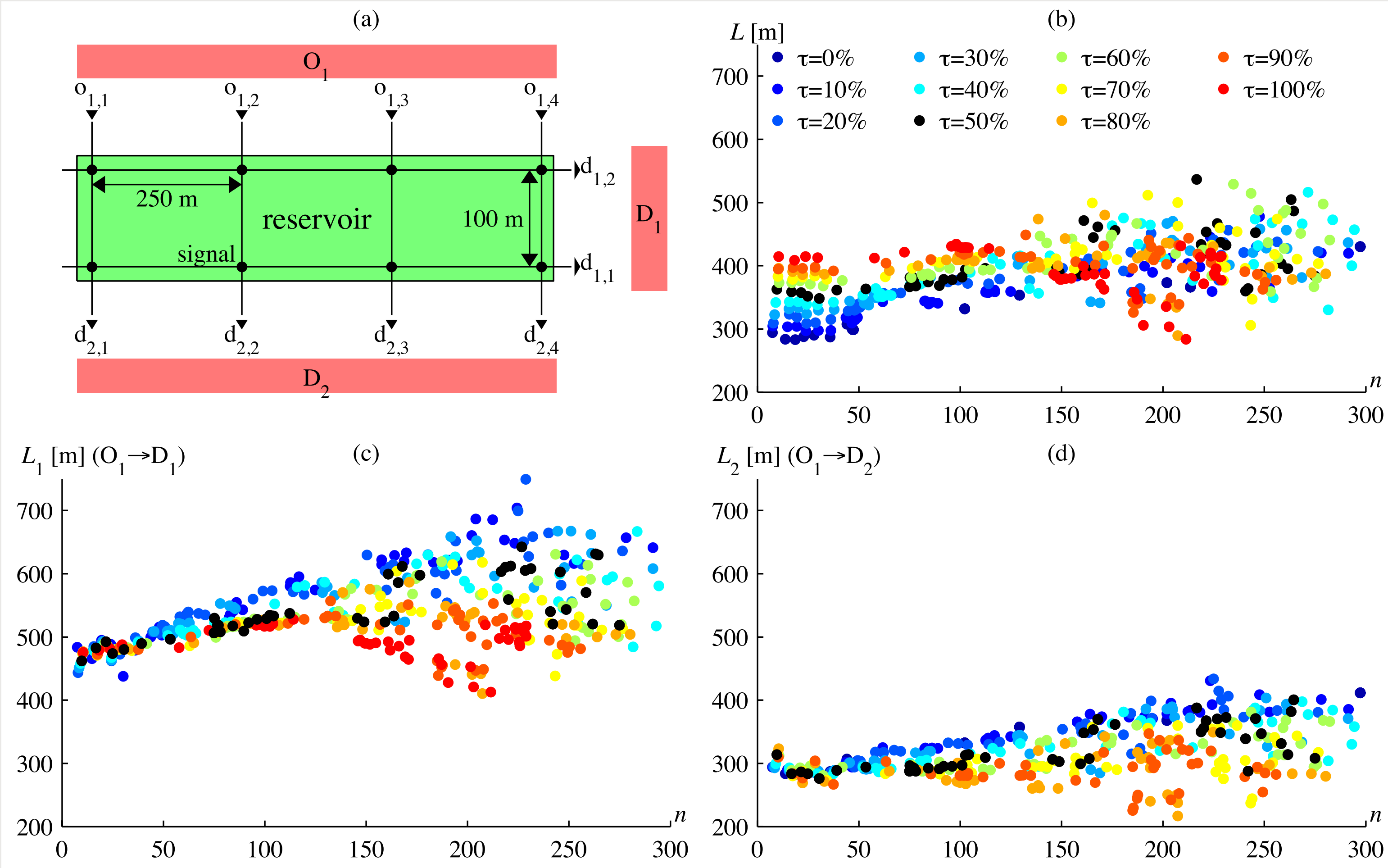
- the number of vehicles (accumulation), *n*;
- the travel production, *P*;
- the mean speed, *V*;
- the mean travel distance, *L*;
- the outflow, *Q*=*P*/*L*;



