Introduction to Traffic Flow Theory

13-09-16

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Learning goals

- After this lecture, the students are able to:

  - describe the traffic on a microscopic and macroscopic level

  - apply the relationship $q=ku$

  - draw the fundamental diagram, i.e. $q=q(k)$

  - argue the differences and similarities between relationships on the network level and road level

  - explain the steps in numerical traffic flow models

Part 1: Traffic description

Zone description

Traditional

Microscopic

Macroscopic

New

Zones

- Speed in the zone dependent on nr of vehicles

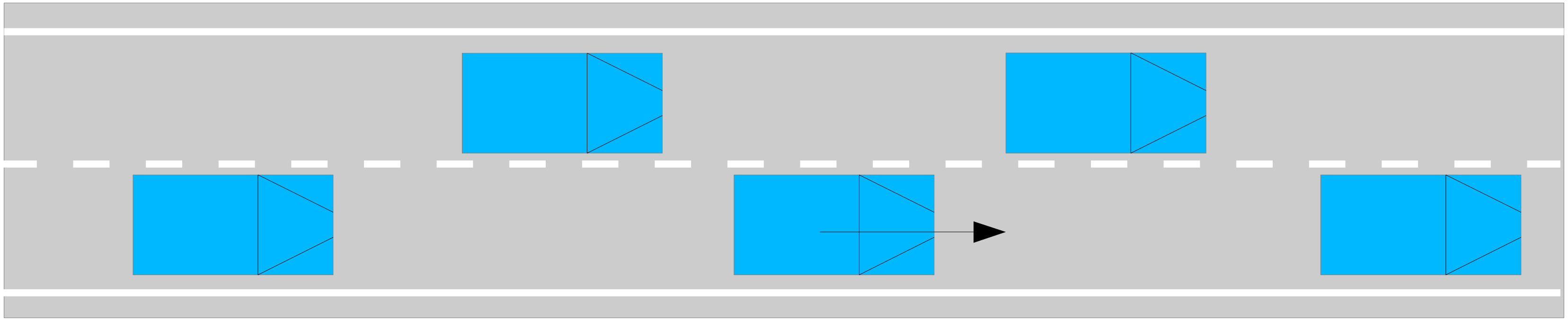
Traffic variables

- Macroscopic equivalents:

1) Speed (v) ~ Average speed (u)

2) Distance headway (s) ~ density (k)

3) Time headway (h) ~ flow (q)



From micro to macro

- Average speed $u = \langle v \rangle$
- density $k = 1/\langle s \rangle$
- Flow $q = 1/\langle h \rangle$
- Pay attention to units!

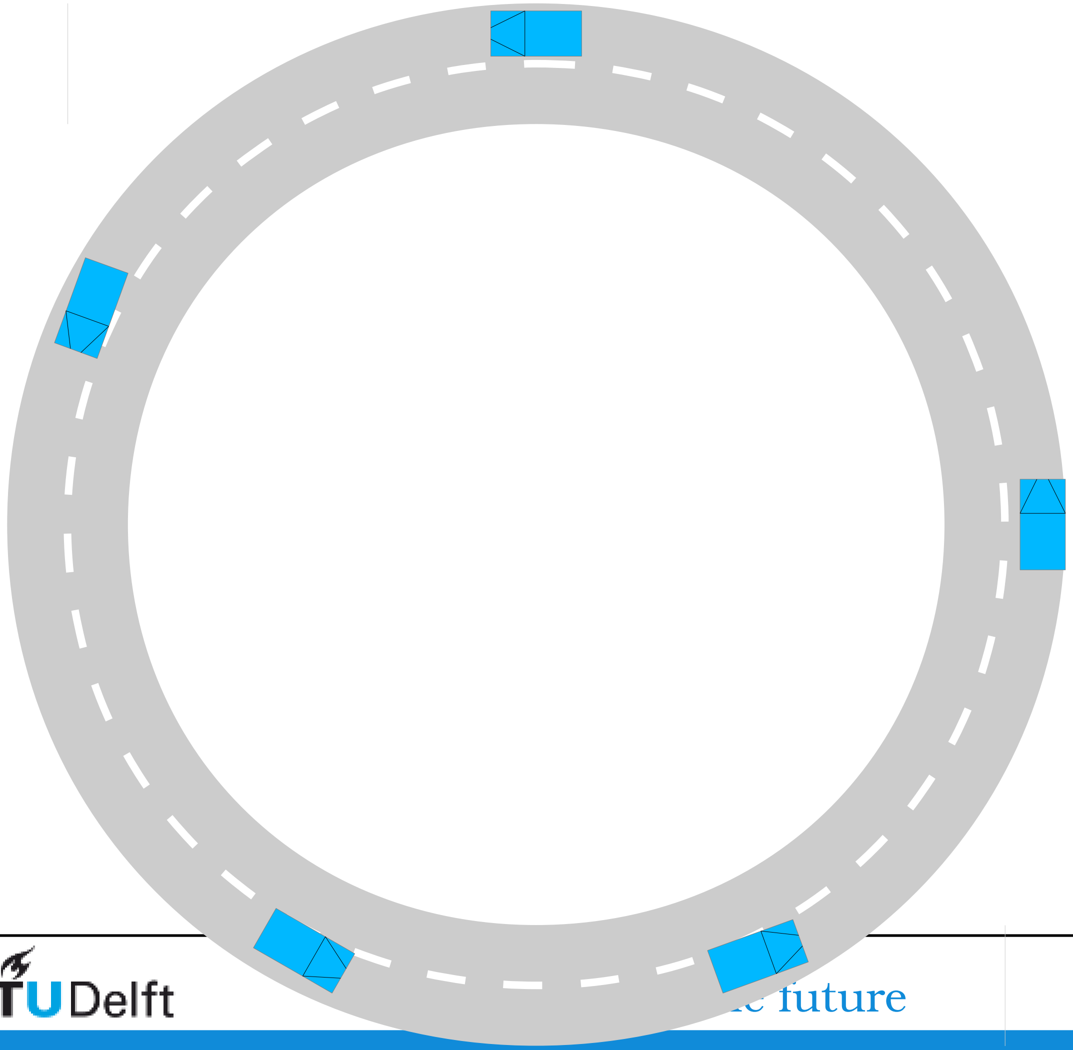
From micro to macro

- Average speed u = <v>
- density k = 1/<s>
- Flow q = 1/<h>
- A road has a density of 20 veh/km,
  what is the average distance headway?
- The average time headway is 4s
  what is the flow?
- The speed is 1 miles/second and the gross
  headway is 5s, what is the flow

