To queue or not to queue

Interesting phenomena from traffic flow theory

20-05-16

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Introduction: traffic

- Traffic jams: €1,5 bil/yr
- Queuing due to too many vehicles on the road
- Queuing on vehicle level, patterns on higher levels
- What are these levels, and what are the patterns?

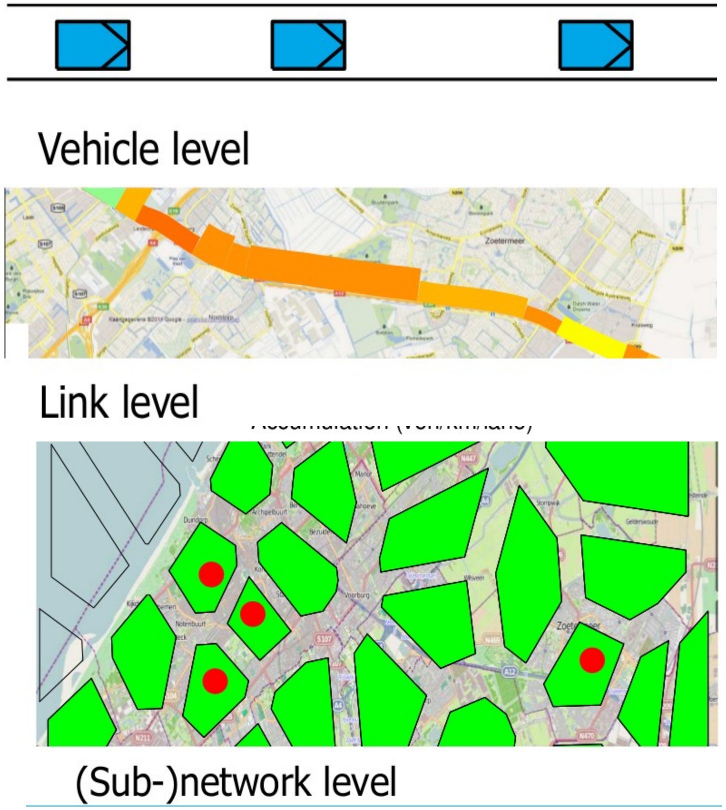
Relationships

Microscopic (vehicle-based)	Macroscopic (flow-based)
Space headway (s [m])	Density (k [veh/km])
Time headway (h [s])	Flow (q [veh/h])
Speed (v [m/s])	Average speed (u [km/h])
s=h*v	q=k*u

- Fundamental relation between q and k and v
- Behavioral relation between k and u (or s and v)

Scales

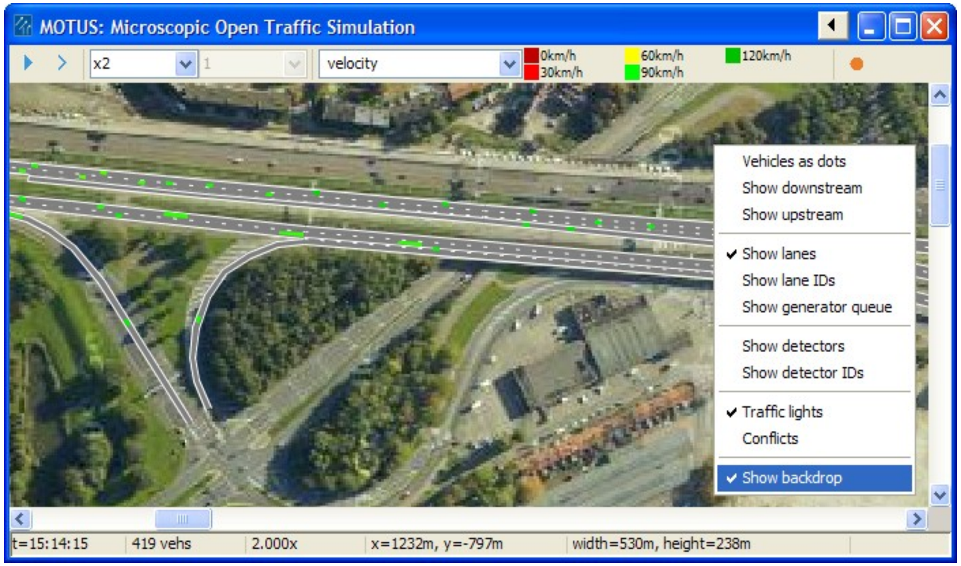
- Microscopic: vehicle level
- Macroscopic: road level
- New level: network level



Microscopic description

To queue or not to queue?

- On a microscopic scale, (average) relations can be given for the accelerations of a driver
- Full system description is possible
  (but time intensive, dependent on models used)



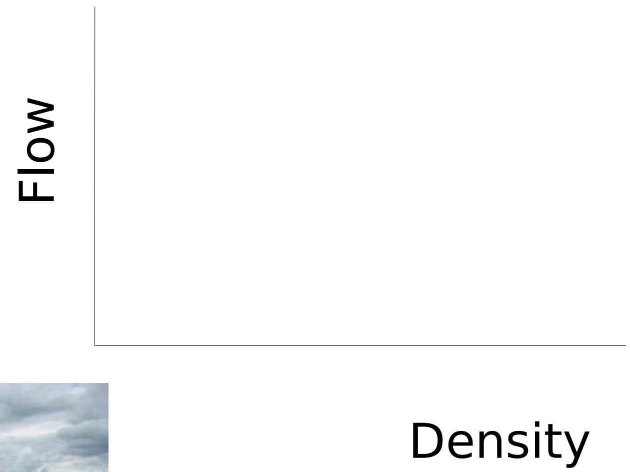
To queue or not to queue?

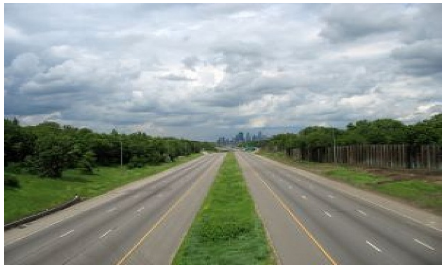
- But: when is traffic congested??
- How to observe as individual driver?

Macroscopic description

Relationships variables

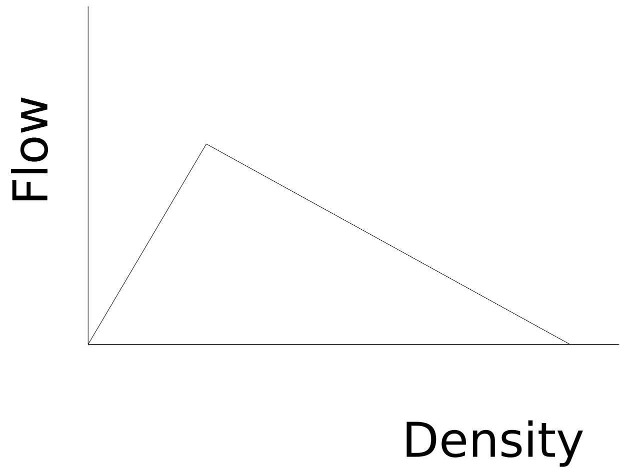
- Given q=ku
- Given a relationship, e.g. u=u(k) (does that make sense?) the traffic state is determined by one variable





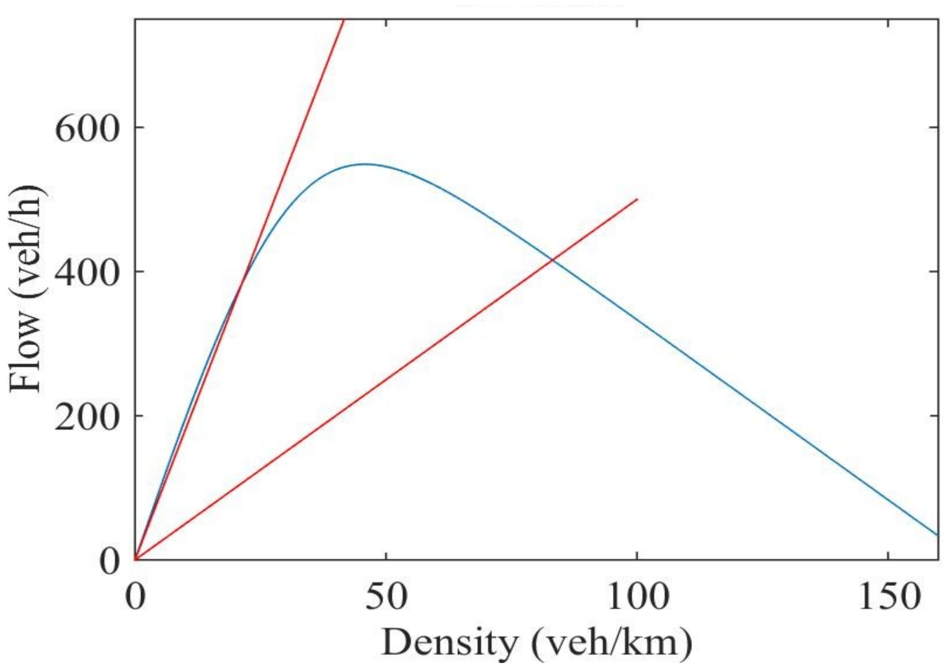
Points characterising the FD

- Up and down in flow-density (often: triangular)
- Critical speed: 100 km/h
- Jam density: 125 veh/km (8 m/veh)
- Capacity: 1/1.5*3600=2400 veh/h/lane
  (=min time headway 1.5 s)



