Traffic Flow Theory and Simulation

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Lecture 10
Car-following and Stability

Car-following & stability
Three phases of traffic flow

24-3-2014

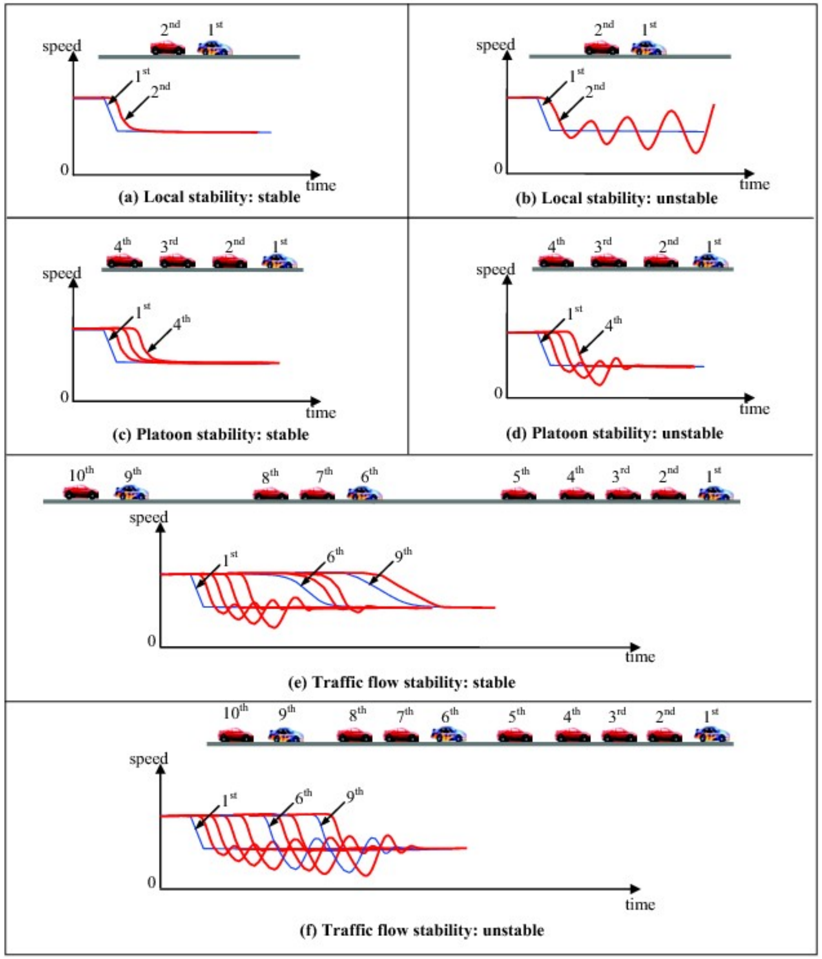
Recap traffic stability

Local stability
(1 follower instable)