Part 2: Traffic relationships

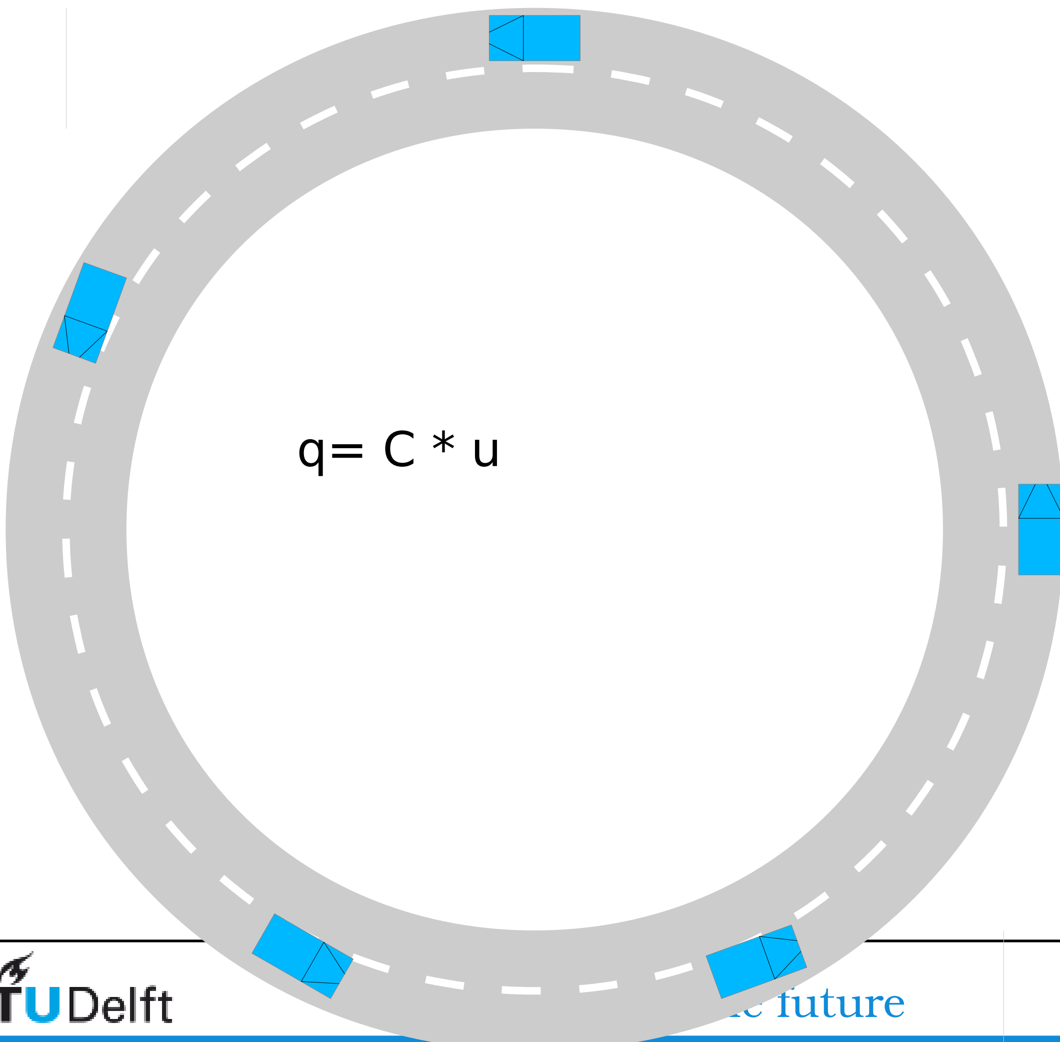
Traffic relationships

- Macroscopic



Traffic relationships

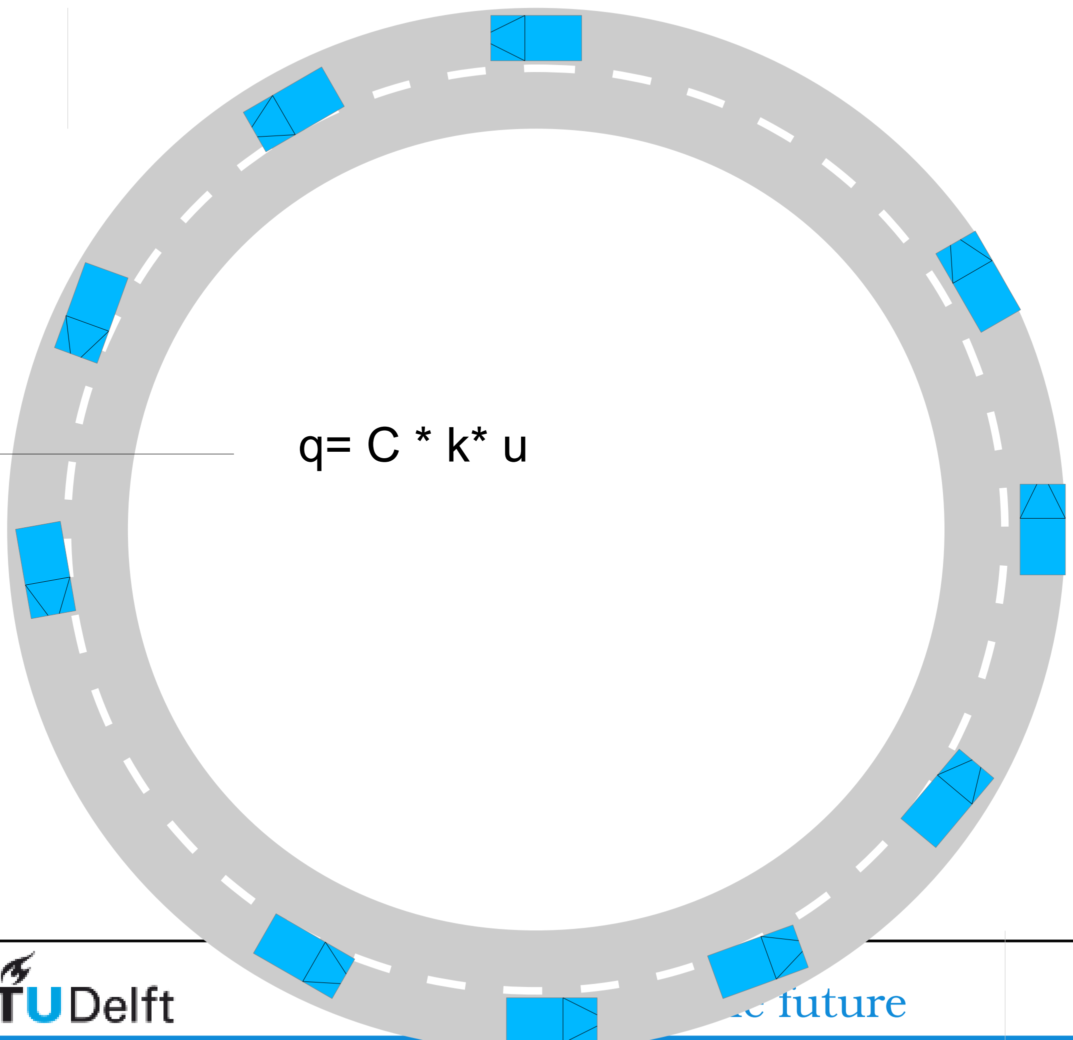
- Macroscopic



$q = C * u$

Traffic relationships

- Macroscopic



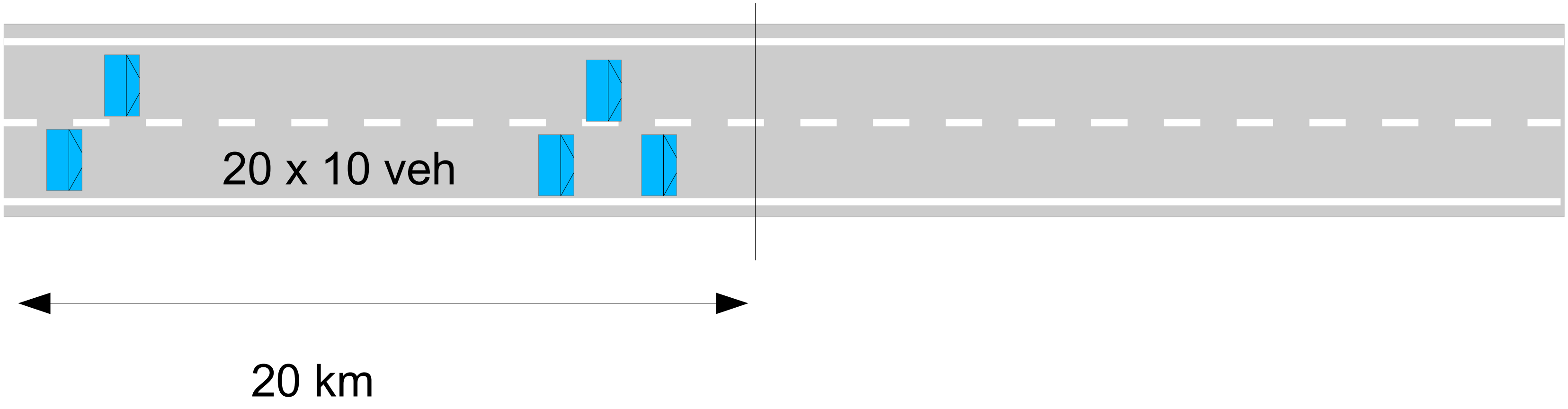
q= C * k* u

Traffic relationships

- Macroscopic

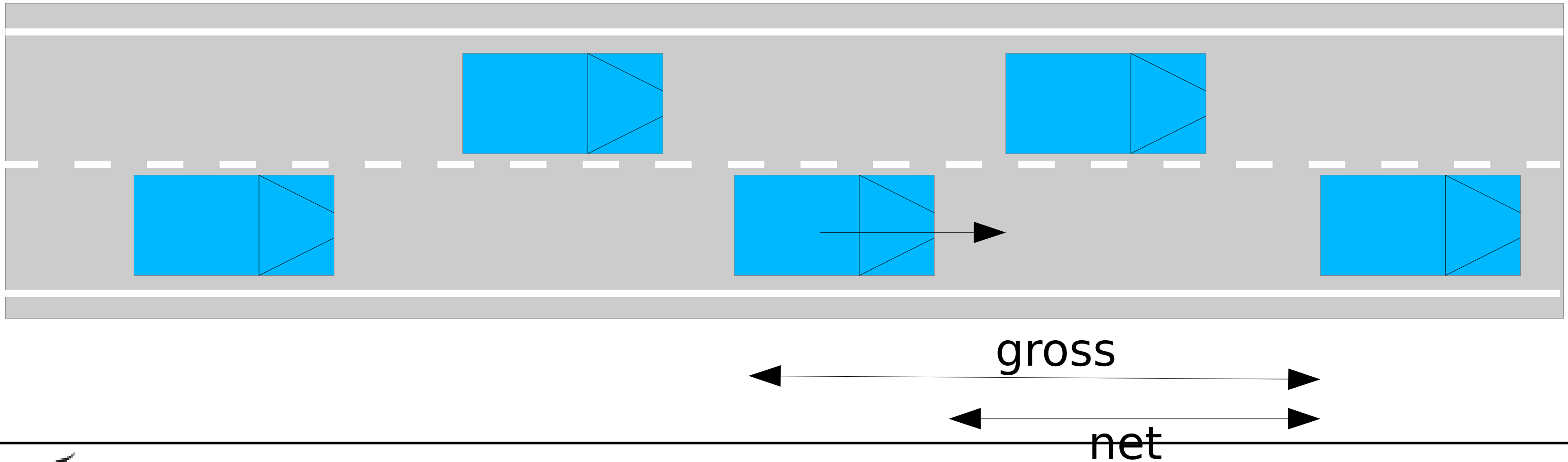
Example:
k=10 veh/km
v=20 km/h

Take a 2x20 km road
In the first 20 km, 20x10=200 veh
All these vehicles pass the detector
in one hour => q=200 veh/h



Traffic relationships

- Microscopic
- Differentiation between gross and net space/time headways
  What is the space headway expressed from the time headway and the speed?



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

Apply q=ku

A road has a density of 20 veh/km, and the average speed is 100 km/h:
what is the flow?

- The flow is 1500 veh/h and the density is 30 veh/km,
  what is the speed?
- The speed is 1 miles/minute and the headway is 5s,
  what is the density?

Part 2b: Behavioral relationships

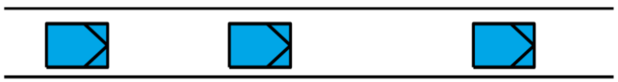
Relationships

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])
$s=h*v$	$q=k*u$

- q is found from k and u (theoretically)
- Additionally is there a (behavioral) relation between k and u

Zone description

Traditional



Microscopic

Macroscopic

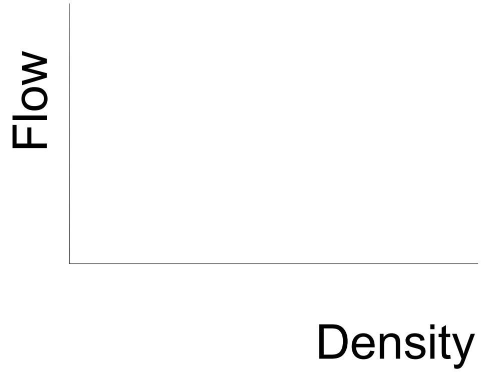
New

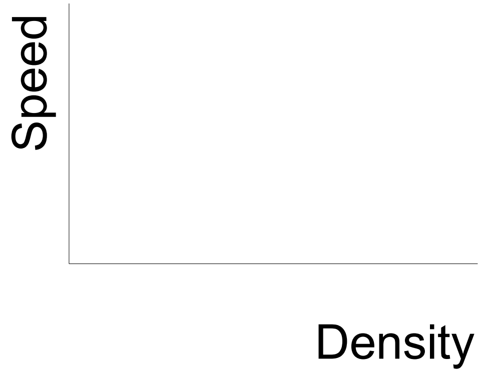
Zones

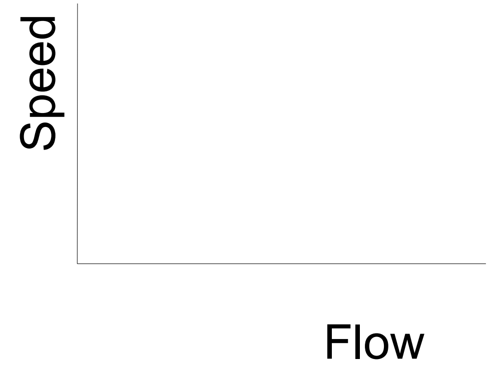
- Speed in the zone dependent on nr of vehicles

Relationships variables

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

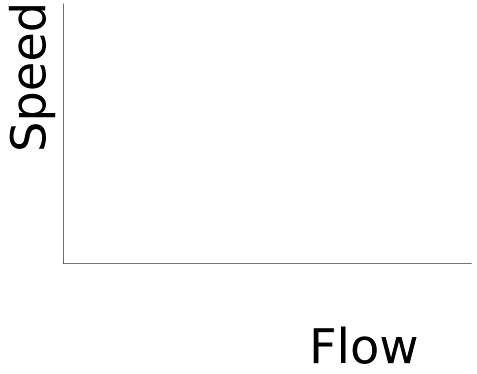






Exercise

- Determine a realistic relationship between two variables (First qualitatively, maybe add typical points later)
- Derive the fundamental diagrams:



Exercise

- Determine a realistic relationship between two variables (First qualitatively, maybe add typical points later)
- De ental d
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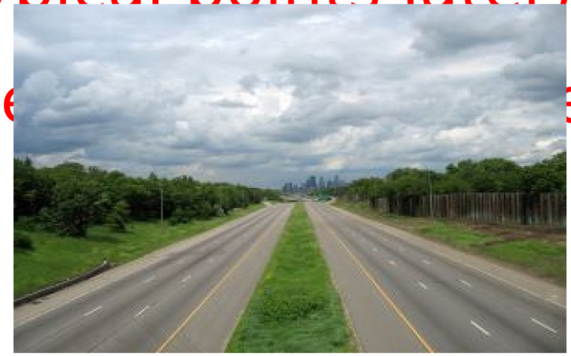
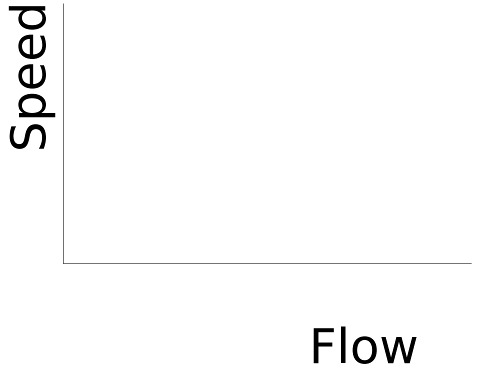
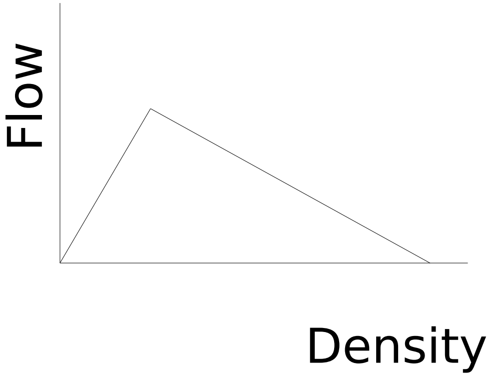
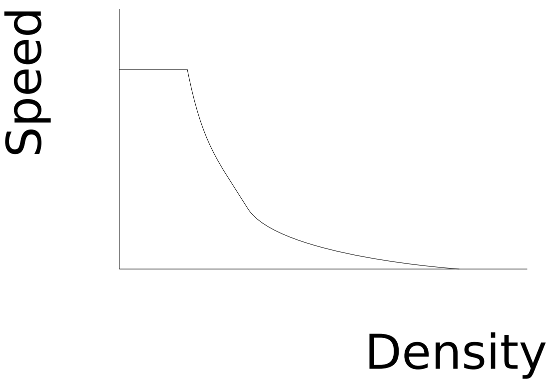


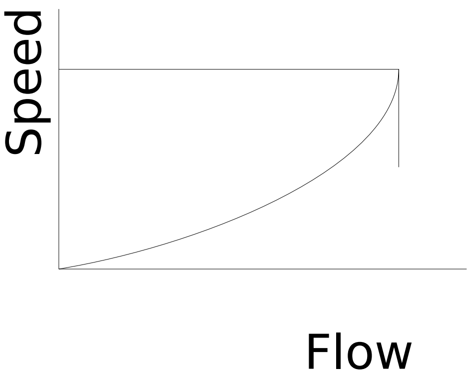


Points characterising the FD

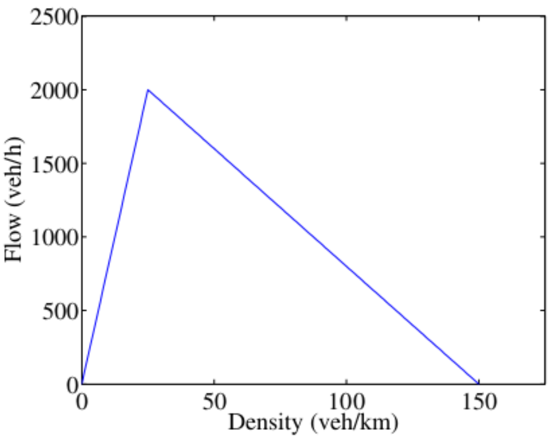
- Often modelled: triangular in flow-density
- Critical speed: 100 km/h
- Jam density: 125 veh/km (8 m/veh)
- Capacity: 1/1.5*3600=2400 veh/h/lane (=min time headway 1.5 s)



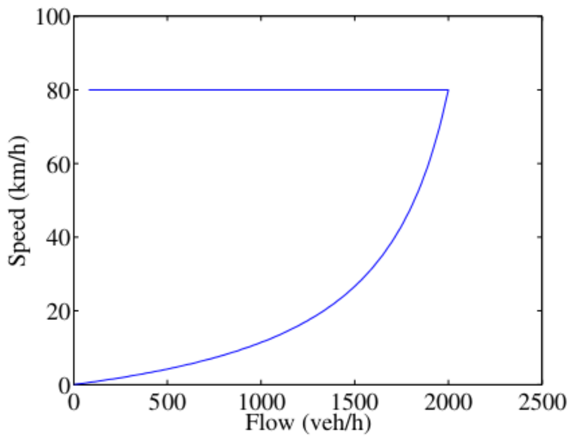




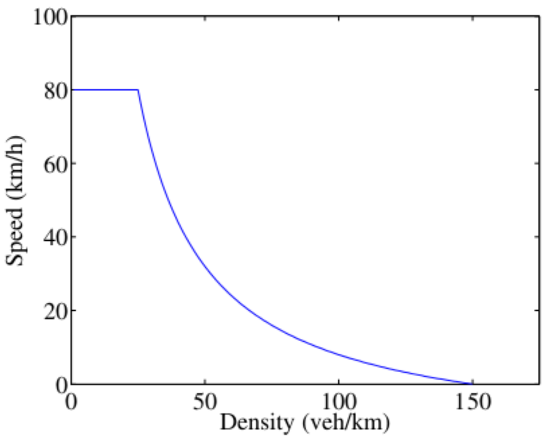
Triangular



Flow (veh/h)
2500
2000
1500
1000
500
0
0
50
100
150
Density (veh/km)

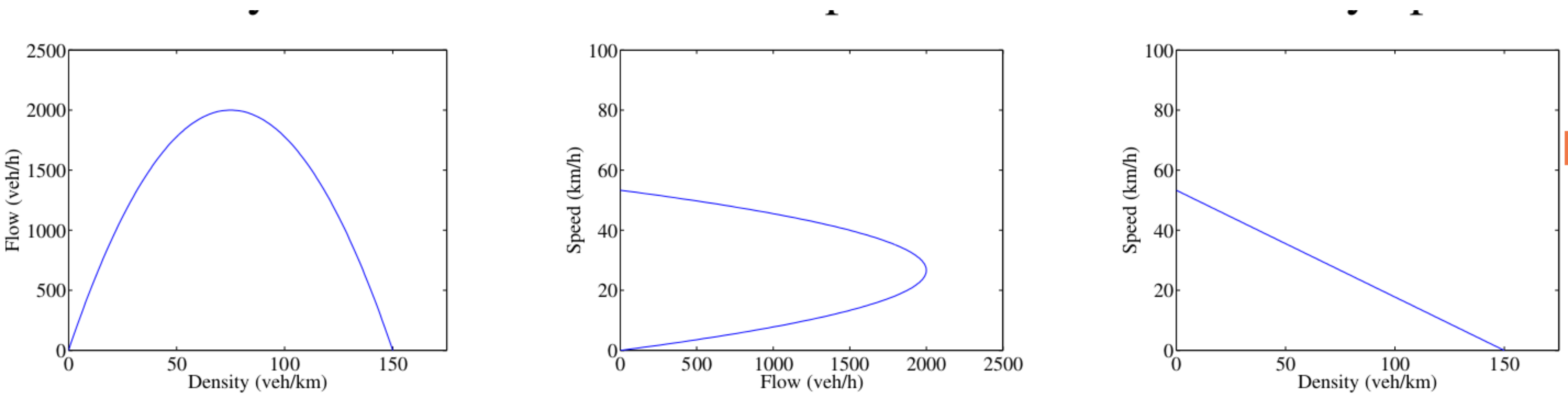


Speed (km/h)
100
80
60
40
20
0
0
500
1000
1500
2000
2500
Flow (veh/h)

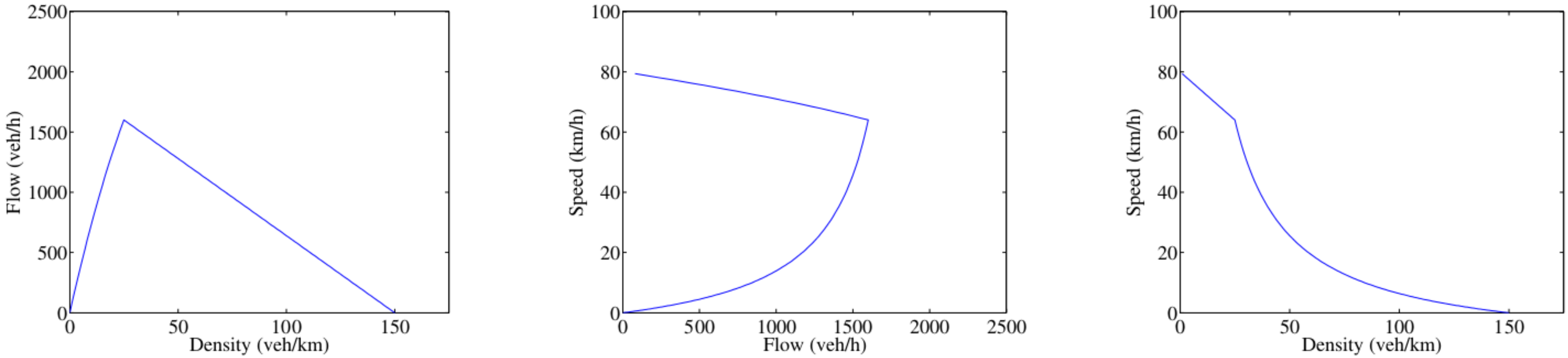


Speed (km/h)
100
80
60
40
20
0
0
50
100
150
Density (veh/km)