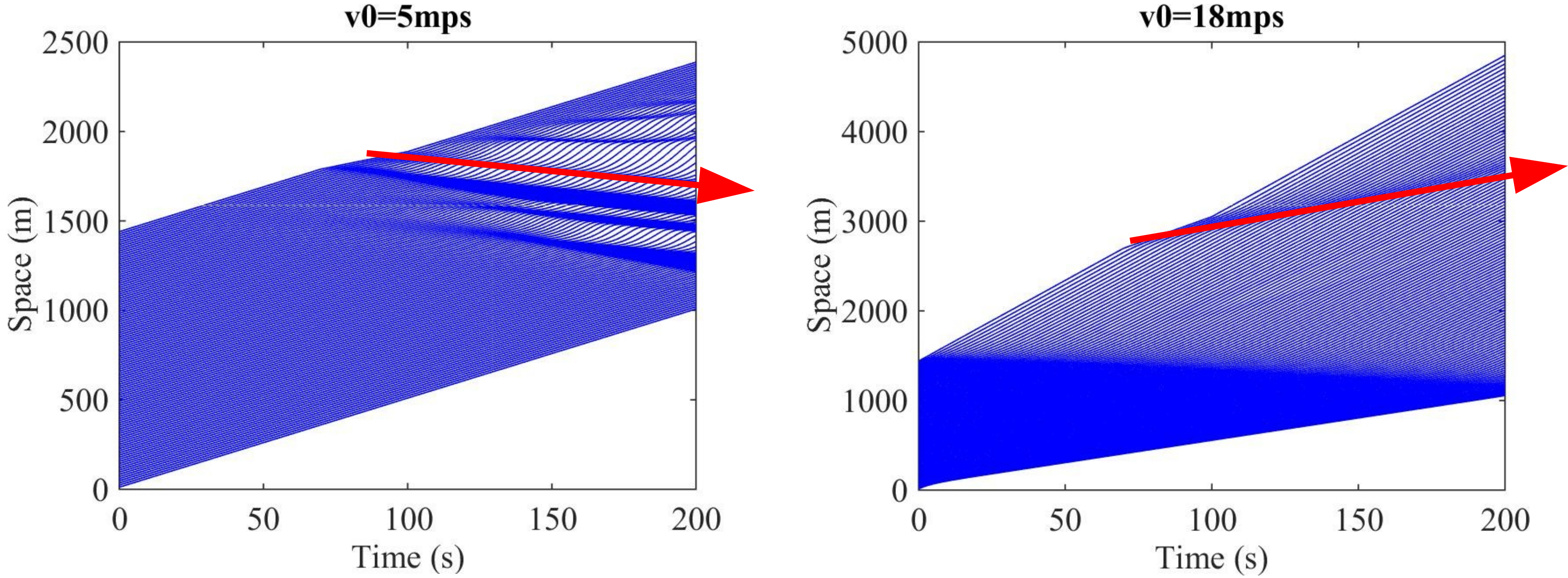
Traffic dynamics

- Fundamental diagram represents equilibrium conditions
- What happens to disturbances?



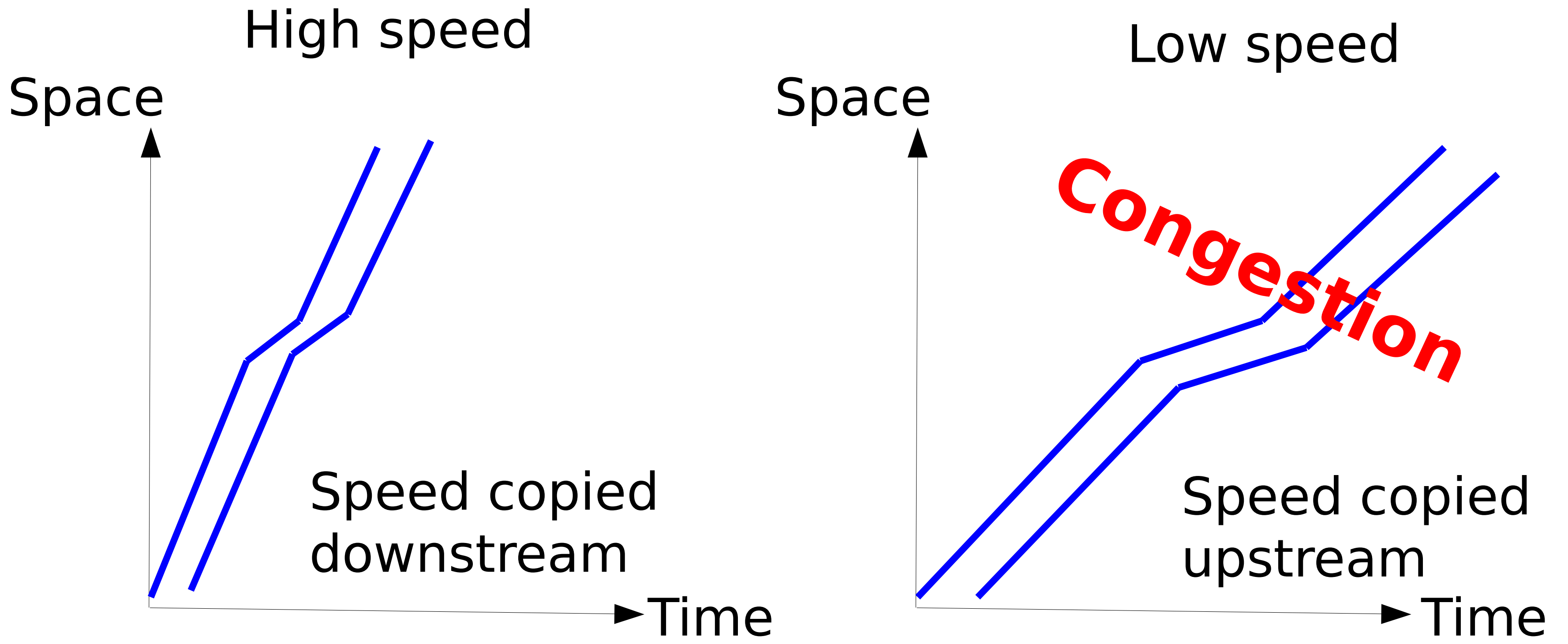
Traffic dynamics

- Fundamental diagram is equilibrium
- What happens to disturbances?



To queue or not to queue

- But: when is traffic congested??
- How to observe as individual driver?

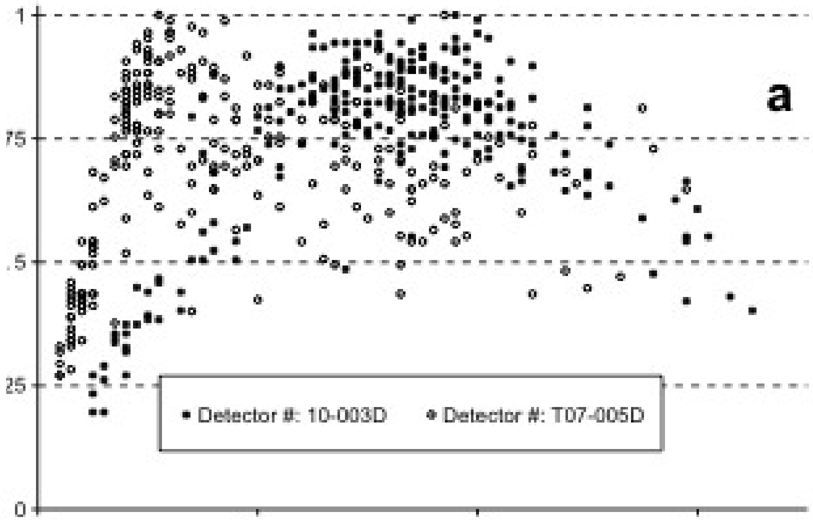


Network Level

Fundamental diagram

- Network Fundamental Diagram
- Average fundamental digram for an area

• Flow

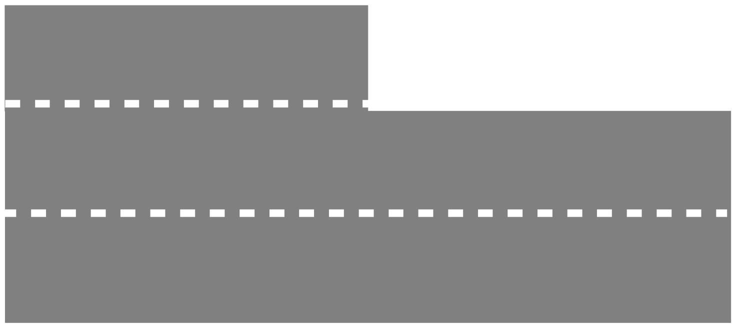


Density

Fig: (Geroliminis and Daganzo)