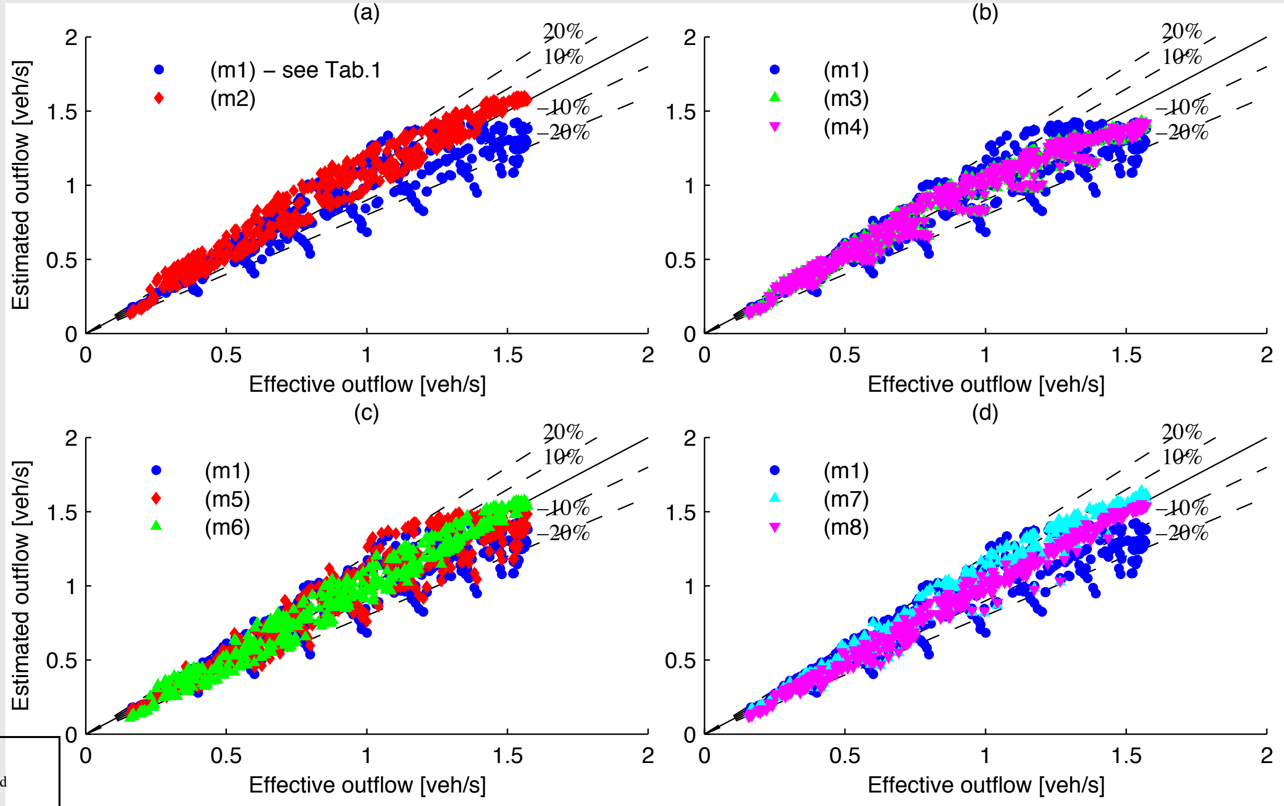


Same networks with same productions
Two outflows due to different route distributions
(and different mean travel distance)

Mean travel distance vs OD matrix



Outflow estimations



Method label	Route lengths (L_1 & L_2)	OD Matrix (τ)	Traffic conditions (n)	Calculation method
(m1)				$L=E(L)$
(m2)	✔			$L=\alpha E(L_1)+(1-\alpha)E(L_2)$
(m3)		✔		$L=E(L\|\tau)$
(m4)	✔	✔		$L=\alpha E(L_1\|\tau)+(1-\alpha)E(L_2\|\tau)$
(m5)			✔	$L=a\,n+b$
(m6)	✔		✔	$L=\alpha(a_1n+b_1)+(1-\alpha)\,(a_2n+b_2)$
(m7)		✔	✔	$L=a_{\|\tau}\,n+b_{\|\tau}$
(m8)	✔	✔	✔	$L=\alpha(a_{1\|\tau}\,n+b_{1\|\tau})+(1-\alpha)\,(a_{2\|\tau}\,n+b_{2\|\tau})$

Conclusion

General conclusion

- MFD is a very promising tool to represent traffic dynamics at large scale
- Lots of researches still to be done:
  - To properly estimation MFD accounting for heterogeneous network loadings and the influence of OD matrix
  - To properly use this concept for simulation purpose

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Thank you for your attention

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