Greenshields



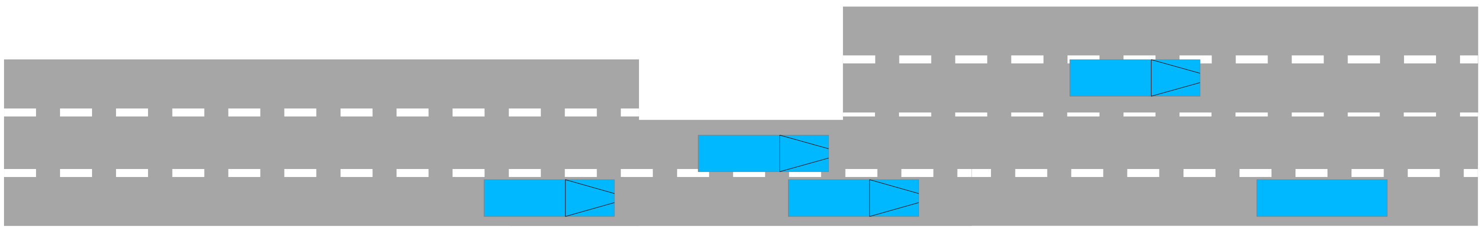
Smulders

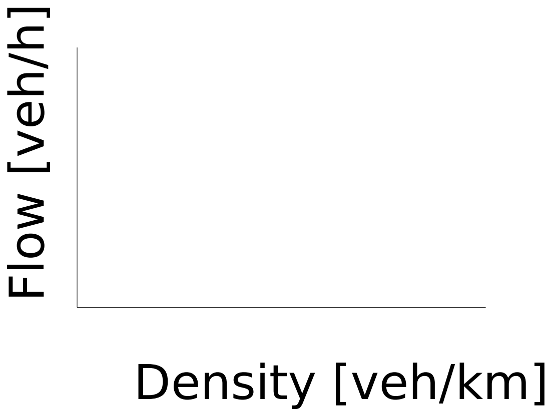

Flow (veh/h)
2500
2000
1500
1000
500
0
0
50
100
150
Density (veh/km)
Speed (km/h)
100
80
60
40
20
0
0
500
1000
1500
2000
2500
Flow (veh/h)
Speed (km/h)
100
80
60
40
20
0
0
50
100
150
Density (veh/km)

Differences

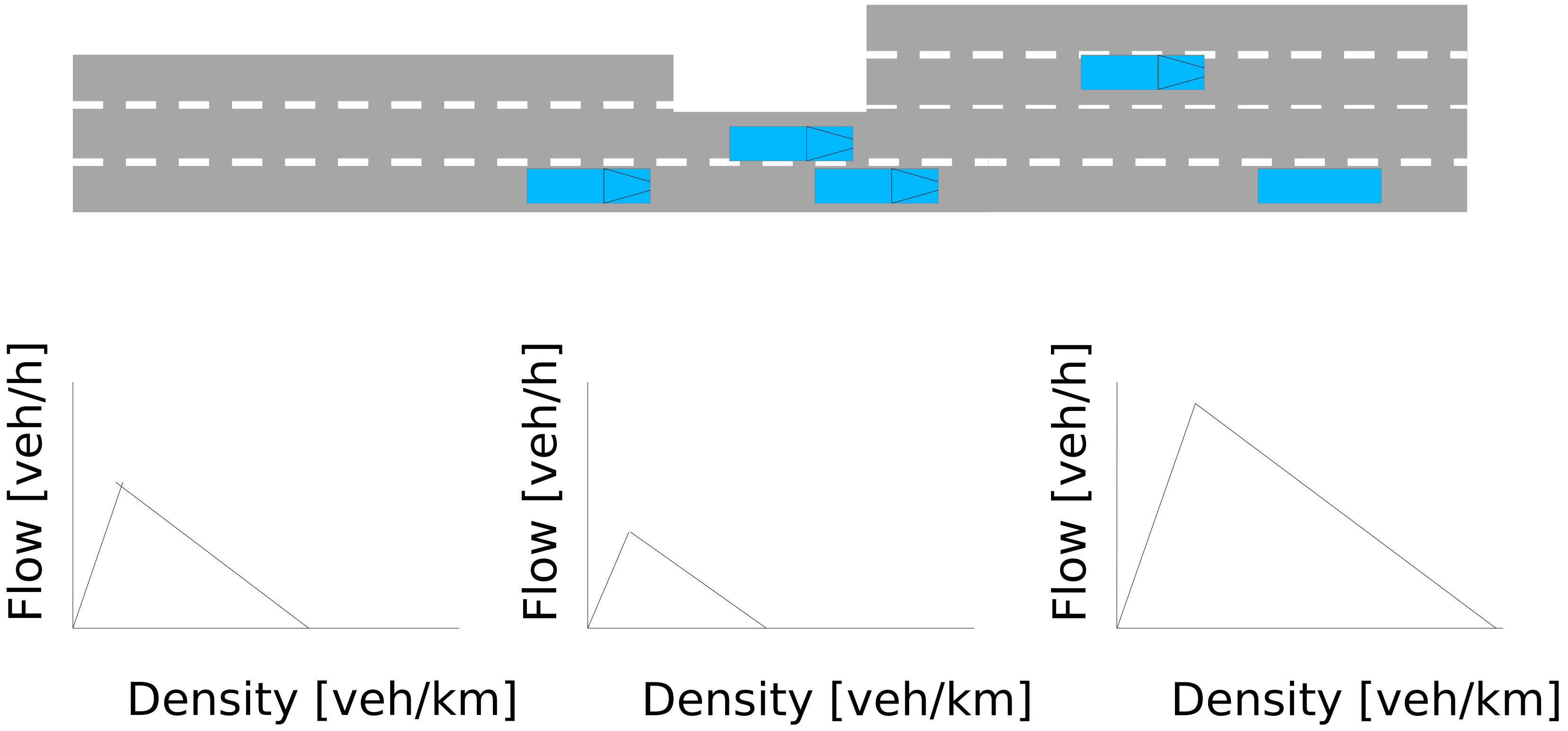
- Mainly in free flow branch
  - Speed reduction
  - Functional form
- Most have a straight line in q-k for the congested branch
  (except Greenshields)
- Capacity drop

How about fundamental diagrams?

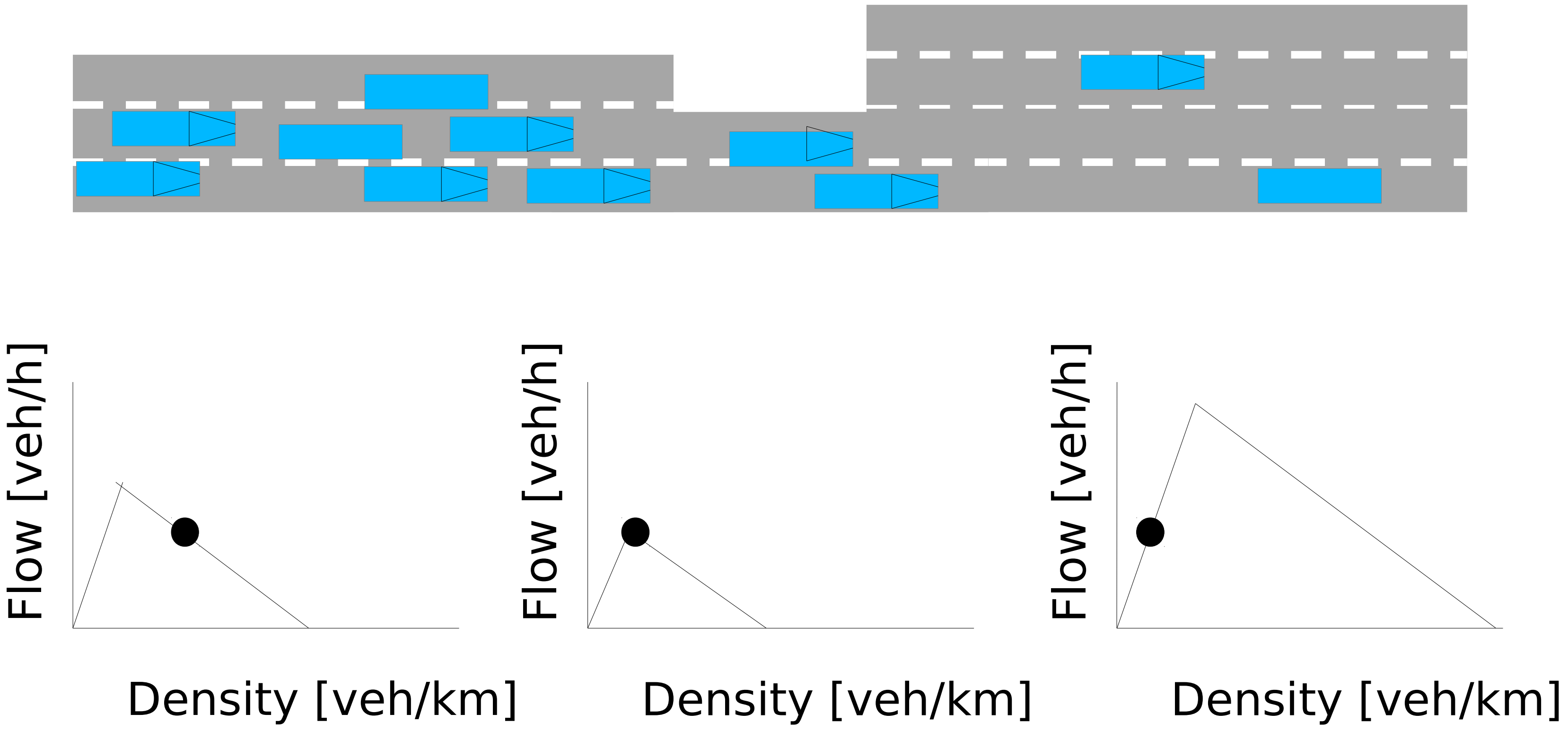




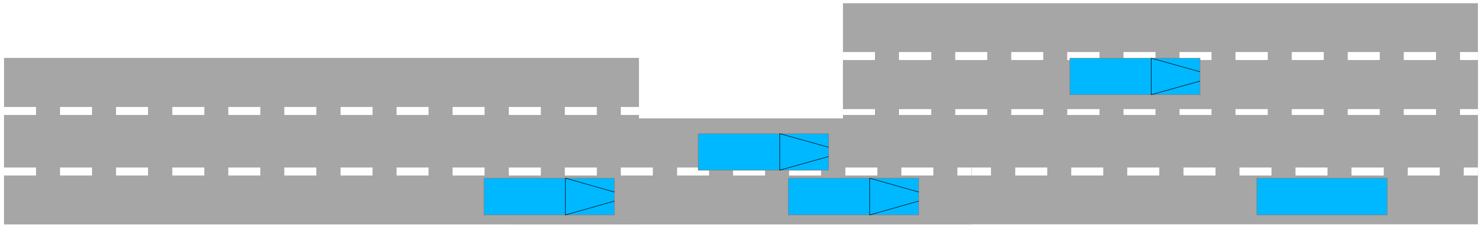
How about fundamental diagrams?

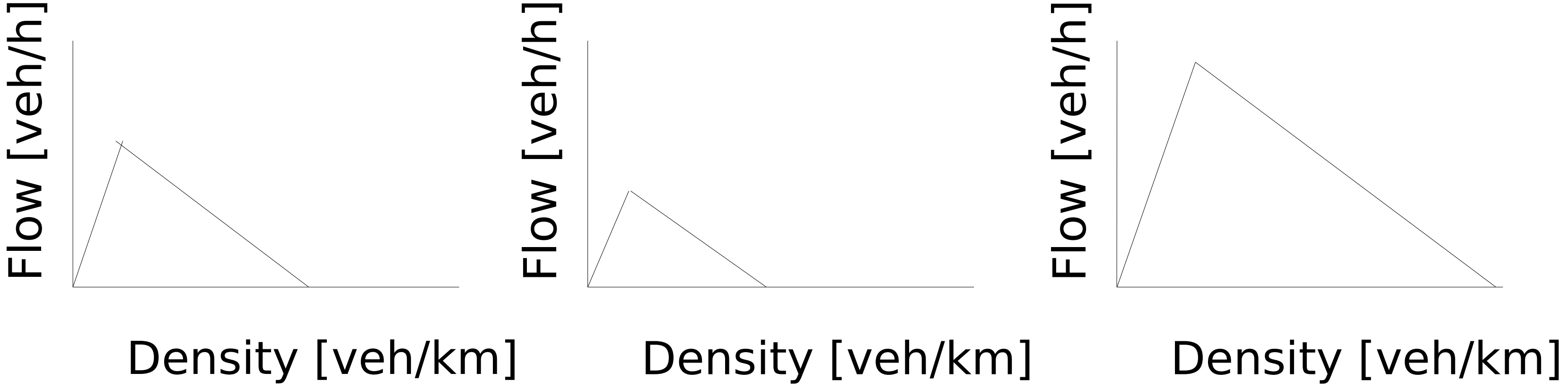


How about fundamental diagrams?

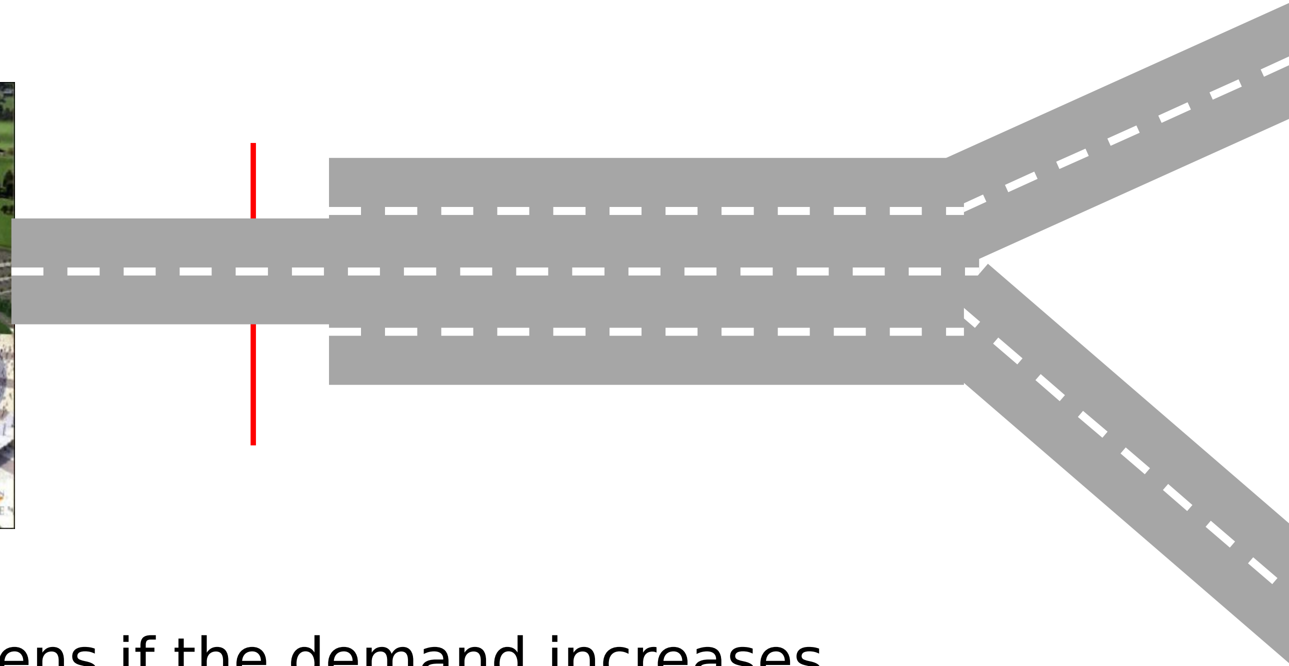


In excessive demand, where is the queue?