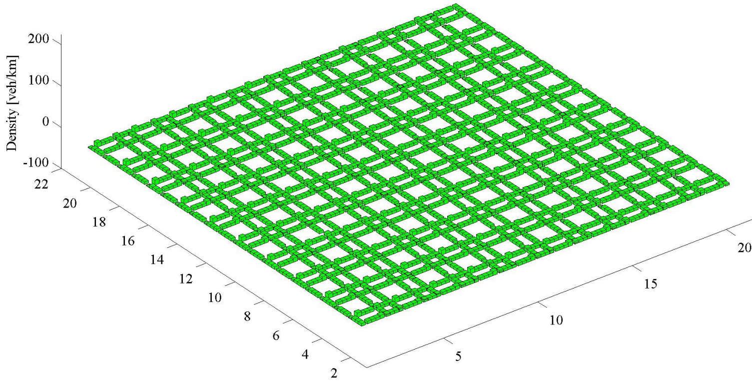
Simple road

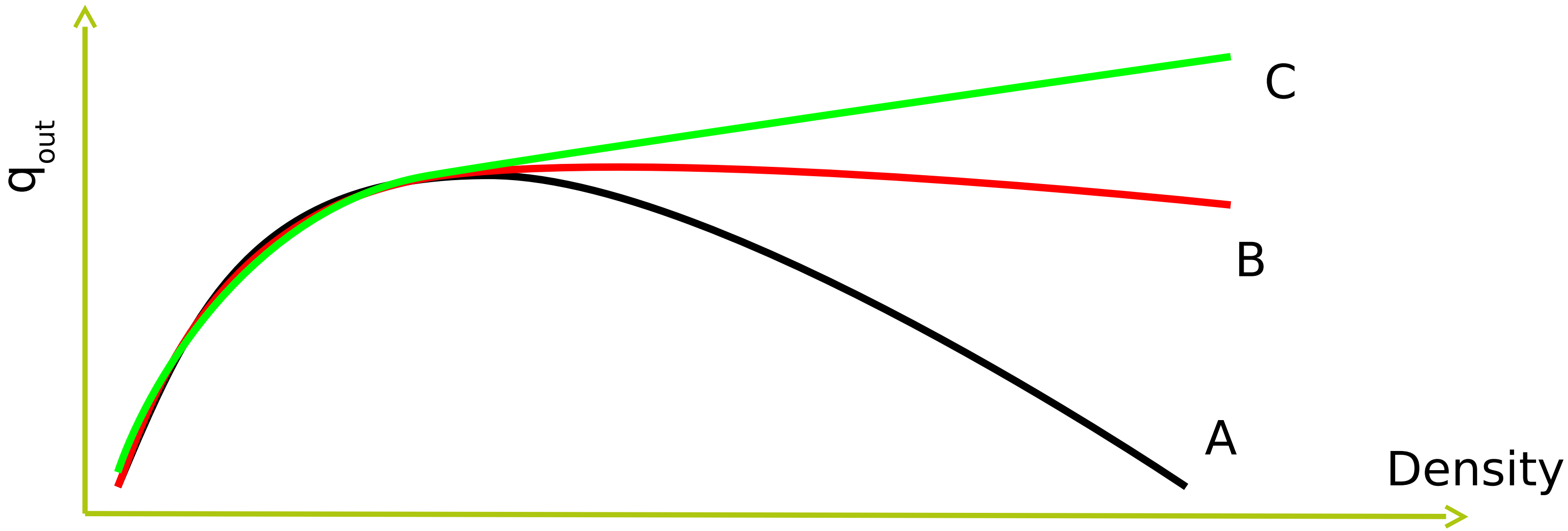
- Road with bottleneck
- Outflow increases with demand and then remains constant