Platoon/asymptotic stability

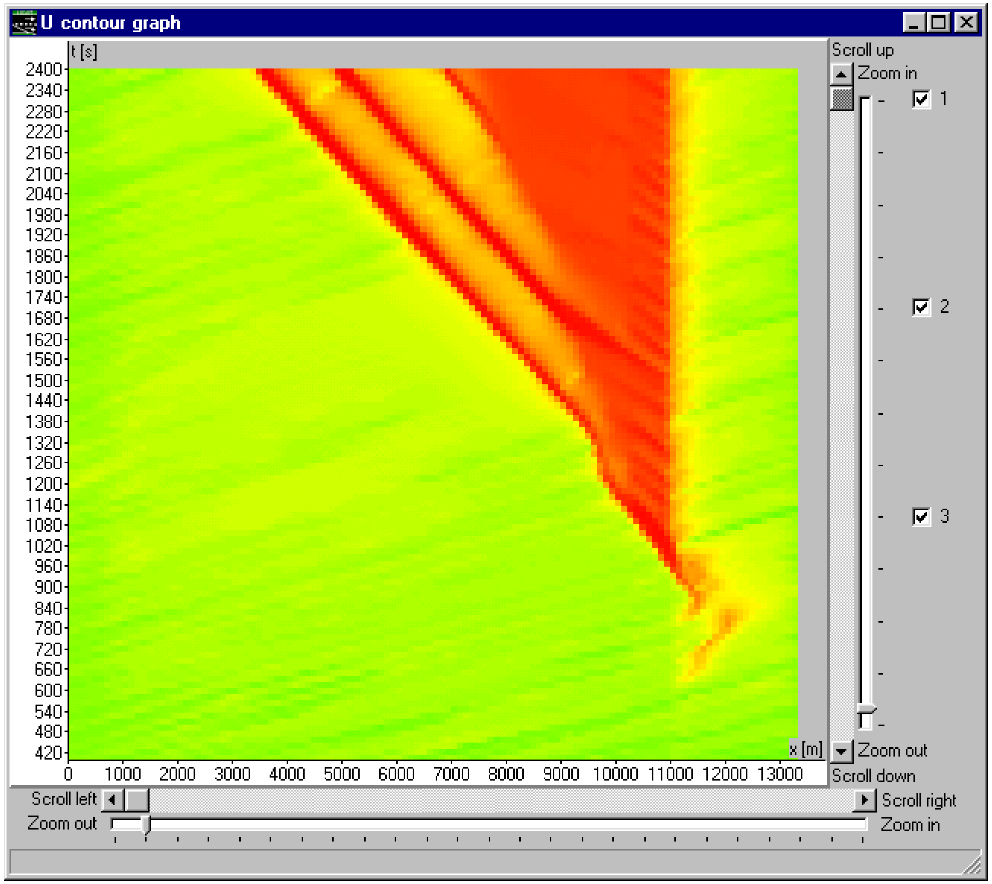
Traffic flow stability /

Traffic flow instability



Hysteresis and the capacity funnel

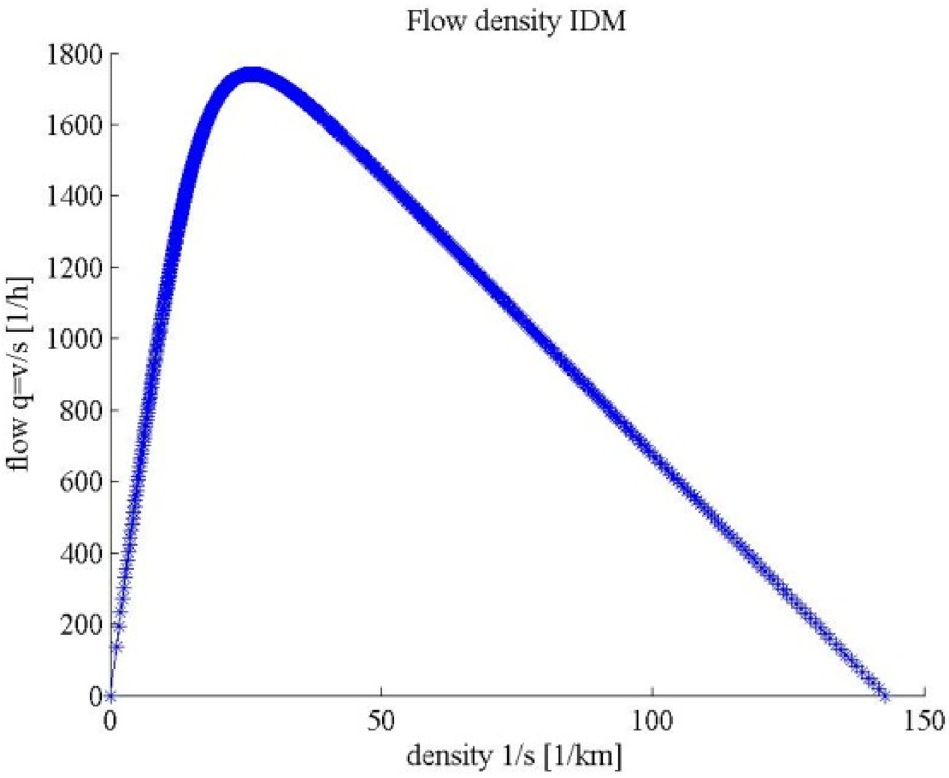
- Capacity drop + temporary acceptance (or occurrence!) of small headways
- Retarded reaction to worsened traffic conditions
- Jam starts inside or downstream bottleneck and moves upstream
- Also note instability of congested flow