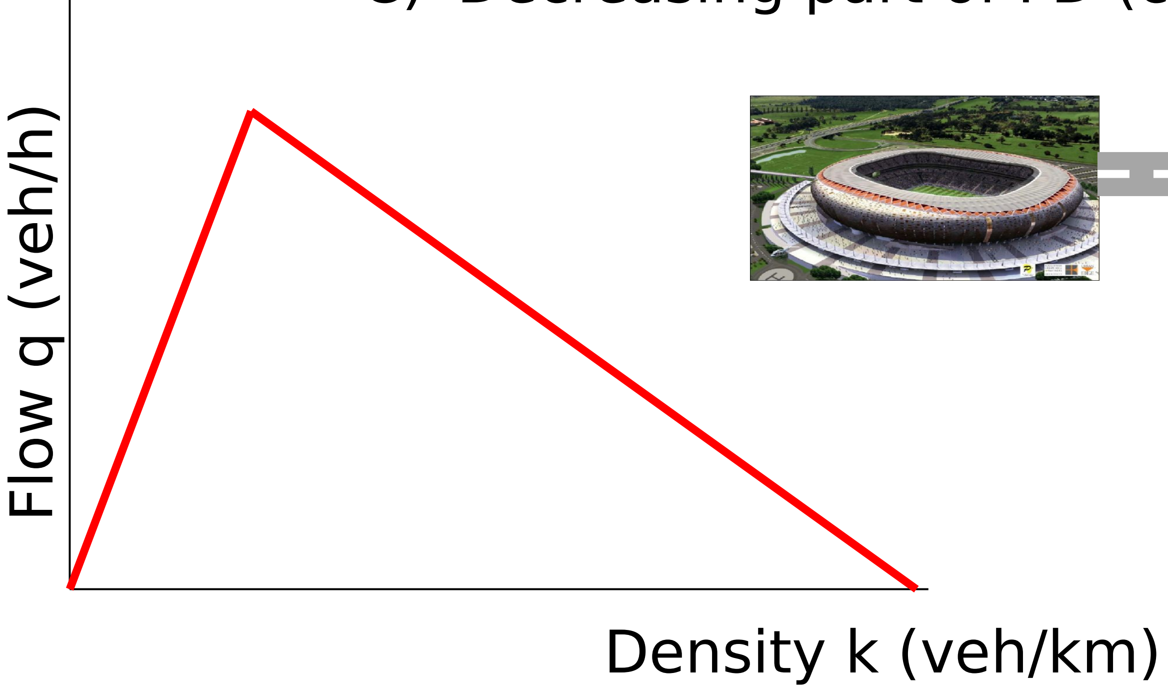
Simple road with increasing demand

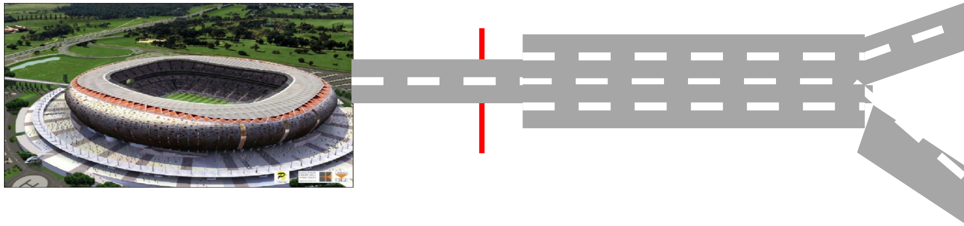


What happens if the demand increases

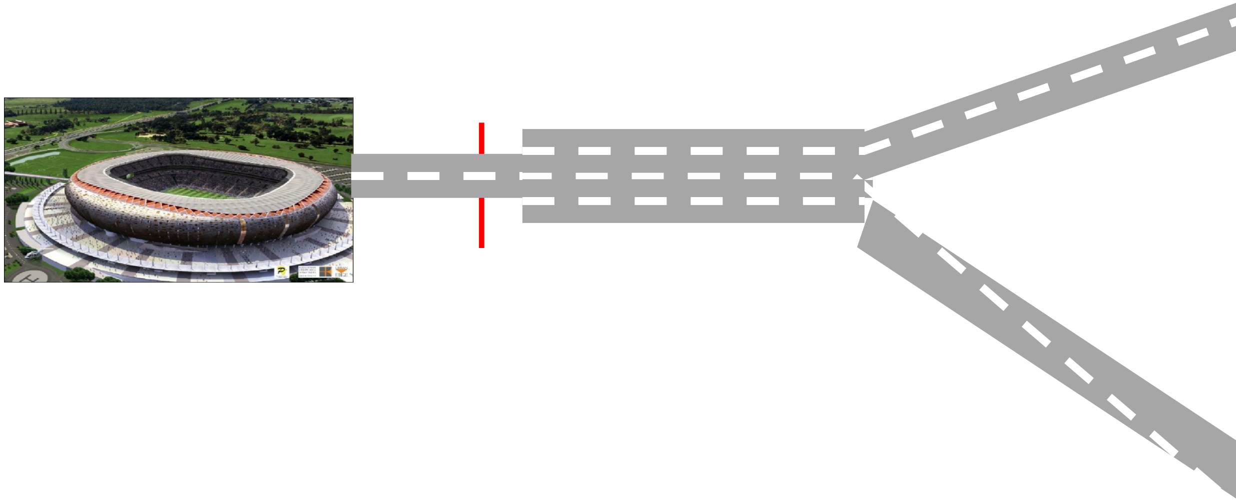
What observations can be made?

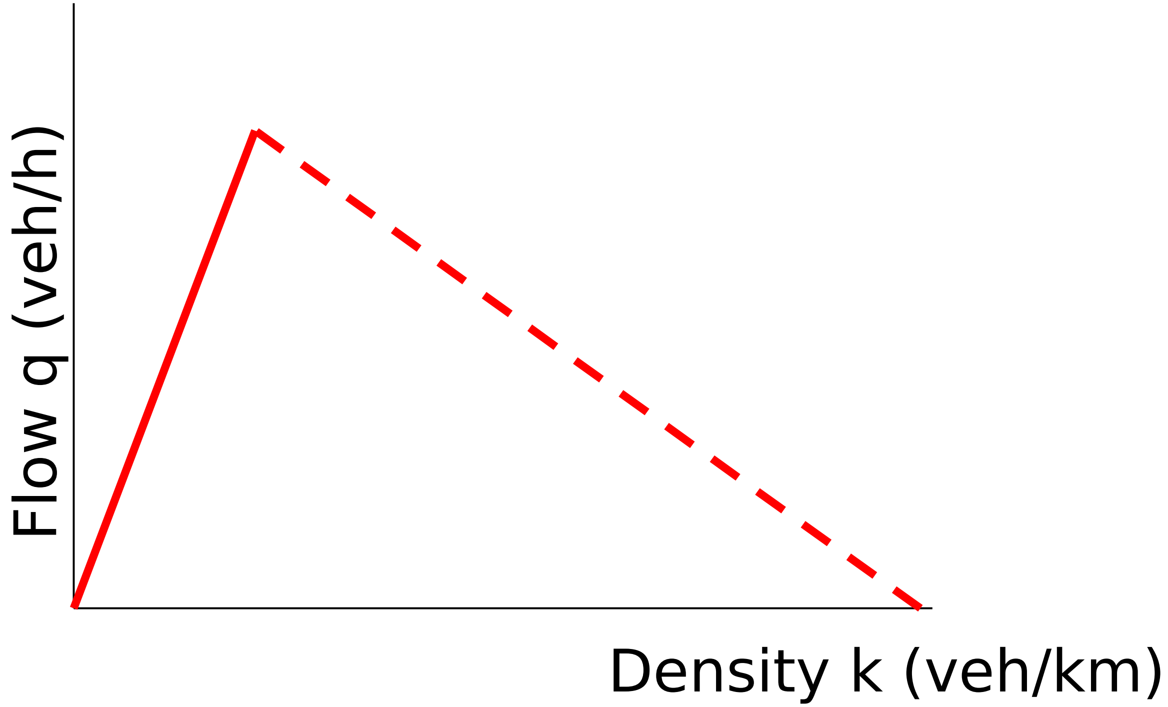
A) Whole FD
B) Increasing part of FD (free flow)
C) Decreasing part of FD (congestion)





Simple road with varying demand





Part 3: Network description

Zone description

Traditional

Microscopic

Macroscopic

New

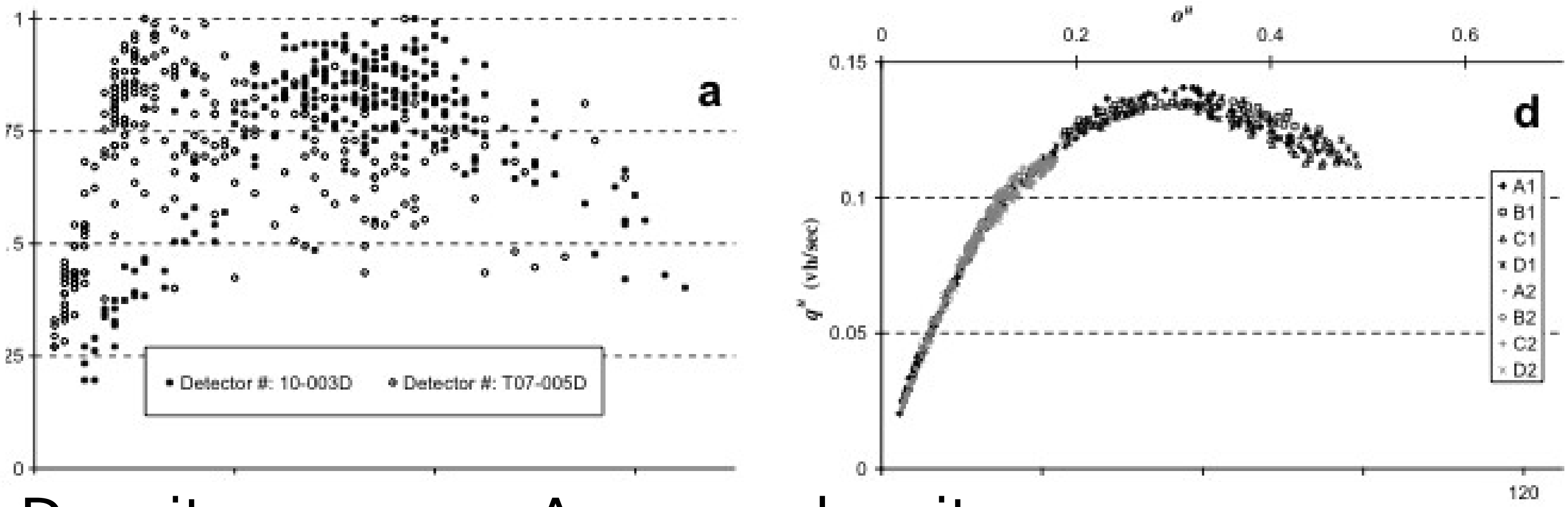
Zones

- Speed in the zone dependent on nr of vehicles

Stochasticity in local data

- Macroscopic fundamental diagram
- “Average” fundamental diagram for an area

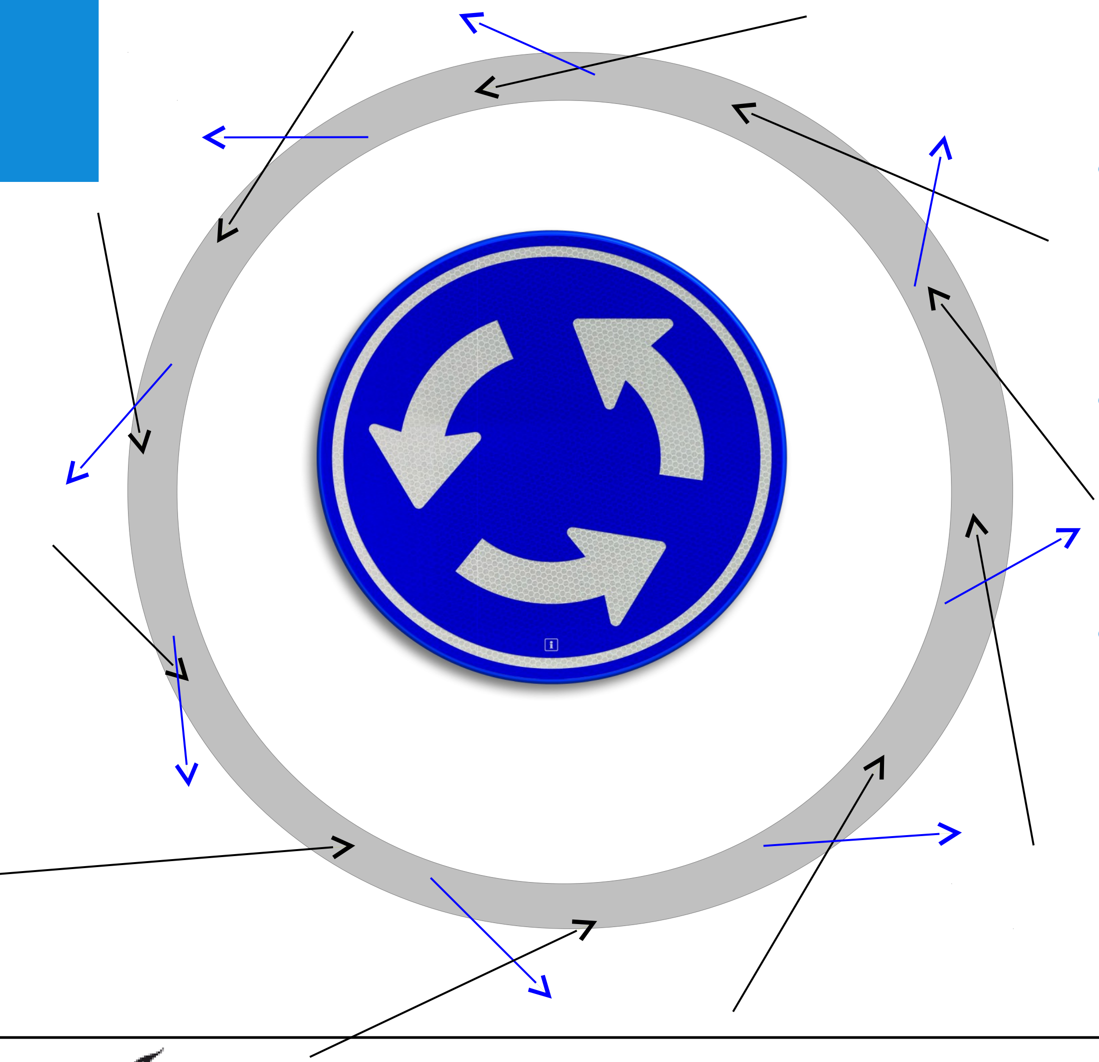
- (Avg.) Flow =>



Density Average density

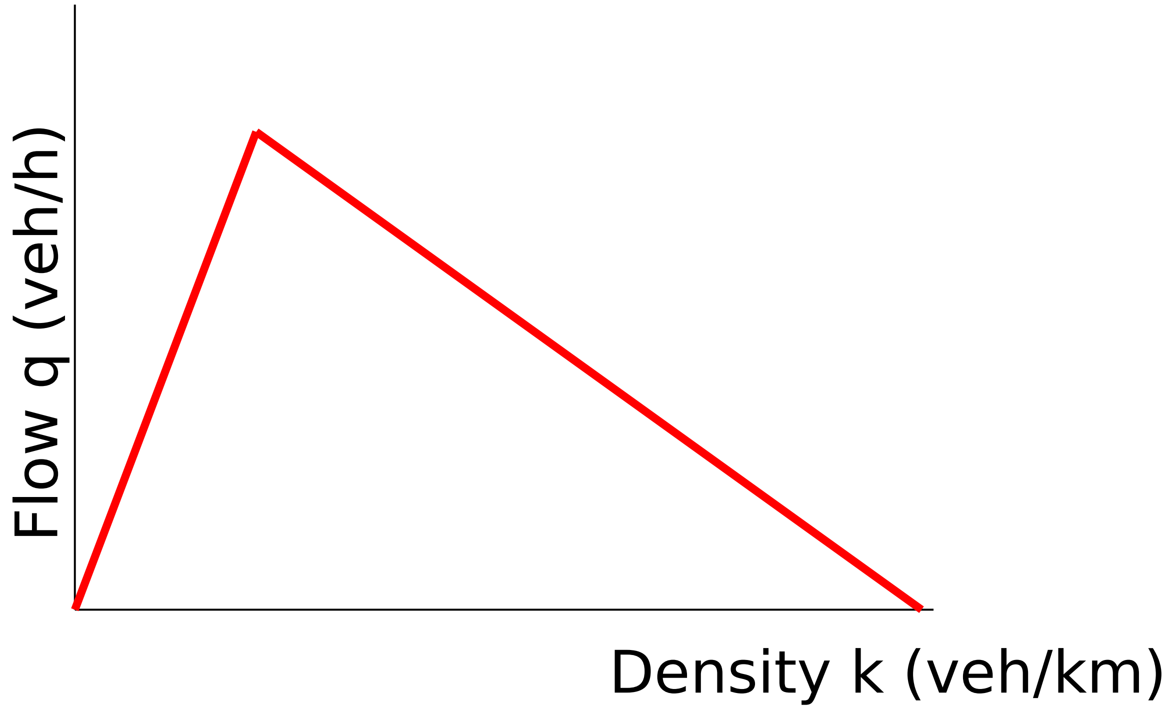
Fig: (Geroliminis and Daganzo)