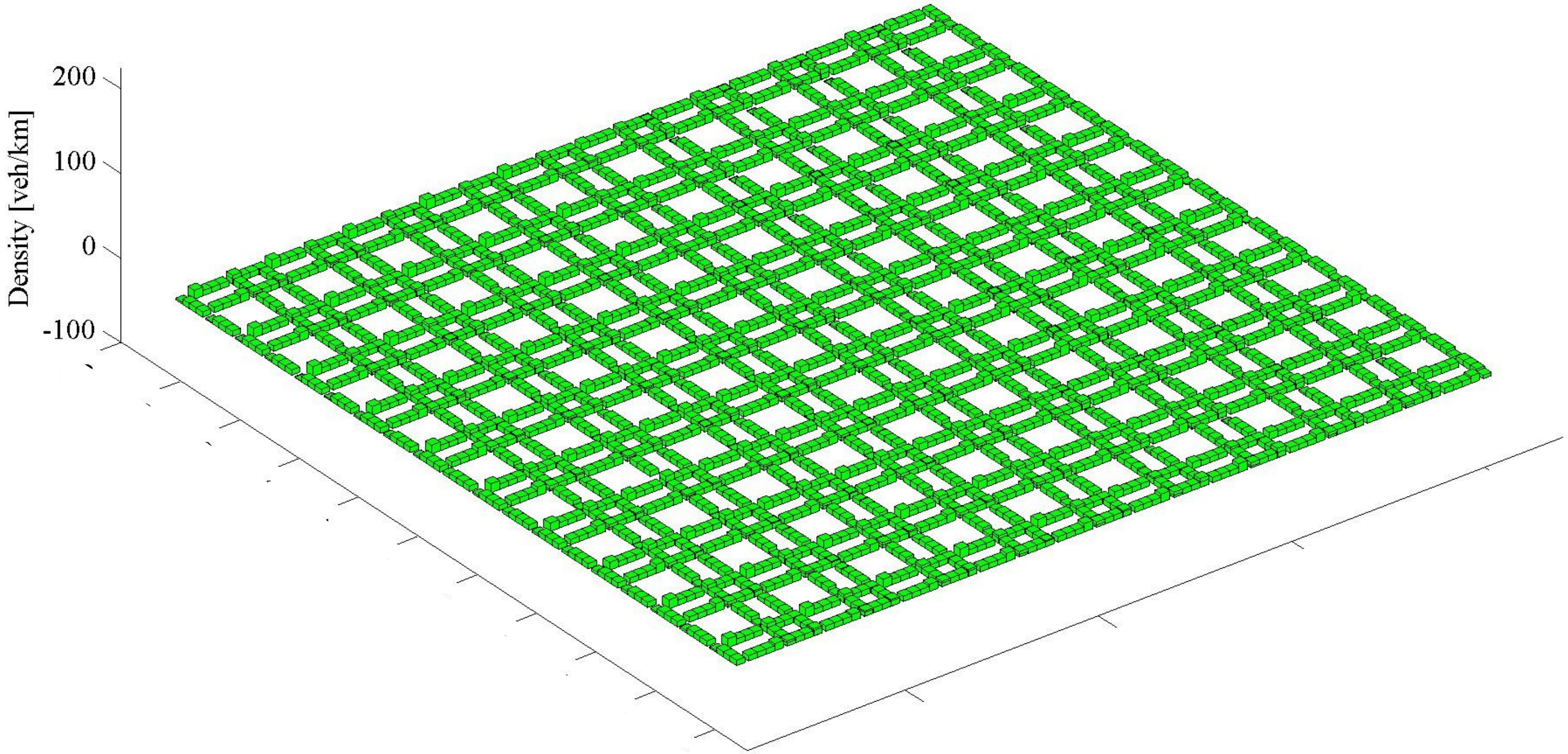
Network Fundamental Diagram

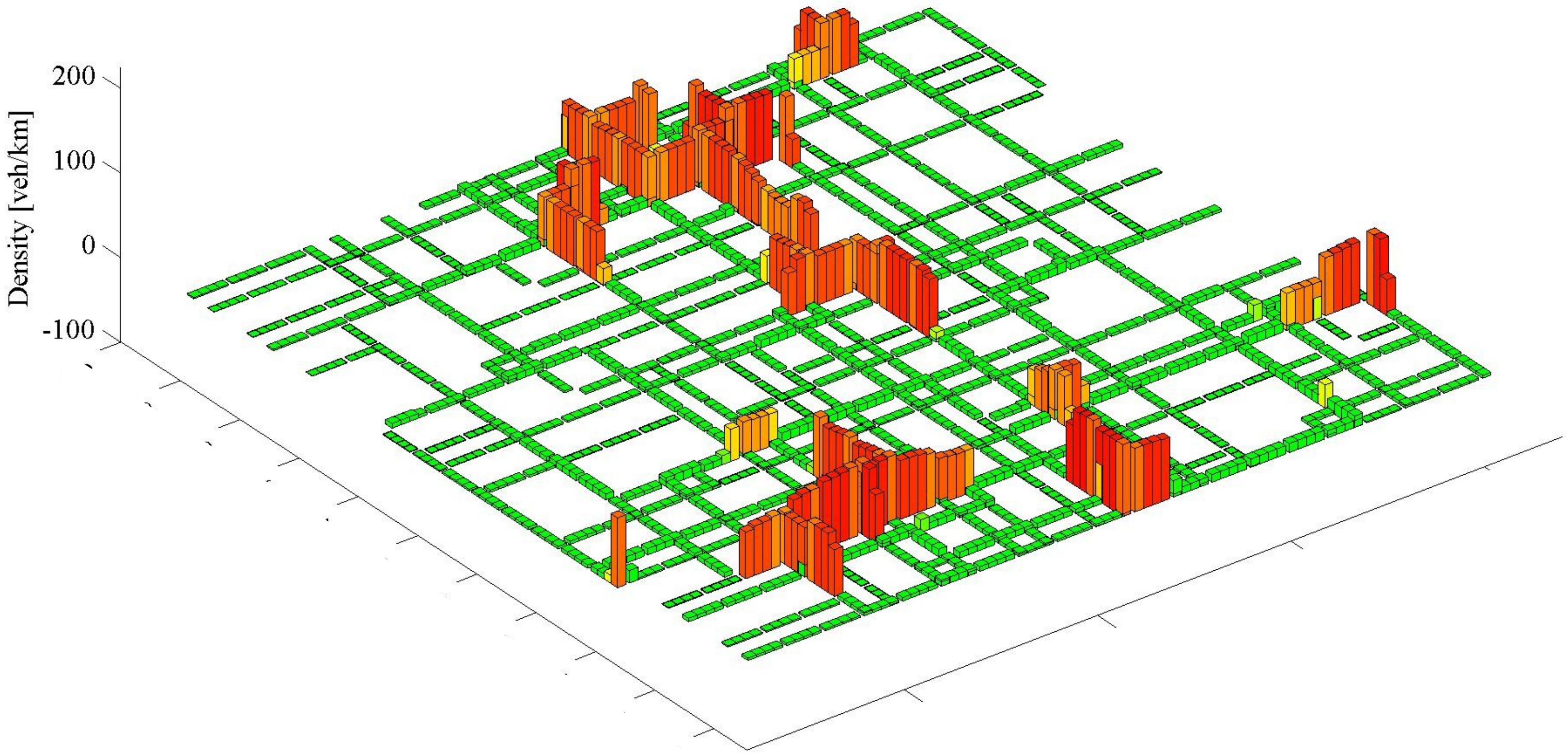
- What happens to the flow if the density increases?

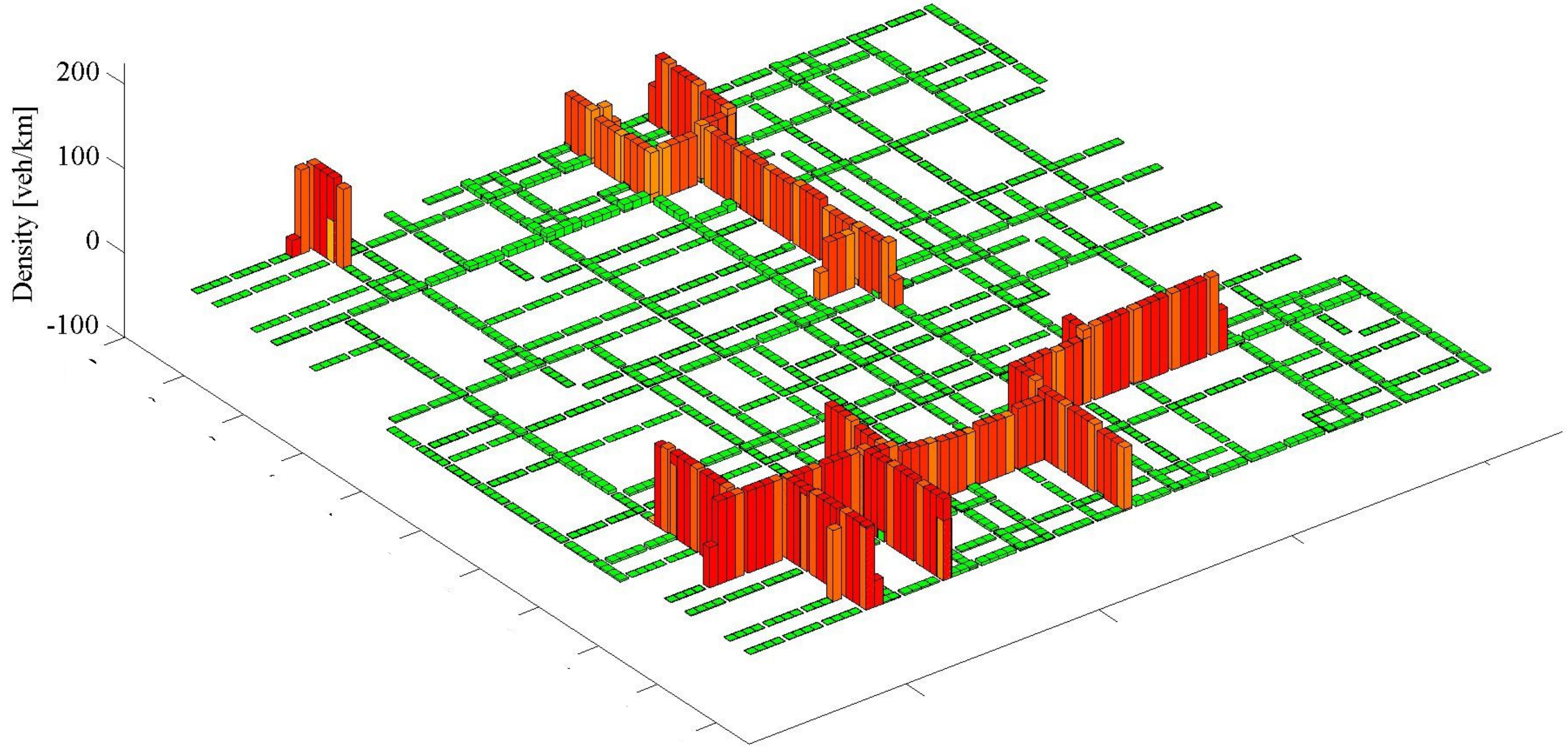




Build up of congestion



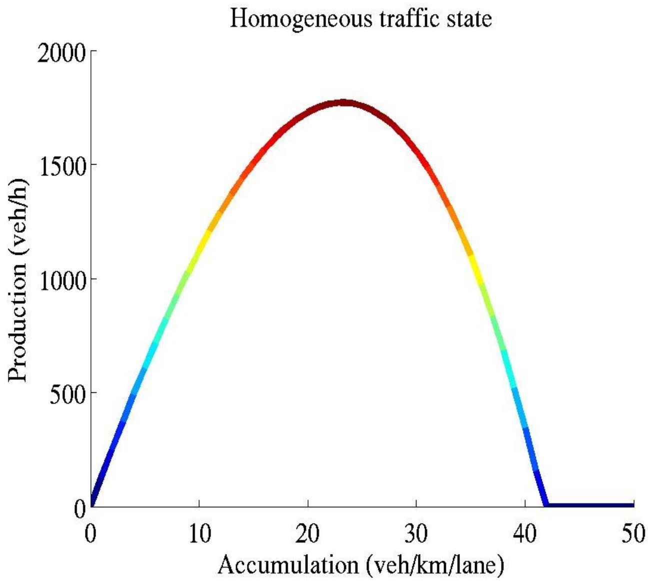

200
100
0
-100
Density [veh/km]