THREE-PHASE TRAFFIC FLOW THEORY

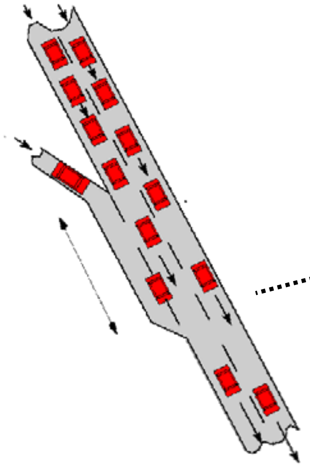
Known so far

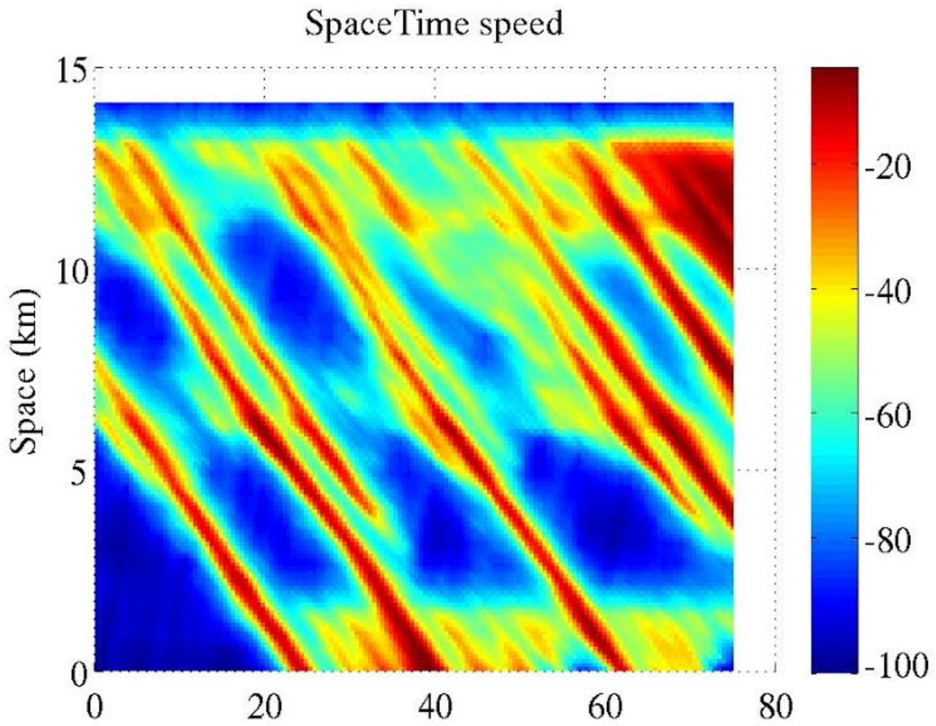
- Congestion
- Free flow



Capacity funnel (real data)