Not so simple road



- Origins and destinations everywhere
- By increasing input => **congestion**
- **Major difference with road!**

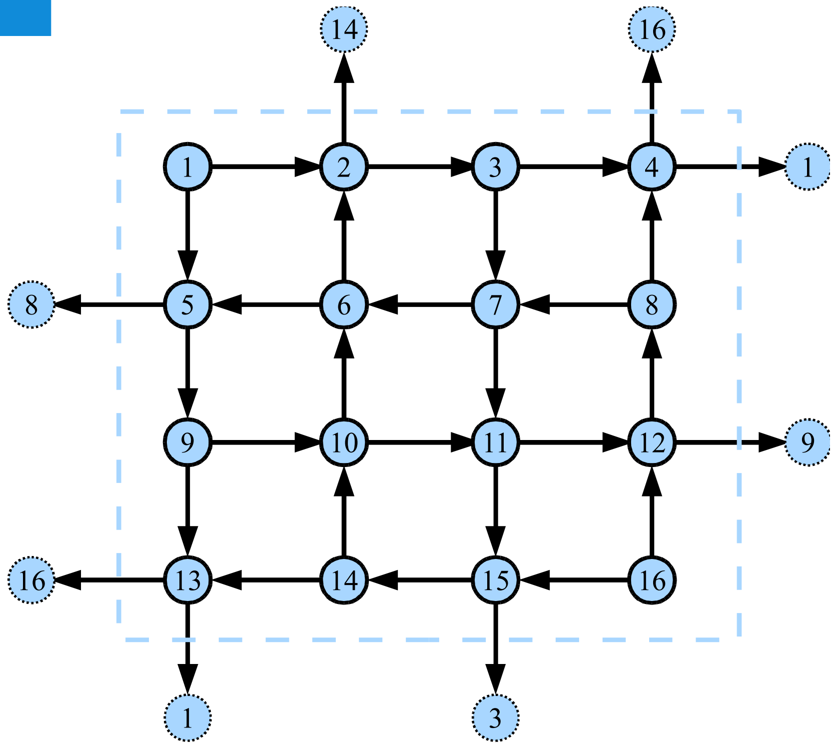
Averaging traffic states leads to lower FD

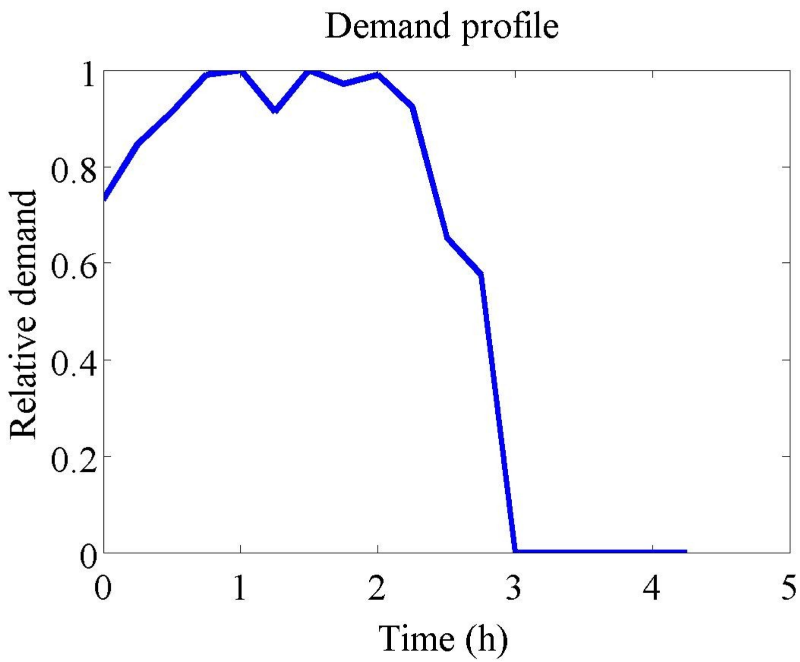


Averaging traffic states leads to lower FD

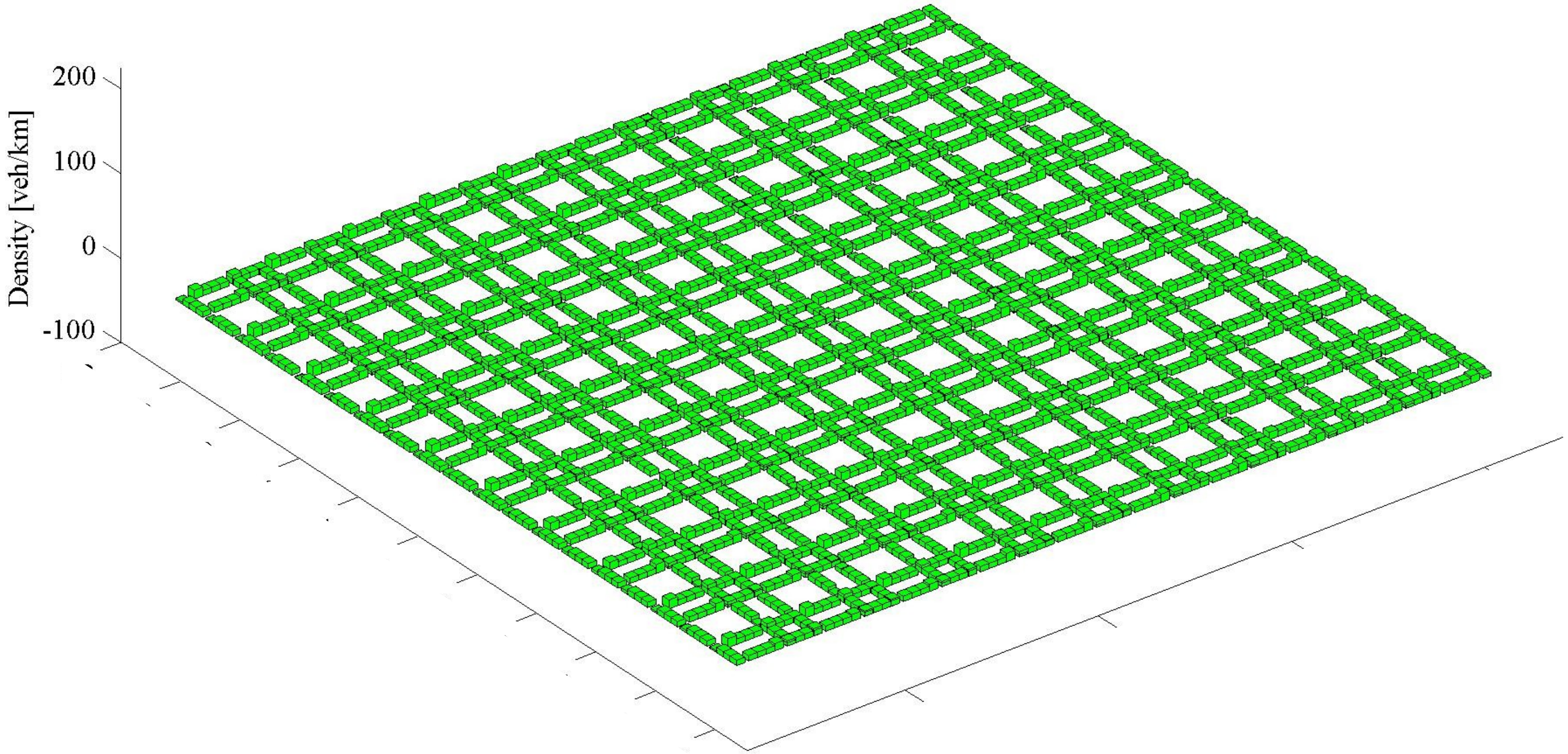
But there is much more...