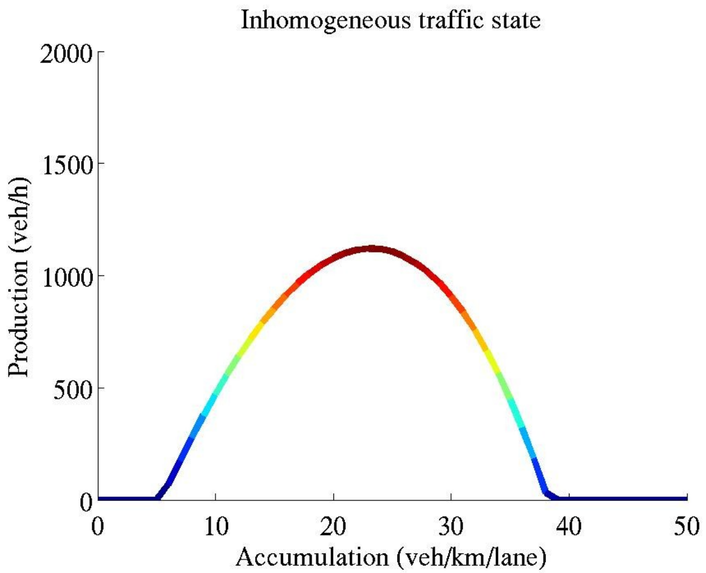


200
100
0
-100
Density [veh/km]