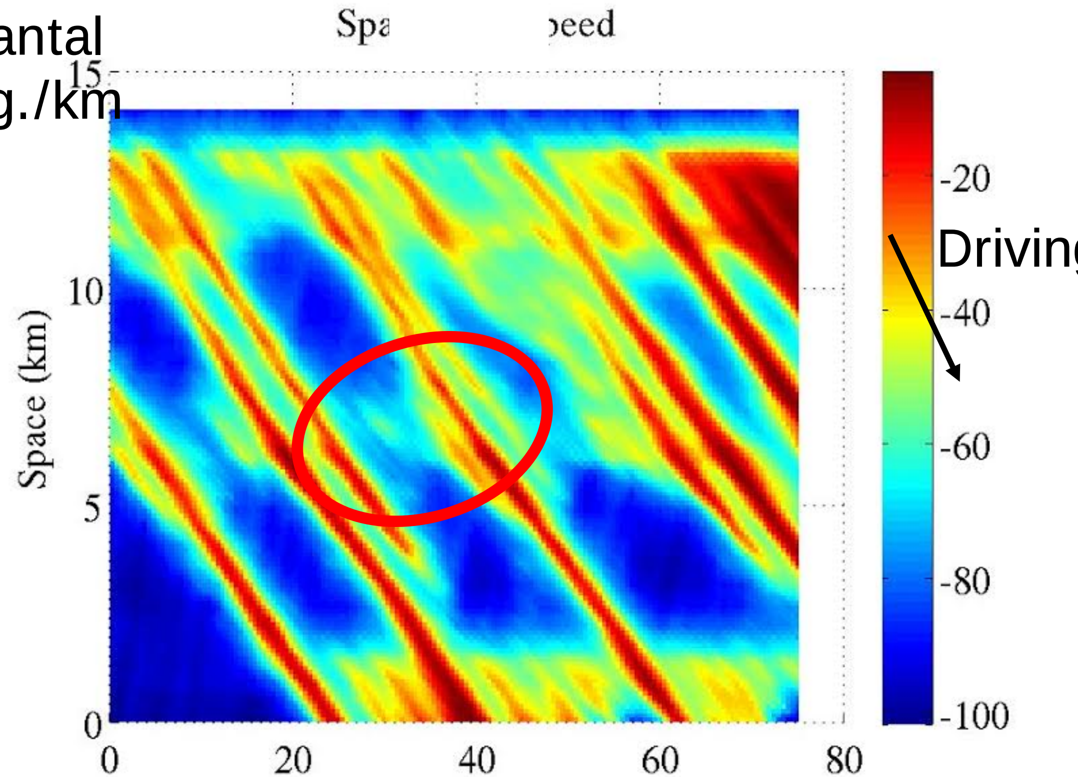
aantal
vtg./km



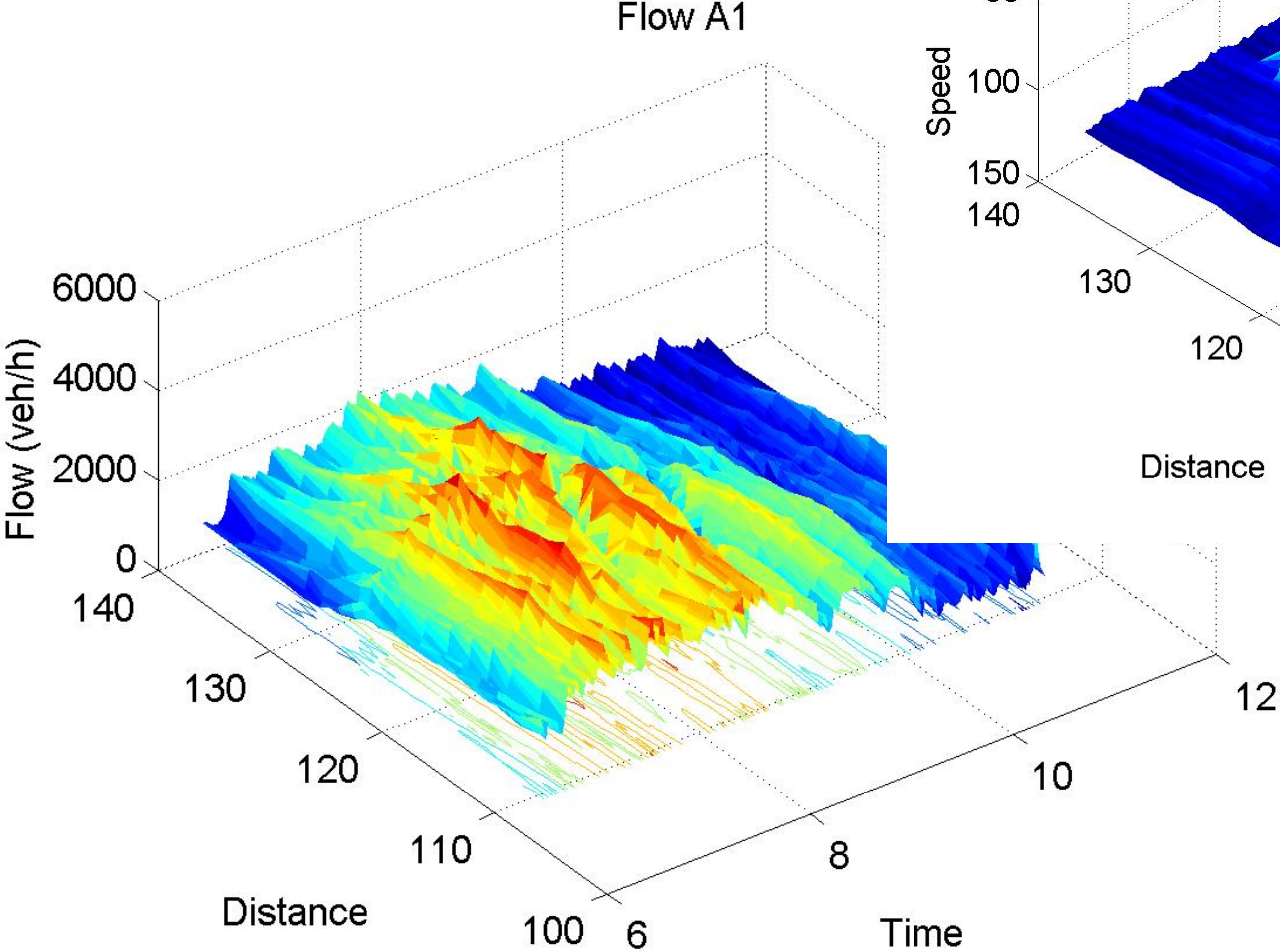


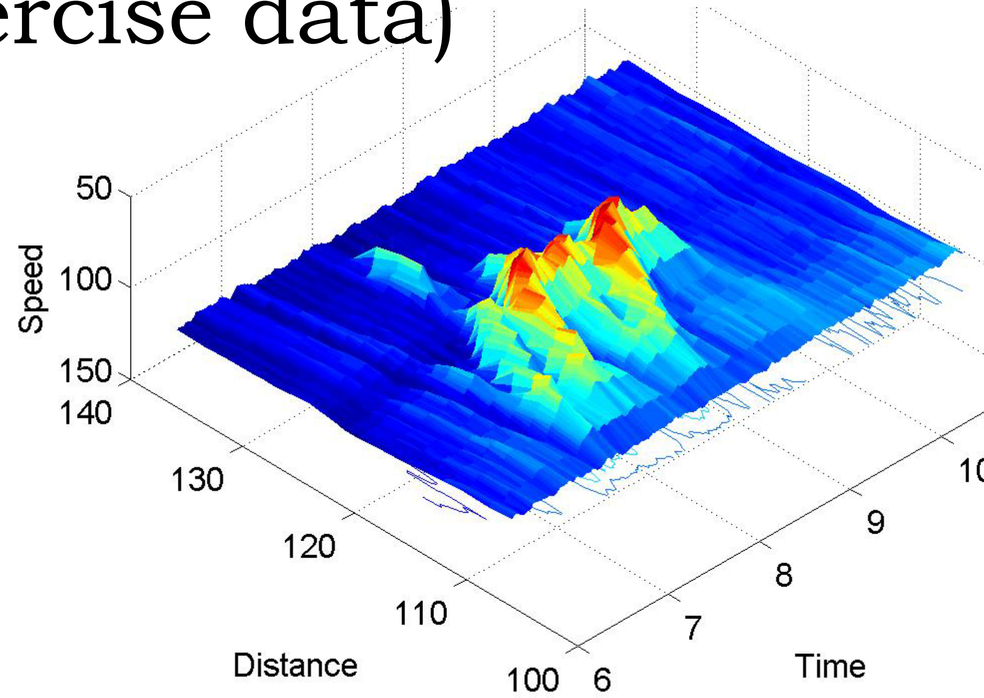