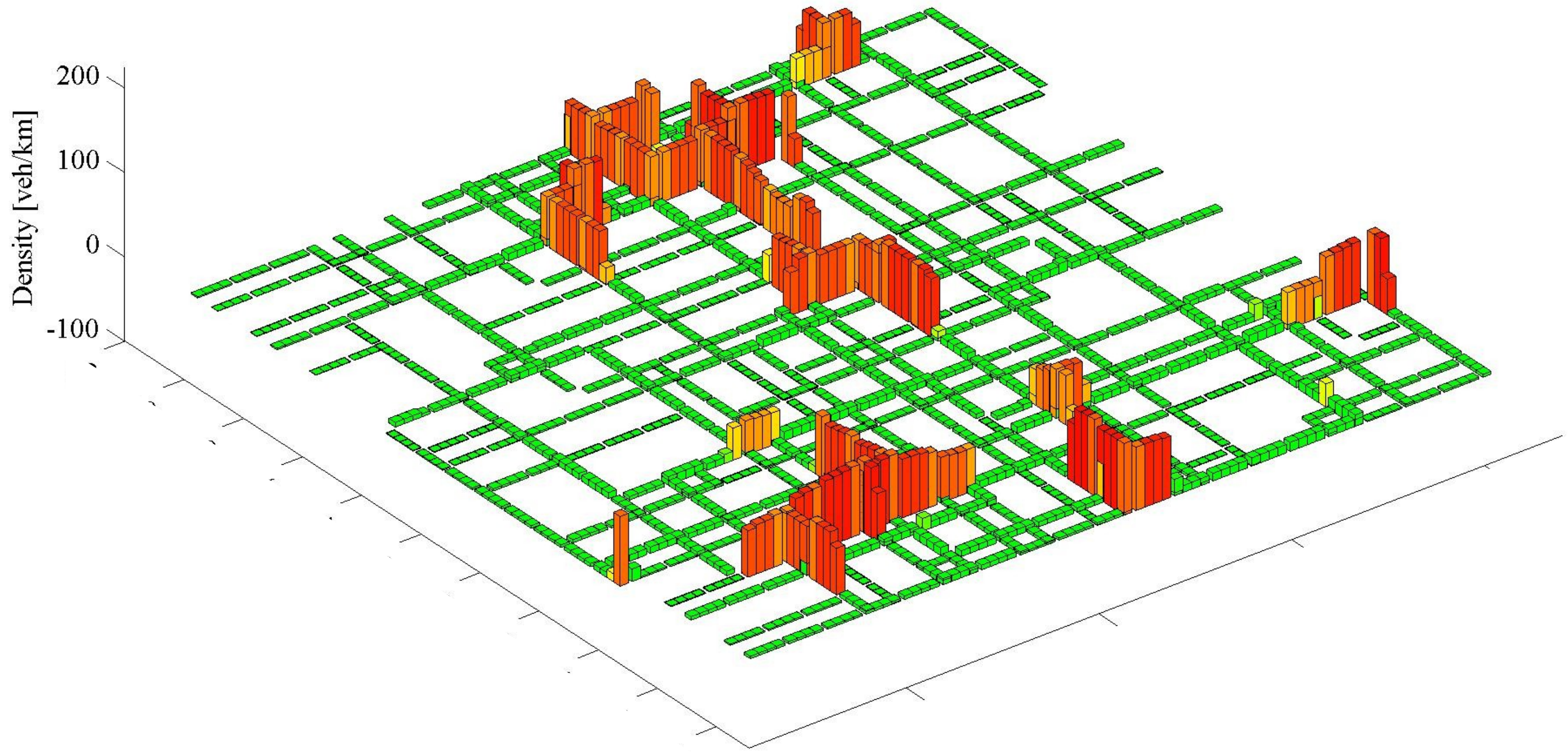
Network with periodic boundary

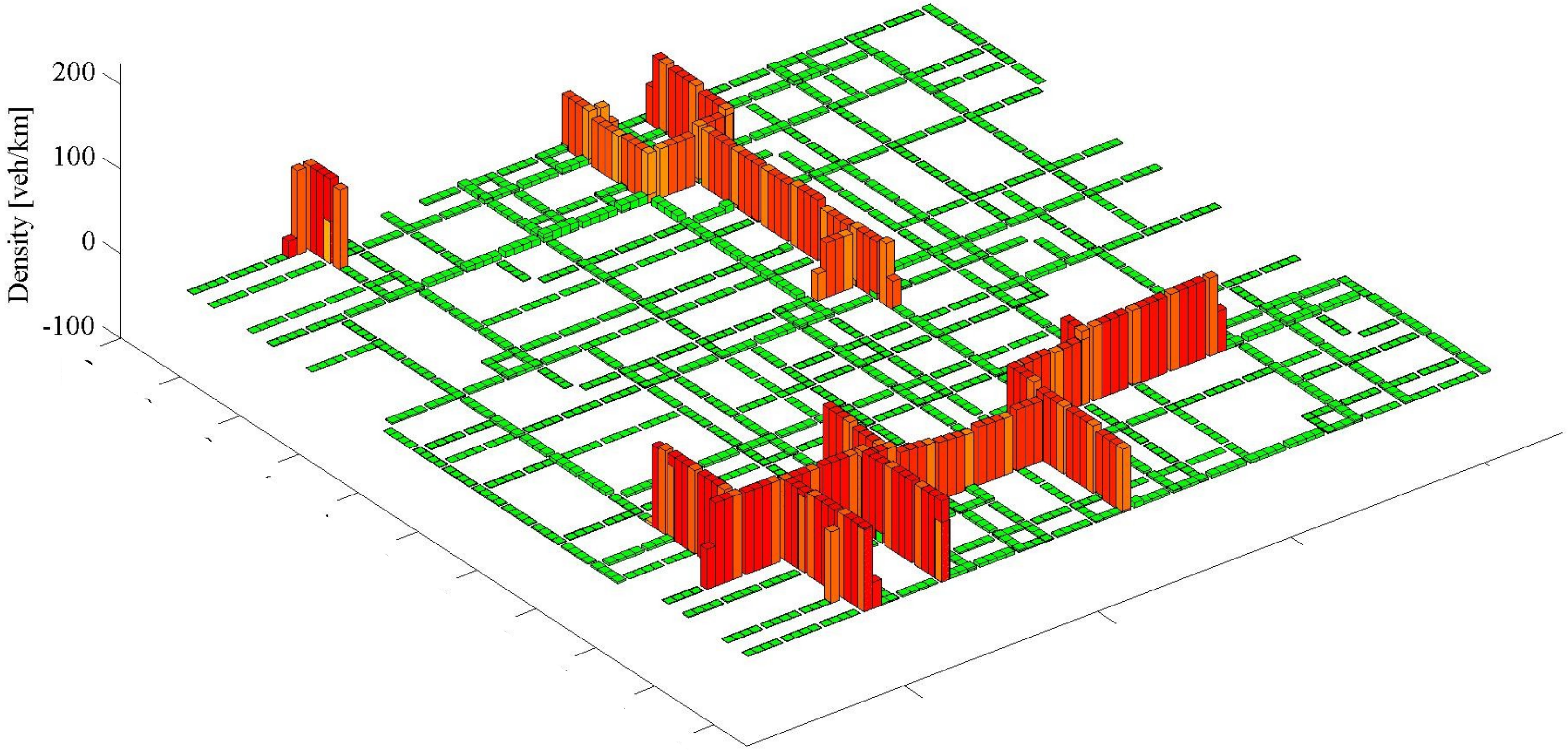




Build up of congestion



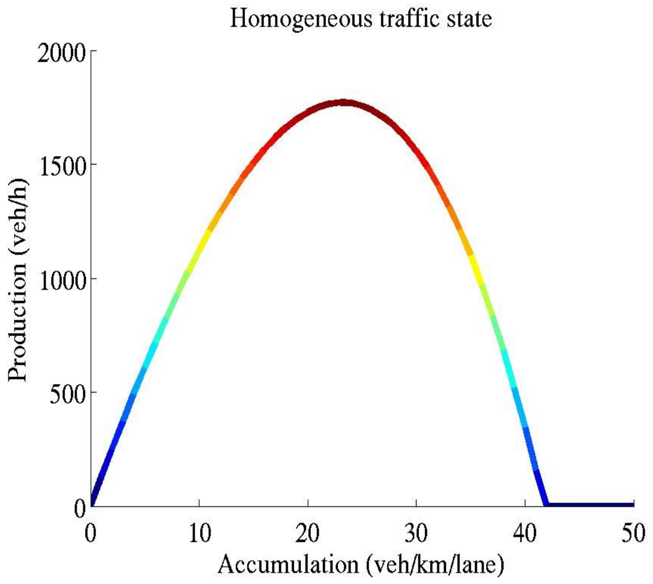

200
100
0
-100
Density [veh/km]



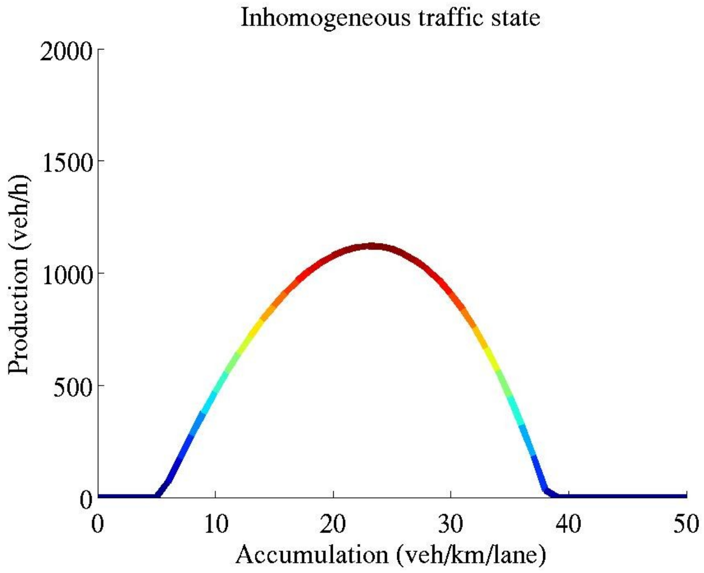
200
100
0
-100
Density [veh/km]

Fitting a functional form

P(A)=A*(c1+c2A+c3A2)-c4σ



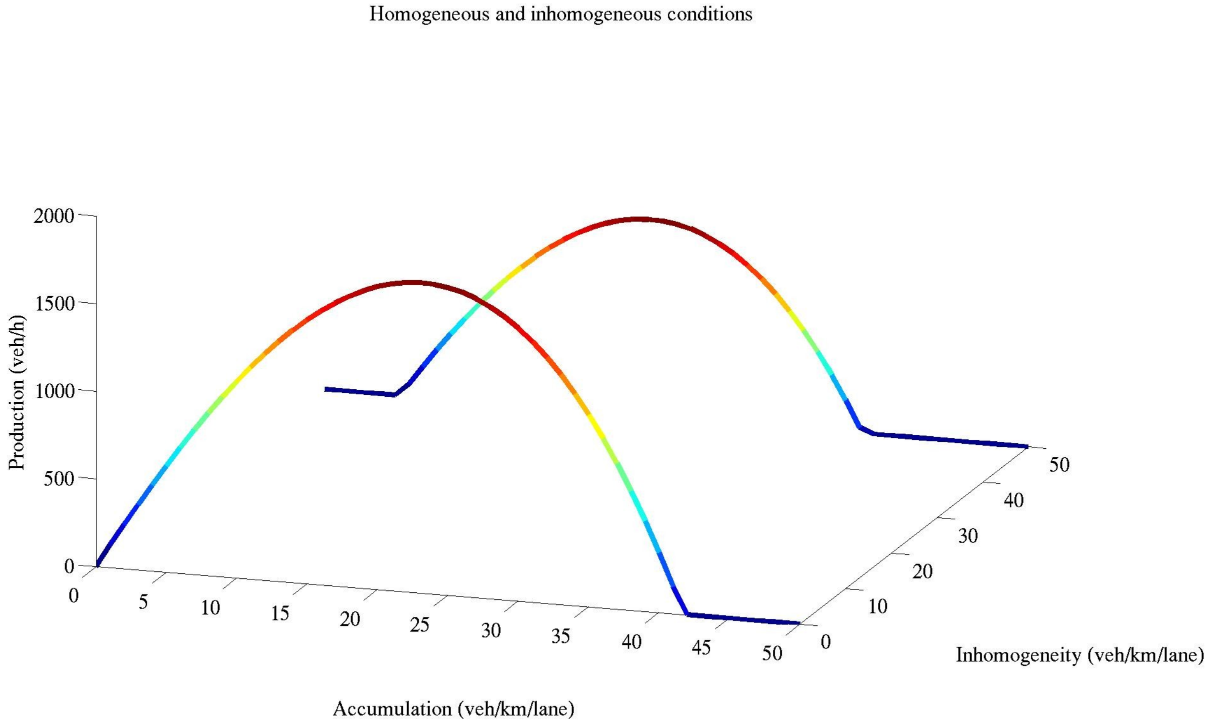
Homogeneous traffic situation



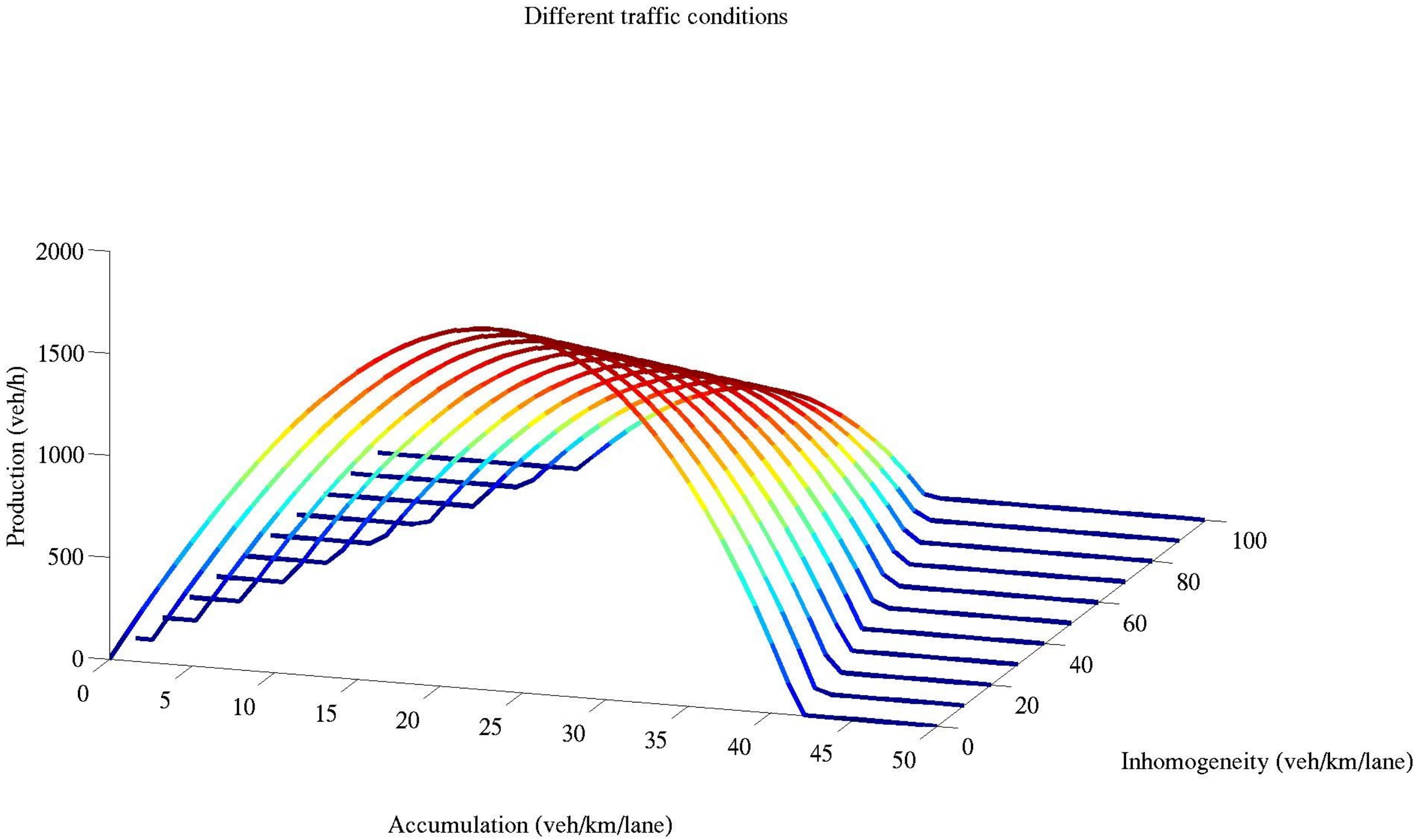
Inhomogeneous traffic situation

Fitting a functional form

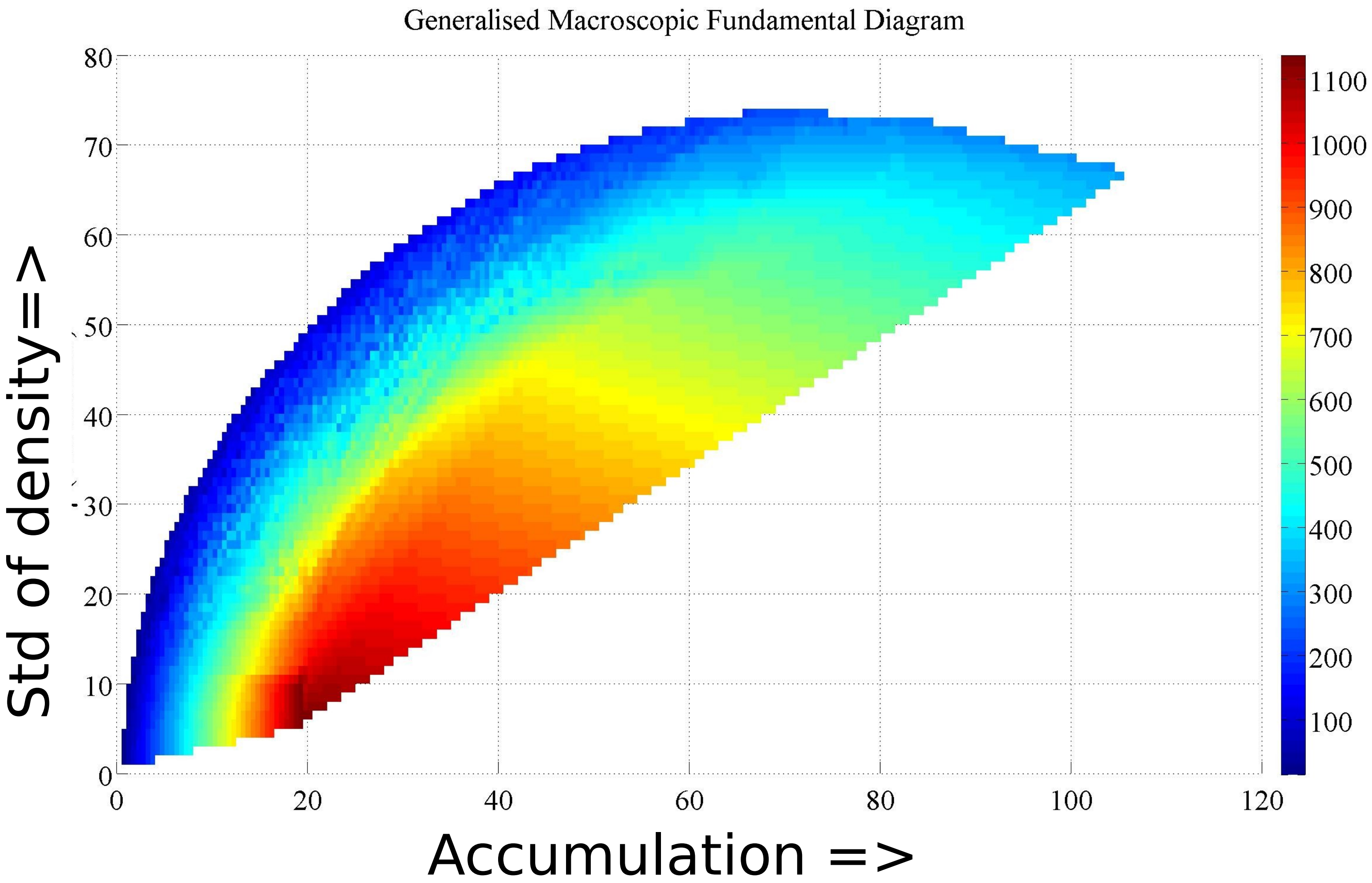
P(A)=A*(c1+c2A+c3A2)-c4σ



Causes of decrease with inhomogeneity



Improvement: Generalised NFD



Use for your desktop

GMFD top view fit

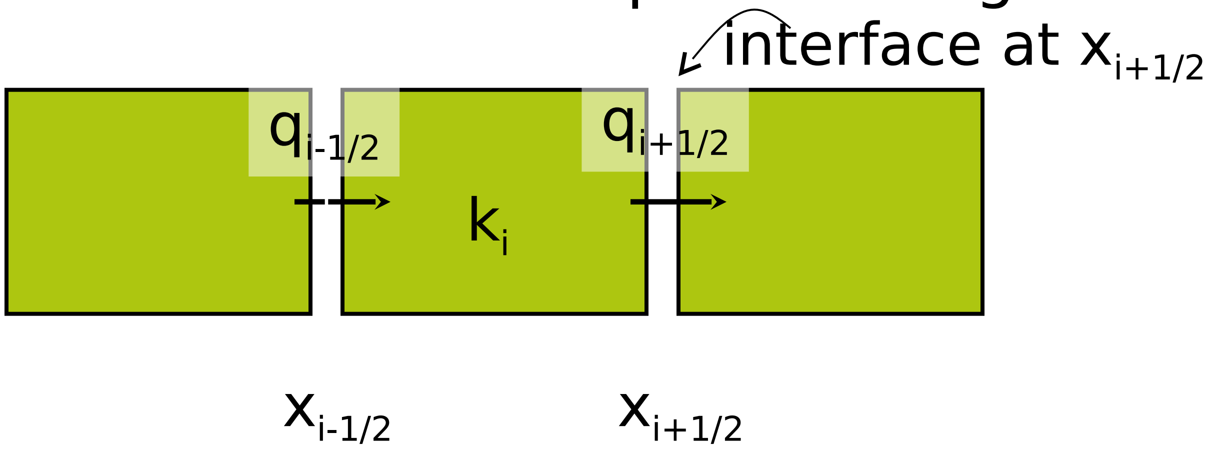
Part 4: Traffic dynamics

Why numerical solutions are needed

- Only applicable in relatively simple situations, e.g. with respect to upstream traffic demand, off-ramps and on-ramps, etc.
- What to do when demand on main-road and on-ramps is changing dynamically? Use numerical approximations!
- Practical applications, e.g. use for network simulation