Fitting a functional form

$$P(A)=A*(c1+c2A+c3A2)-c4\sigma$$



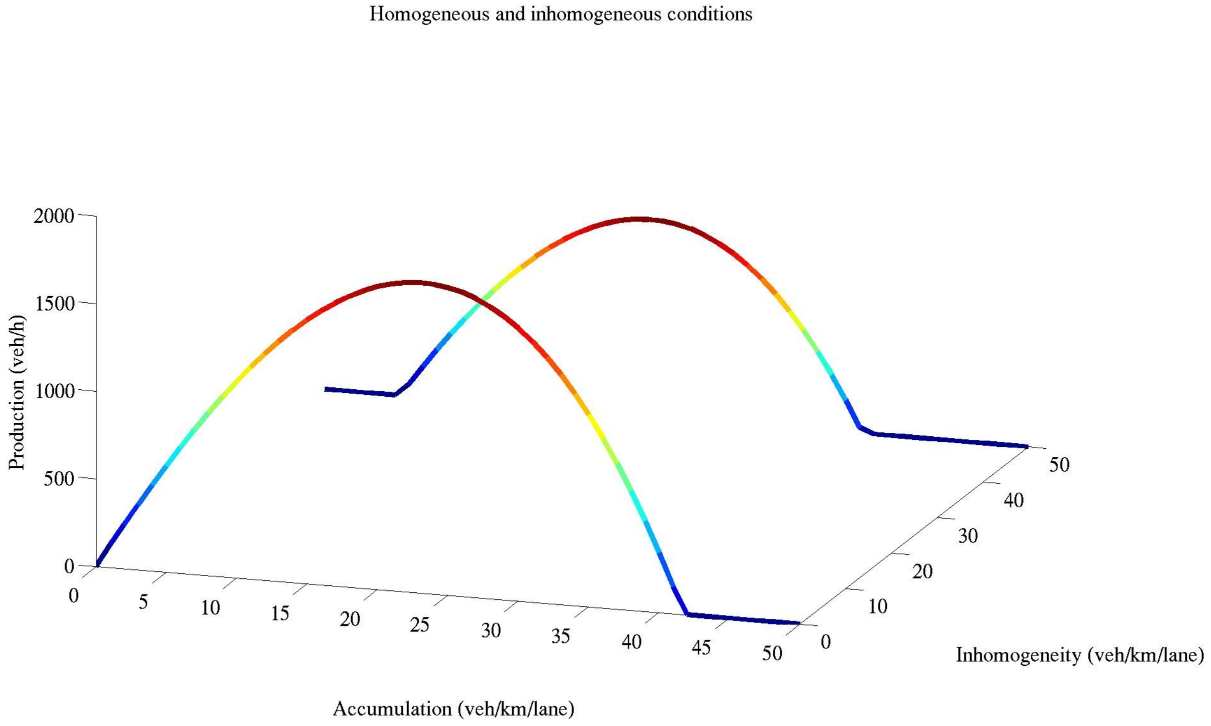


Homogeneous traffic situation

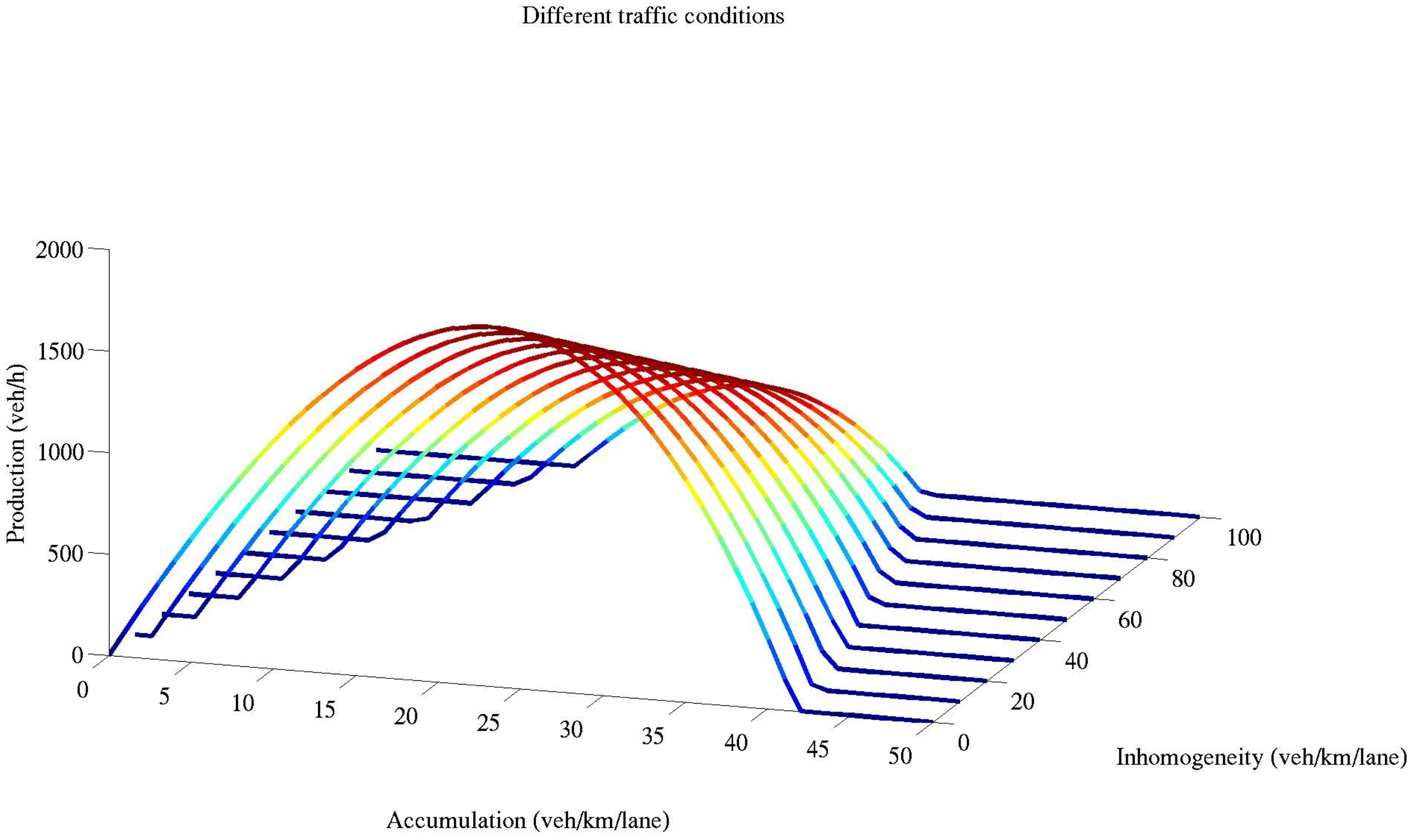
Inhomogeneous traffic situation

Fitting a functional form

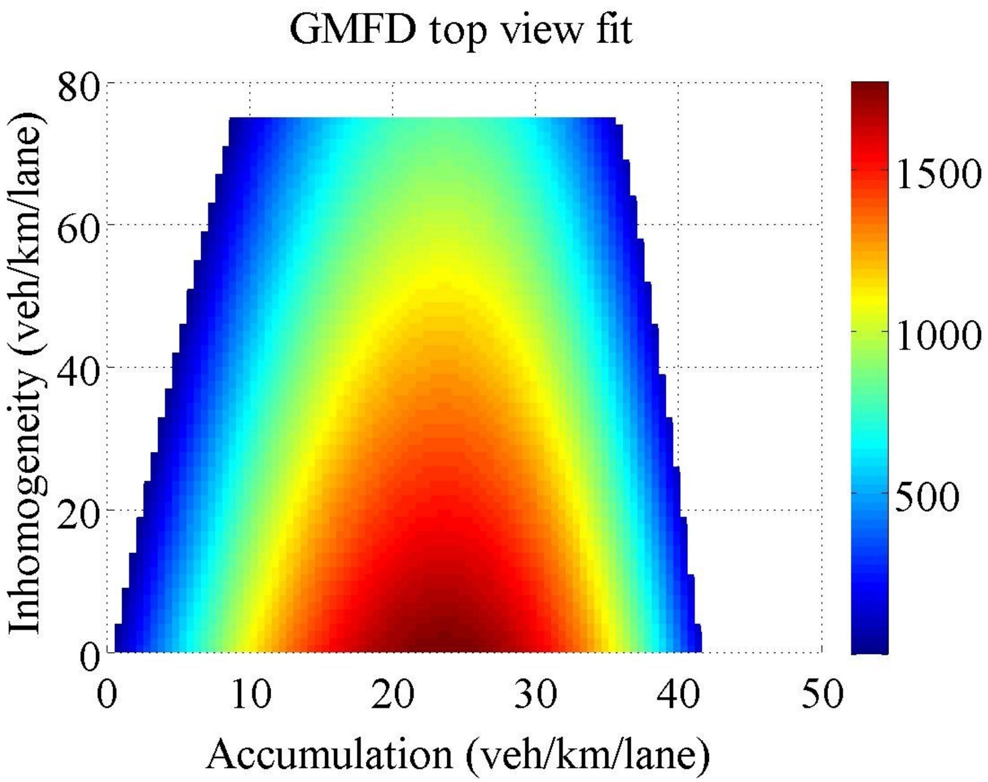
P(A)=A*(c1+c2A+c3A2)-c4σ



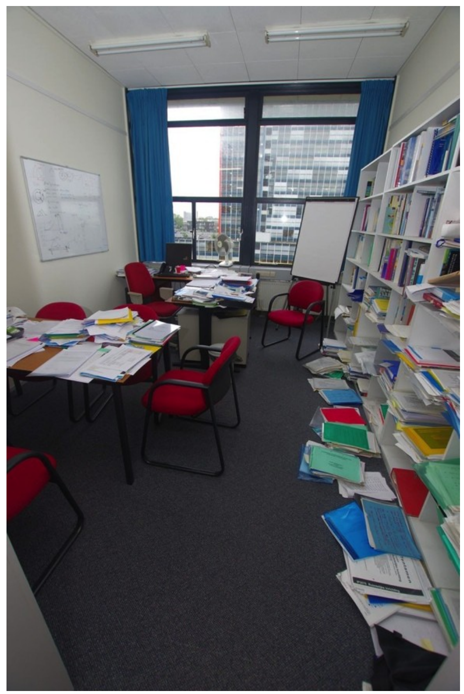
Fitting a functional form



Empirical evidence



Suitable for any queuing application?



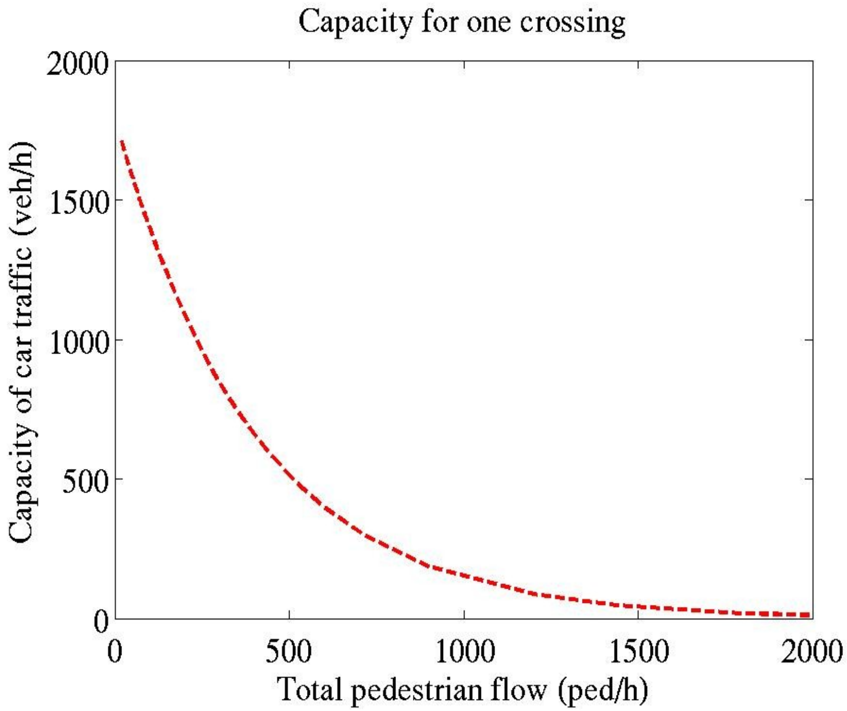
Impact of pedestrians

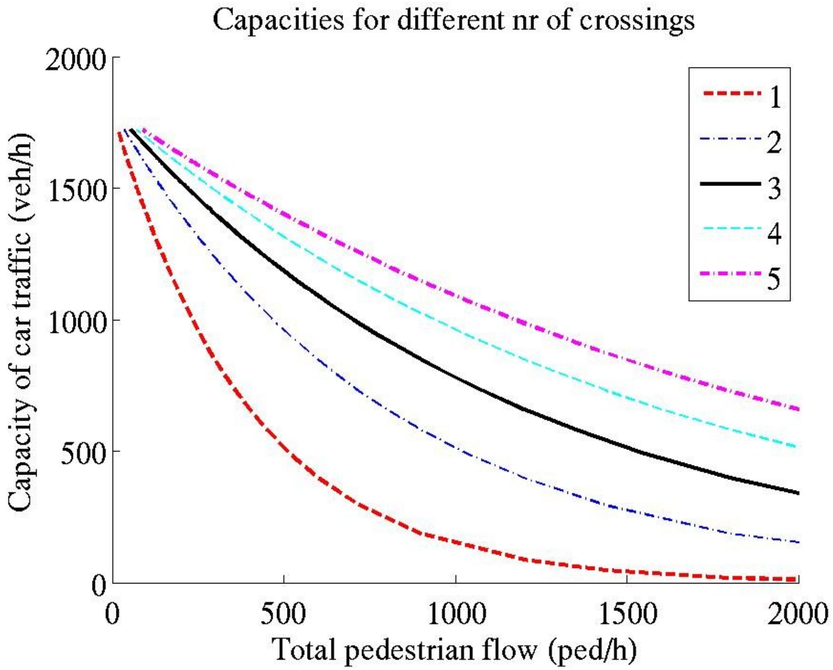
Background

- Known: capacity of the road under one single (fixed timing) pedestrian crossing
- Pedestrian crossings: determine capacity by allowing capacity flow between the pedestrians
- Calculate microscopically: how often do gaps occur which are larger then n times the required time for one vehicle to pass, *gcrit*

$$q_{\text{enter}} = q_{\text{ ped}} \sum_{n=1:\inf} \int_{n \times gcrit}^{(n+1) \times gcrit} P(h) dh$$