Spontaneous phase transitions

- Consider conditions upstream of active bottleneck
- What will shockwave theory predict?
- Unstable traffic states: transition from jam upstream of bottleneck to stop-and-go waves



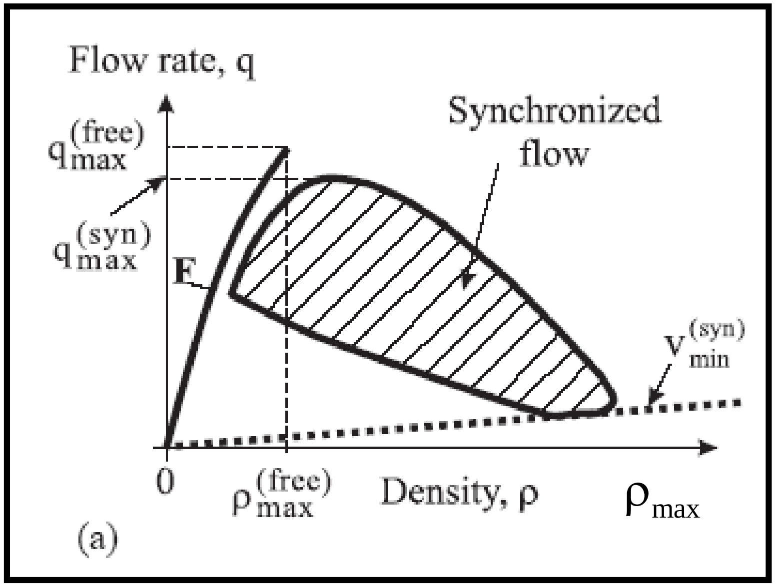
A1 motorway (exercise data)