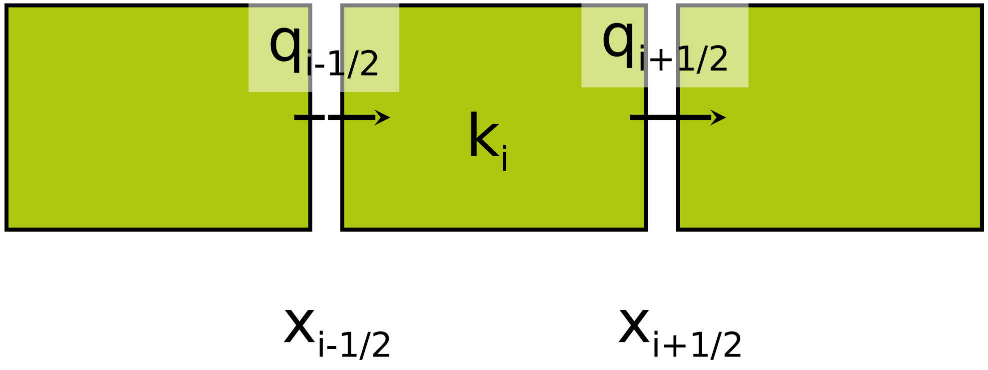
Basic principles

- Various approaches exist to trace traffic dynamics
- Simplest:
  - Divide roadway into cells i, length dx
  - Divide time into steps with length dt



Assumptions

- Cells are homogeneous, length dx
- Within a time step (dt) , traffic flow is stationary
- Express $k_{i,t+1} = f(k_{i,t}, q_{i-1/2,t}, q_{i+1/2,t}, dt, dx)$



Basic principles (2)

- For the slides: this is the answer…

$$k_{i,t+1} = k_{i,t}+(q_{i-1/2,t}-q_{i+1/2,t})*dt/dx$$

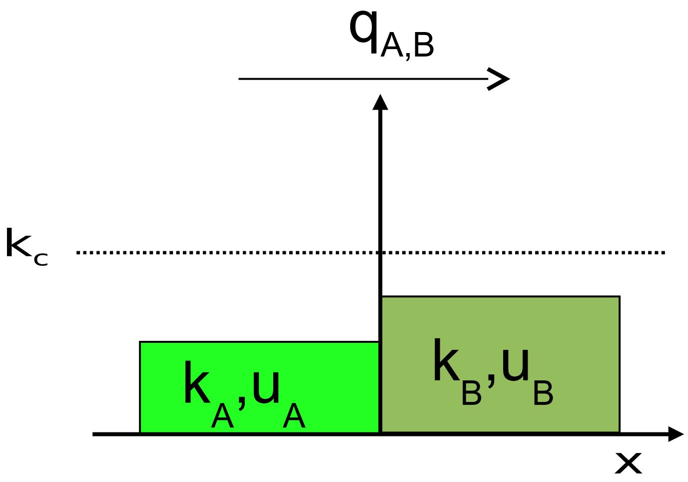
$$q_{i+1/2,j} = \bar{q}(k_{i,j}, k_{i+1,j}, k_{i,j+1}, k_{i+1,j+1})$$

- But how to get to:

$$q_{i+1/2,j} = k_{i,j}u_{i,j} = Q\left(k_{i,j}\right)$$

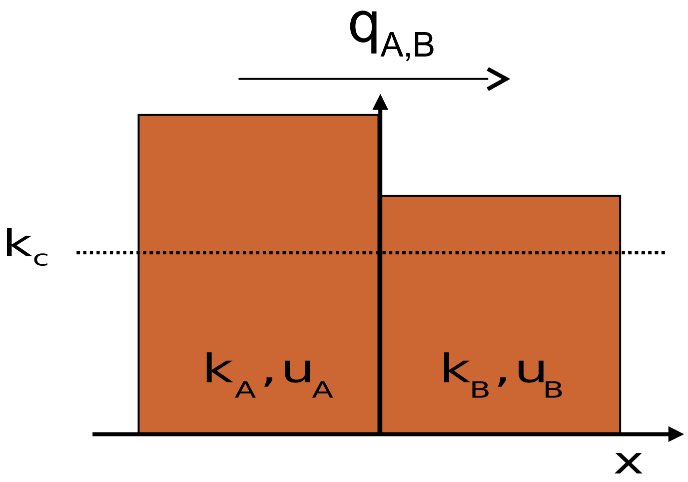
What if uncongested?

- What determines the flow from A to B?
  - A – state in cell A
  - B – state in cell B



What if congested?

- What determines the flow from A to B?
  - A – state in cell A
  - B – state in cell B



The trick:

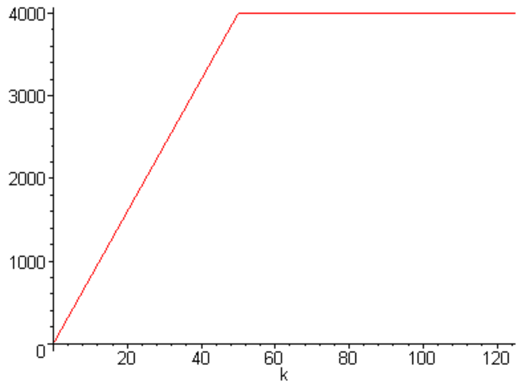
- *Demand* of region A and *supply* of region B

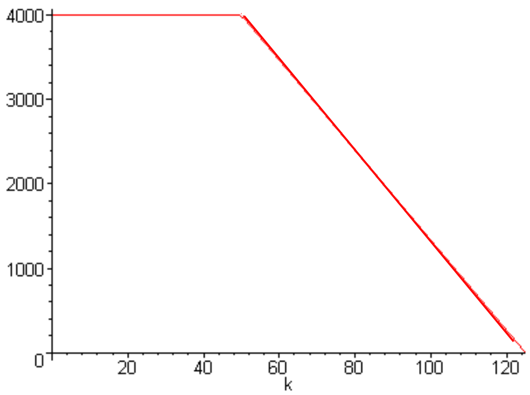
$$D_L = \begin{cases} q_A & k < k_c \\ c & k \geq k_c \end{cases} \qquad S_B = \begin{cases} c & k < k_c \\ q_B & k \geq k_c \end{cases}$$

- D_L = maximum flow out of region L (bounded by the capacity of the road)
- S_R = maximum flow into region R (bounded by road capacity and the space becoming available during one time-step)
- Actual flow at x=0 : min(D_L,S_R)

Graphically

- Flow based on
  Demand & Supply
- => fundamental diagram





Dynamic MFD model
Network Transmission model

Network-wide traffic management

- Microscopic and macroscopic models are OK to simulate small sections
- In cities, congestion spreads and the whole city need to be described
- Another way of describing is needed

Network Transmission Model

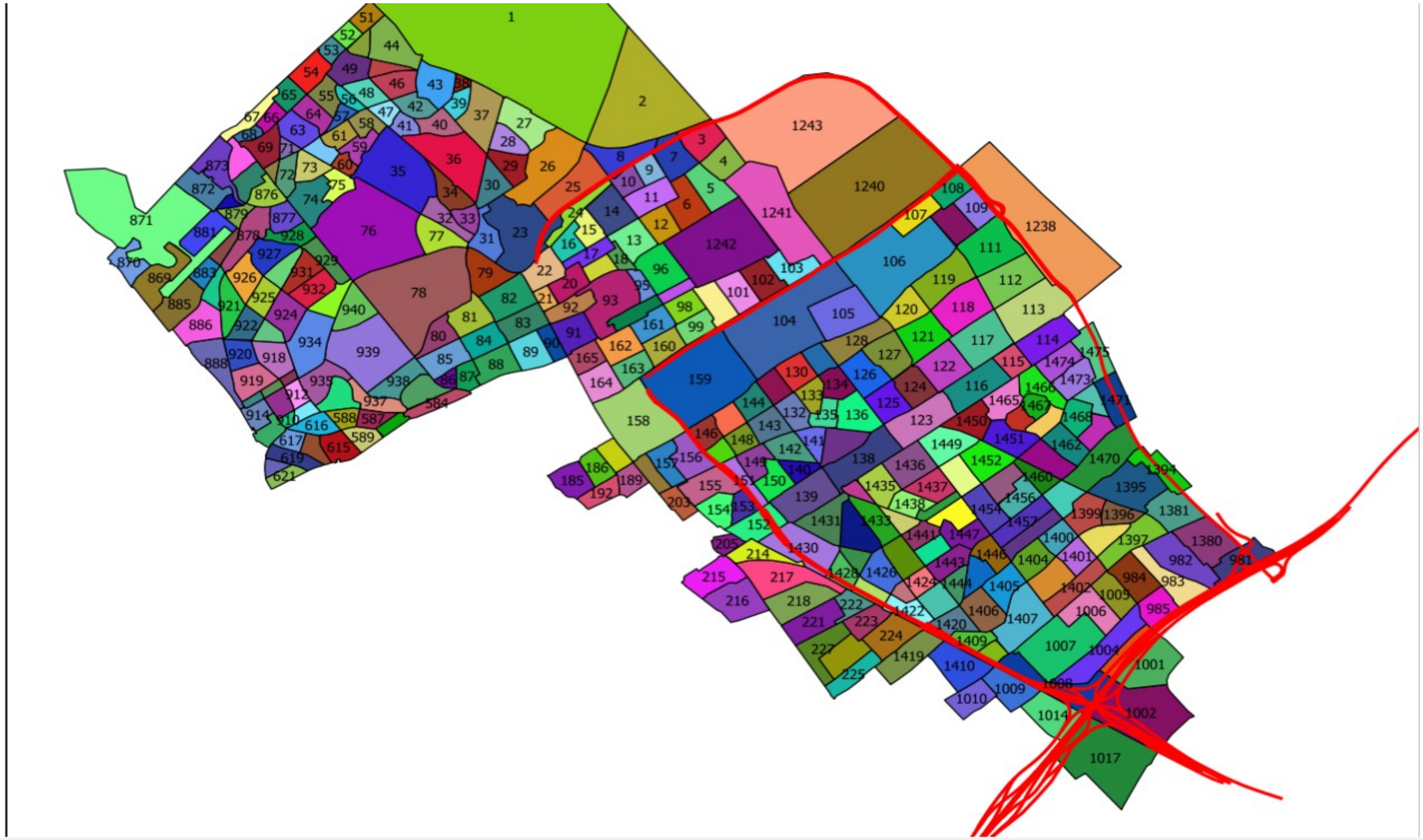
Base qualities

- Compuational speed: few steps
- **Dynamic** traffic patterns
  - Road closure, rerouting
- Schalability
  - bigger or smaller zones
  - use other scale within one zone

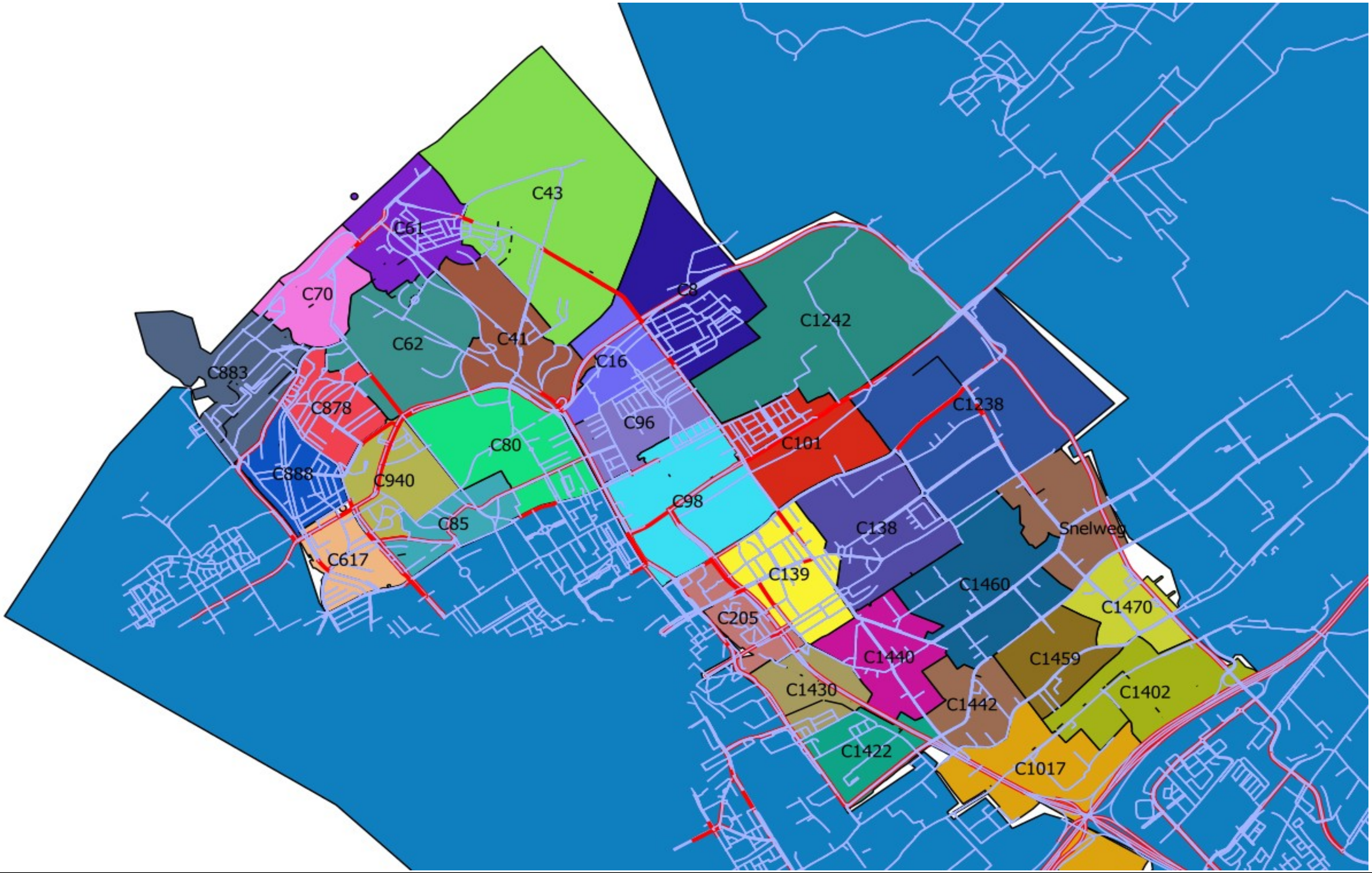
Process

- Implementation in OpenTraffic Sim, TU Delft simulator, enabeling link to other models
- Link to static model:
  ao zone-boundaries, road length per zone