Vehicular capacity with pedcrossings





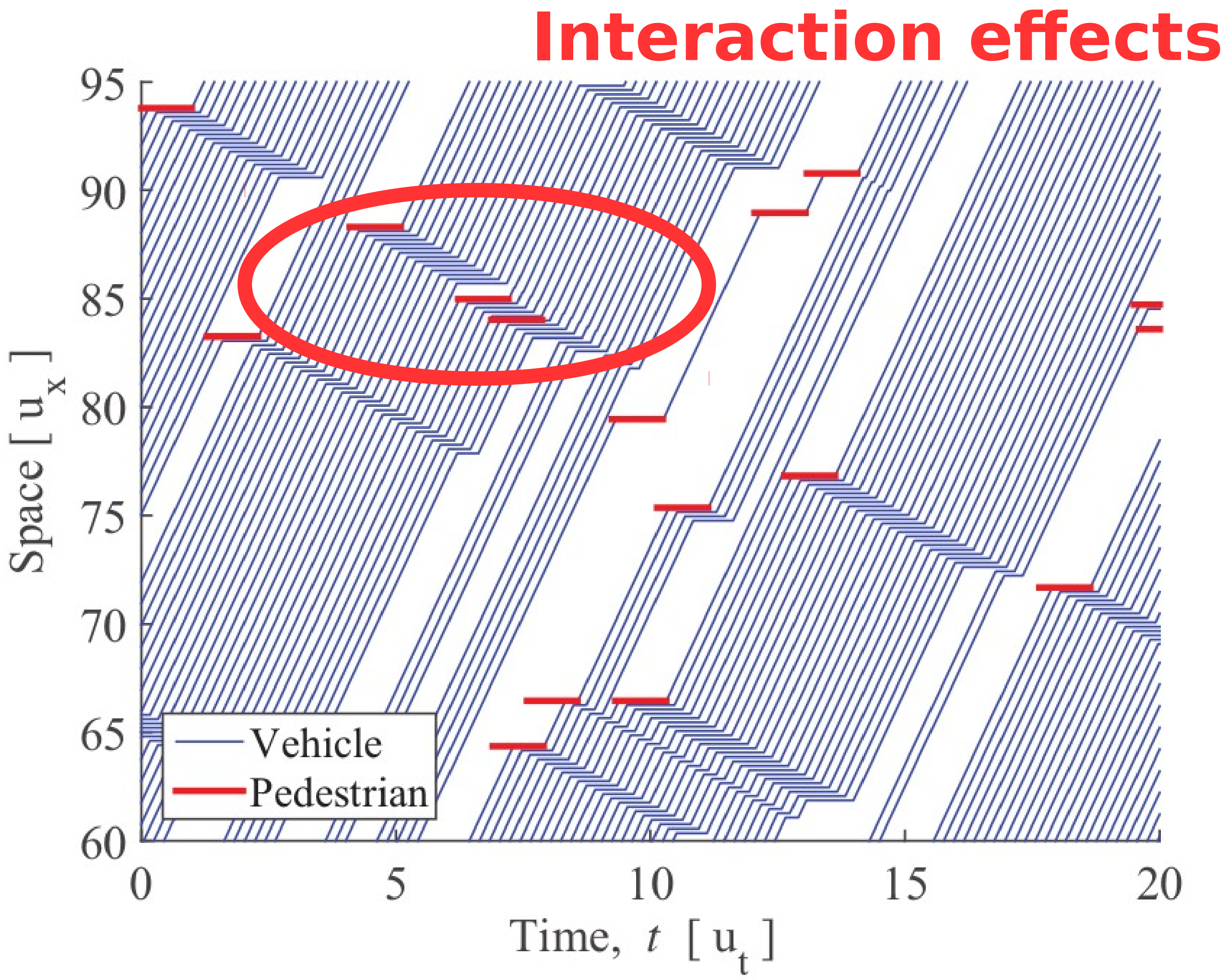
- More crossings help
- No interaction effects taken into accout

Spreading pedestrian load

- Spreading pedestrian load over more pedestrian crossings benefits drivers and pedestrians

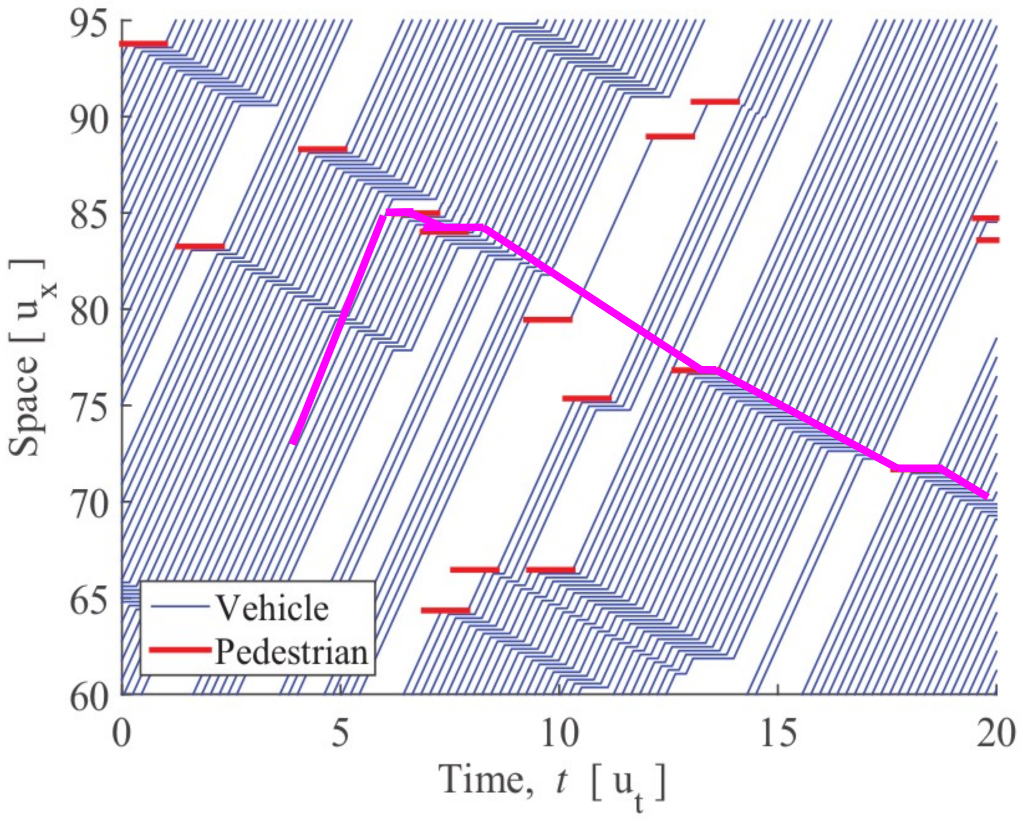
- Extreme case: infinite number of pedestrian crossings, i.e. pedestrians can cross anywhere (but still have priority)

Simulation


Interaction effects
95
90
85
80
75
70
65
60
0
5
10
15
20
Space [u_x]
Time, t [u_t]
Vehicle
Pedestrian

Capacity = shortest path

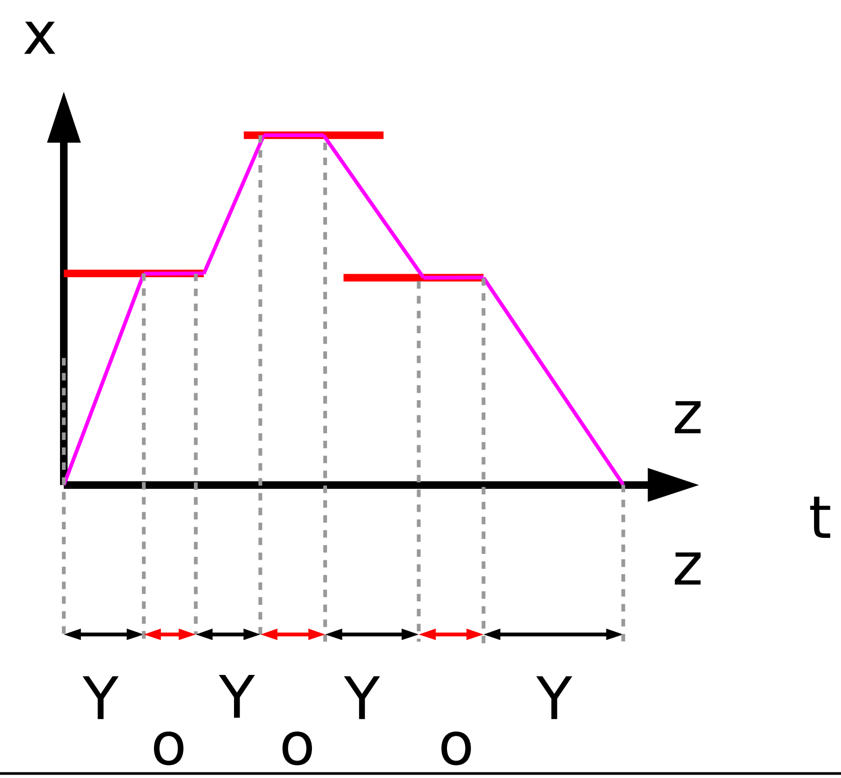
- Flow overtaking moving observer maximized by fundamental diagram
- Capacity minimum overtakings via several paths
- Variational theory: Daganzo, 2005