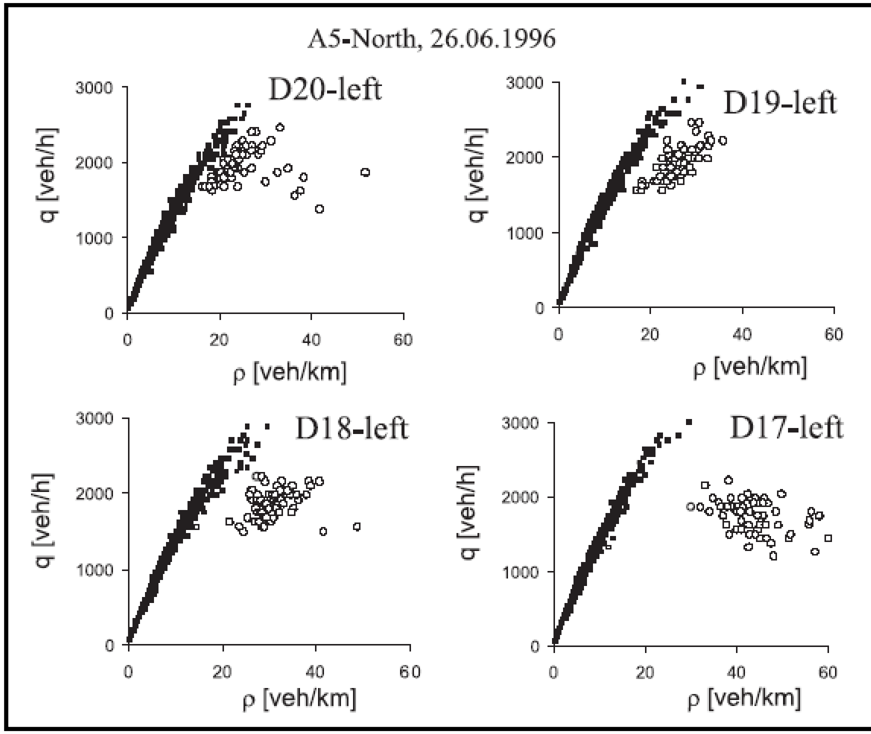
Traffic theory of Kerner

- Three phase (state) theory of traffic flow:
  - Free flow
  - Synchronized flow (density > critical density, but less than jam density)
  - Wide moving jams (density = jam density)

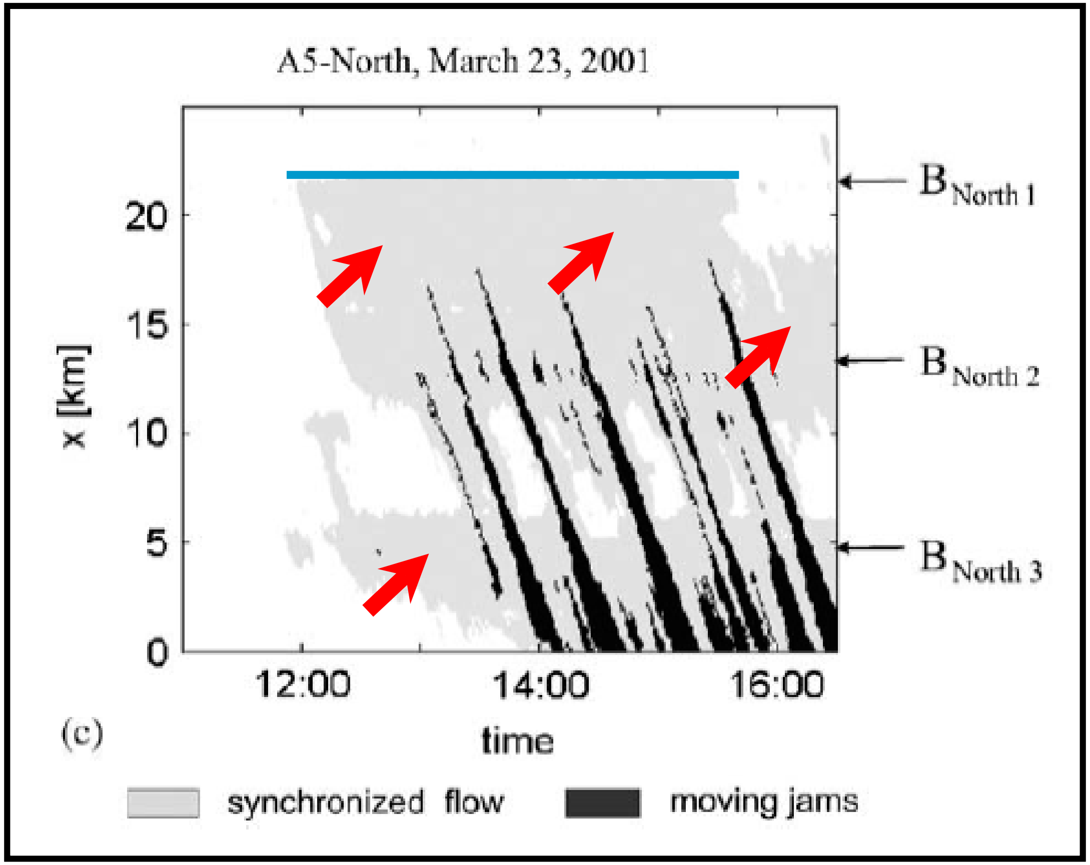


Traffic theory of Kerner

- Synchronized flow
  - Little lane changing, speed of lanes are nearly equal
  - Occurs at bottlenecks (like regular queues)
  - Head of the queue is generally stationary
  - Congested traffic state
  - Multiple stationary states in congested branch, which is an area rather than a line