Oorspronkelijke zones



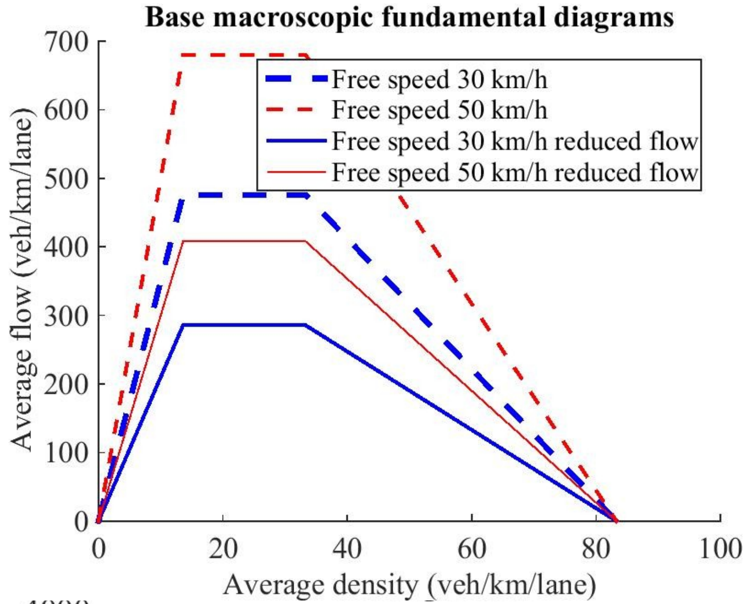
Zones

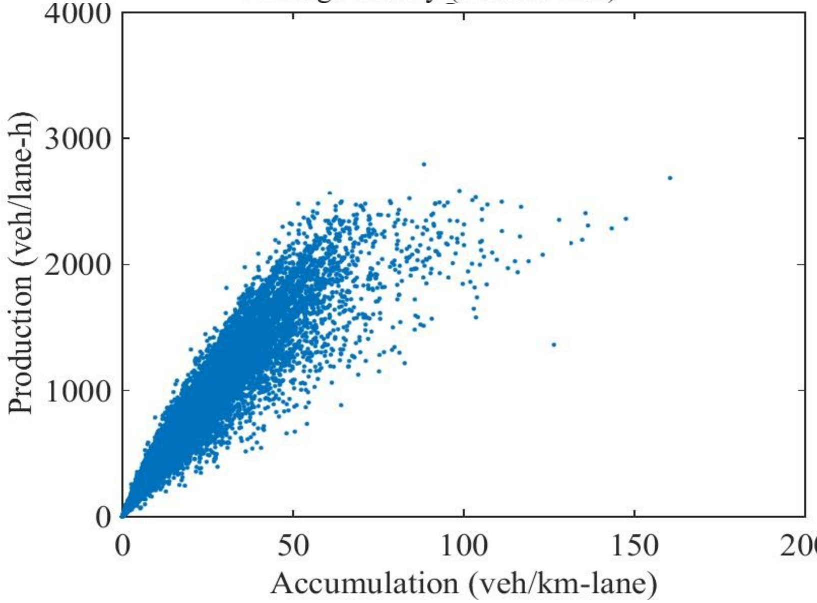

C43
C61
C70
C8
C1242
C62
C41
C883
C16
C878
C96
C1238
C80
C101
C888
C940
C98
C85
C138
Snelweg
C617
C139
C1460
C1470
C205
C1440
C1459
C1430
C1442
C1402
C1422
C1017

Calibration

- Data shows incomplete and biassed view (location of measurements, roads?)
  => no proper NFDs

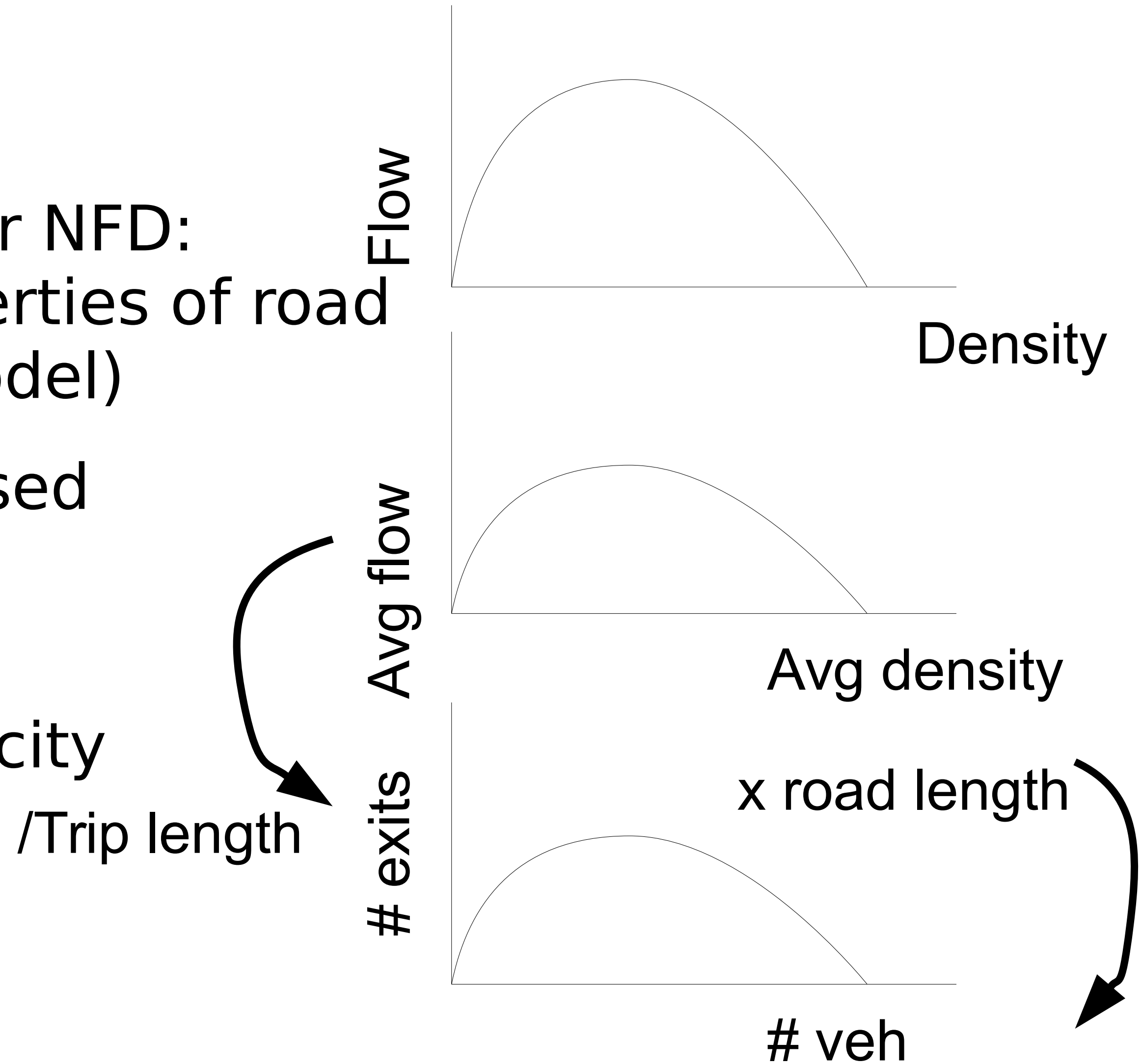
- Estimate model parameters based on theoretical considerations





Solution:

- 1st estimate for NFD: based on properties of road (from static model)
- Then adapt based on speeds
- Adapt as well: boundary capacity



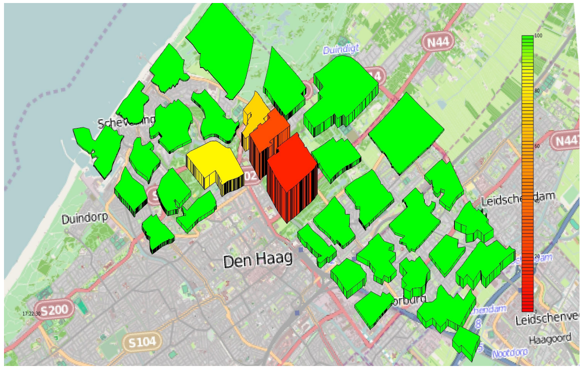
Result:

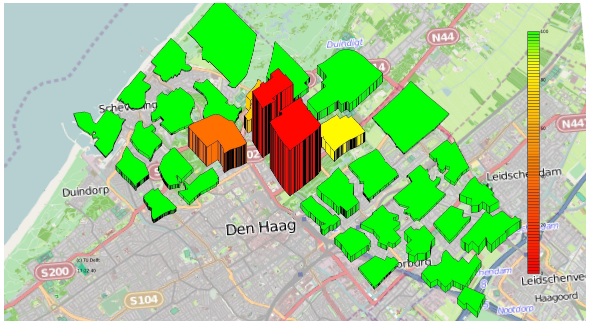
- Dynamic model voor:

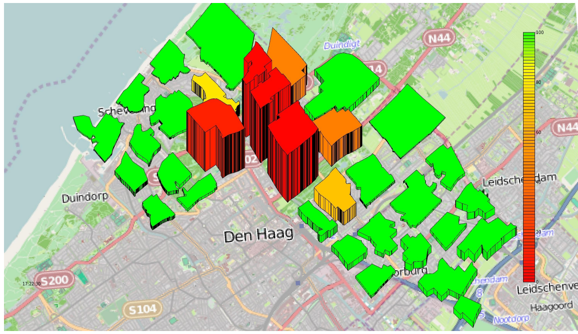
  1) Normal day

  2) Beach traffic
     (adapt OD matrix)

  3) Normal day with incident
     (capacity adapted)







Learning goals

- After this lecture, the students are able to:

  - describe the traffic on a microscopic and macroscopic level

  - apply the relationship q=ku

  - draw the fundamental diagram, i.e. q=q(k)

  - argue the differences and similarities between relationships on the network level and road level

  - explain the steps in numerical traffic flow models

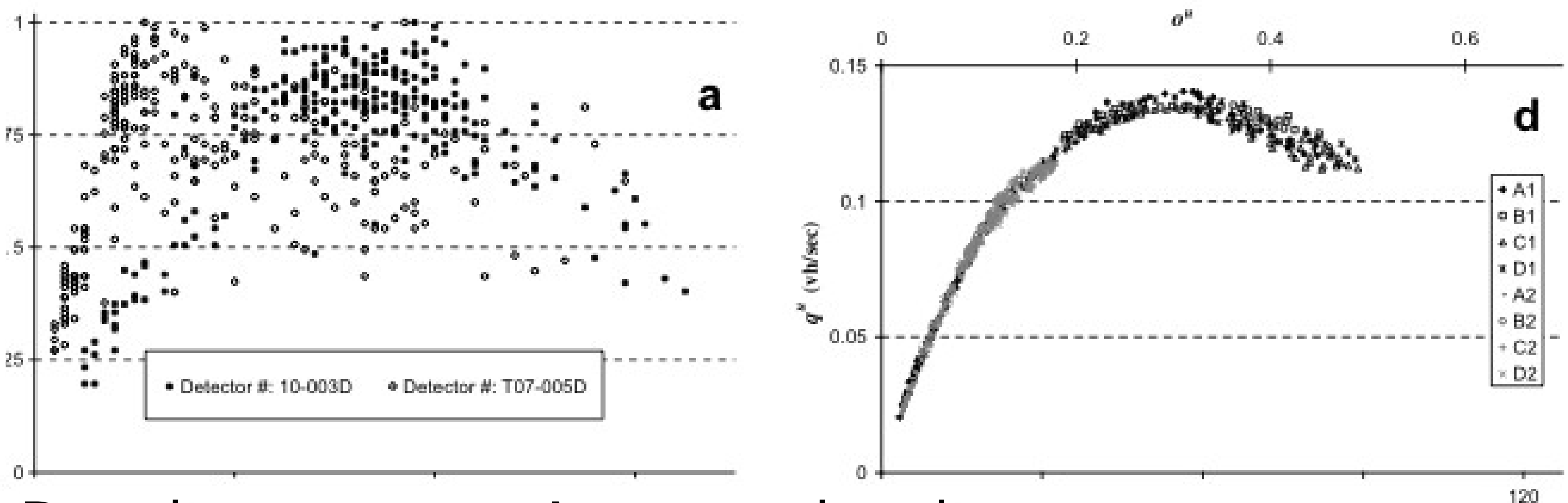
Model: possibilities

- Fast: 15s for 3 h simulation on (old) laptop.
  Expected: factor 10 improvement by recoding?
  Fast enough for on-line computation (including optimalisation!)
- Change OD matrix for events
- Boundary capacity and zone properties change, for instance in incident
- Schaling:
  - zone size (bigger / smaller) (?)
  - combine with other modelling scales
  (eg, one zone on microscopic level)

Stochasticity in local data

- Macroscopic fundamental diagram
- “Average” fundamental diagram for an area

(Avg.) Flow =>



Density
Average density

Fig: (Geroliminis and Daganzo)

Name giving

- Macroscopic Fundamental Diagram = Network Fundamental Diagram
- Name giving
  Average density = *Accumulation*
  Average (internal) flow = *production*
  Outflow = *performance*

Model: volgende stappen

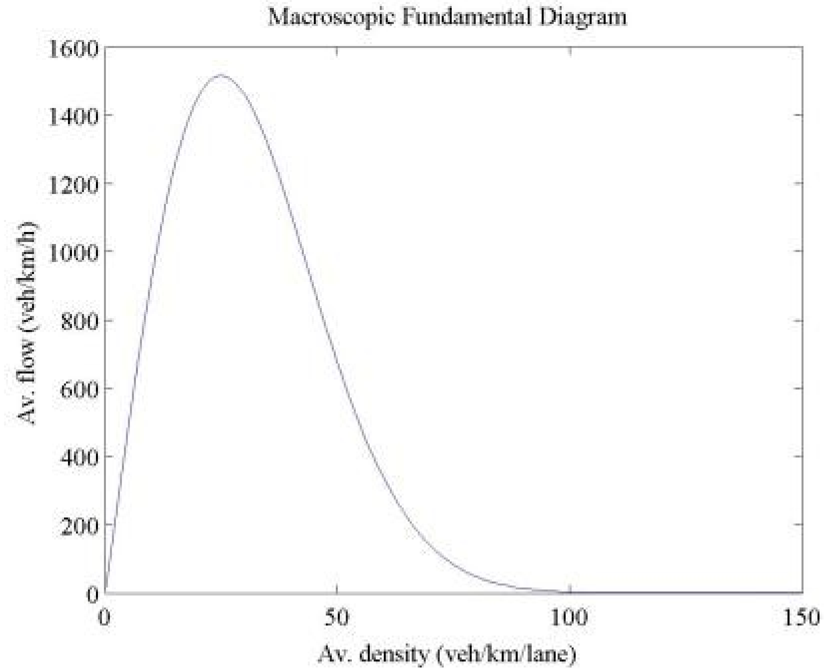
- Kwaliteitsmaten & -eisen definieren
- Inclusie zoekverkeer
- “Stroomwegen” apart houden
- Beperkingen in routekeus (nu alleen wel/niet tussen zones, maar geen opeenvolging: wel A==>B en B==>C, maar niet A==>B==>C)
- Hoe kunnen regelscenario’s in het model meegenomen worden: welke parameters moeten hoe aangepast worden?
- Eventueel schakelbaarheid tussen niveaus
- Data-feed en toestandsschatting (incl HB)

Name giving

- Macroscopic Fundamental Diagram = Network Fundamental Diagram
- Name giving
  Average density = *Accumulation*
  Average (internal) flow = *production*
  Outflow = *performance*

Shape

- Qualitatively like FD (but differences...)



Relation performance - production