Analytical boundaries – lower bound

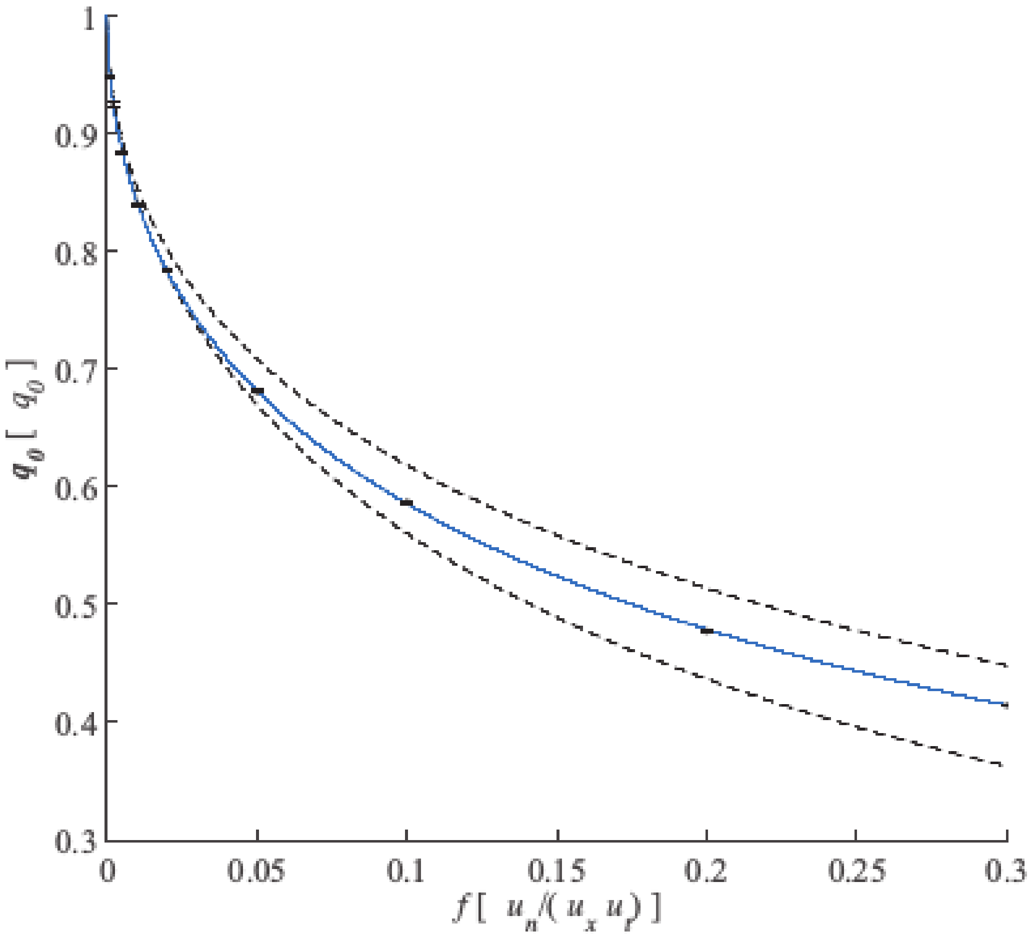
- Given peds,
- Given optimal path = least "cost" = capacity determining path
- Cost for traveling no on ped fixed
- q/qmax= sum(Y)/sum(Y)+sum(o) < q(ped flow f)

$$1/q_o^L = 1 + \left[\frac{2f}{\pi e^{4f}}\right]^{1/2} \left[\tilde{\Phi}(2\sqrt{f})\right]^{-1}$$



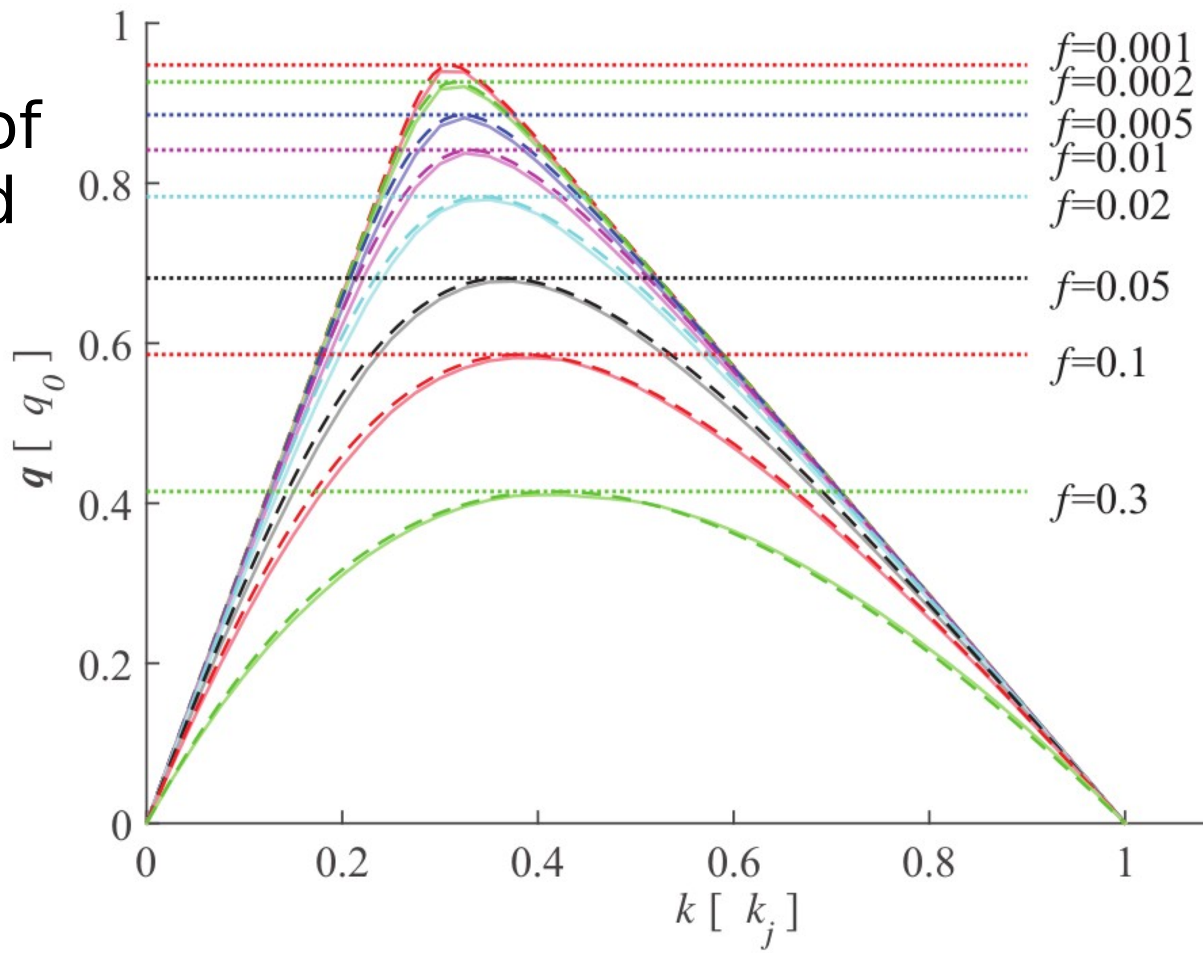
Analytics

- Capacity decreases with pedestrian flow and durtation $f=q_{ped}T_{cross}^2$
- Upper and lower bound analytical
- Capacity estimated (0.2% off)



Simulation and estimation

- Various levels of pedestrian load
- Simulation and estimation
- Very accurate estimation



Conclusions

To queue or not to queue?

- Traffic operates at different levels
- Queuing patterns can be described at macroscopic and network level
- Queues attract queues
- Interaction effects relevant, and solvable
- **Spatial extent is essential**

References and acknowledgement

- Daganzo, C.F. and Knoop, V.L. (2016) Traffic Flow at Pedestrianized Streets. Transportation Research part B, Volume 86, Pages 211-222
- Knoop, V.L., Van Lint, J.W.C., and Hoogendoorn, S.P. (2015), Traffic Dynamics: its impact on the Macropscopic Fundamental Diagram, Physica A, Volume 438, November 2015, pp. 236-250
- Knoop, V.L. and S.P. Hoogendoorn (2013) Empirics of a Generalised Macroscopic Fundamental Diagram for Urban Freeways, in: Transportation Research Records No. 2391, p. 133-141
- Geroliminis, N., and Daganzo. C.F. (2008) Existence of urban-scale macroscopic fundamental diagrams: Some experimental findings. Transportation Research Part B: Methodological Volume 42: 759-770.
- Daganzo, C. F. (2005). A variational formulation of kinematic waves: basic theory and complex boundary conditions. Transportation Research Part B: Methodological, 39(2), 187-196.

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