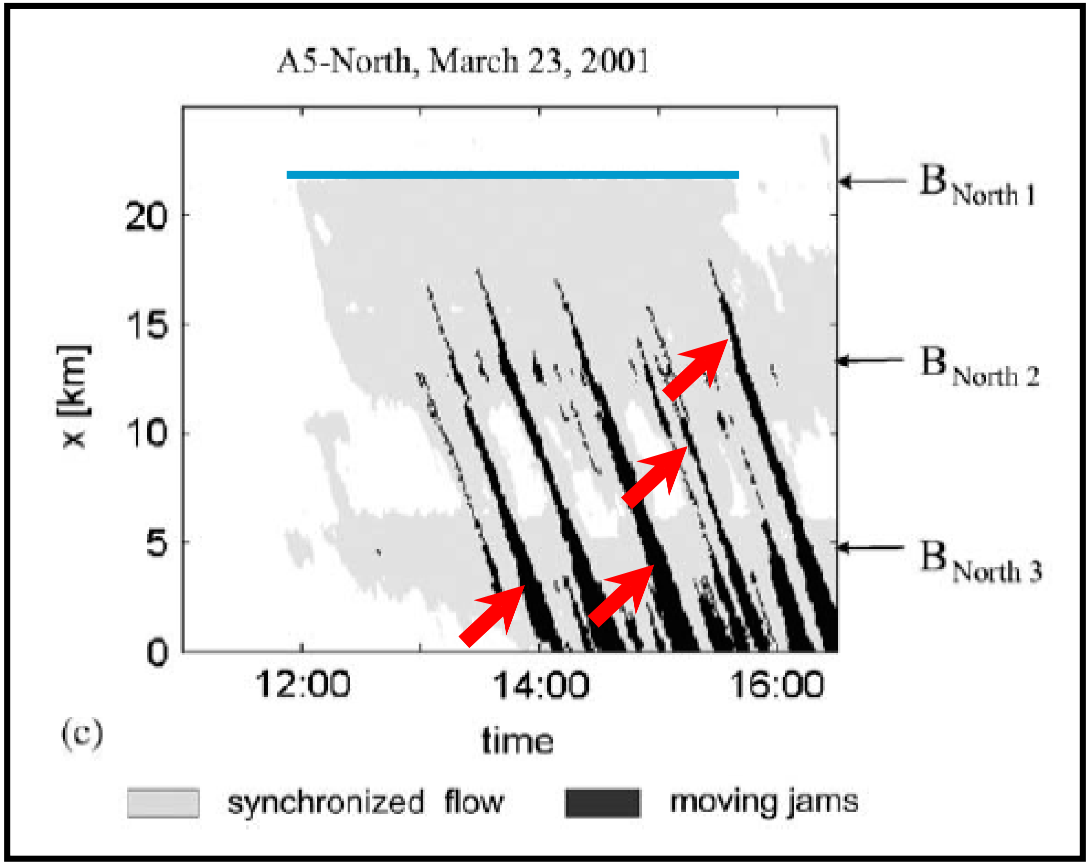
Traffic theory of Kerner



Traffic theory of Kerner

- Dynamic properties of ‘wide moving jam’
  - Density in wide moving jam equals the jam density, vehicles inside the queue are standing still
  - Density upstream equals critical density ρ_{min}
  - Head of queue is moving at a constant speed
  - Wide moving jam can move through other disturbances

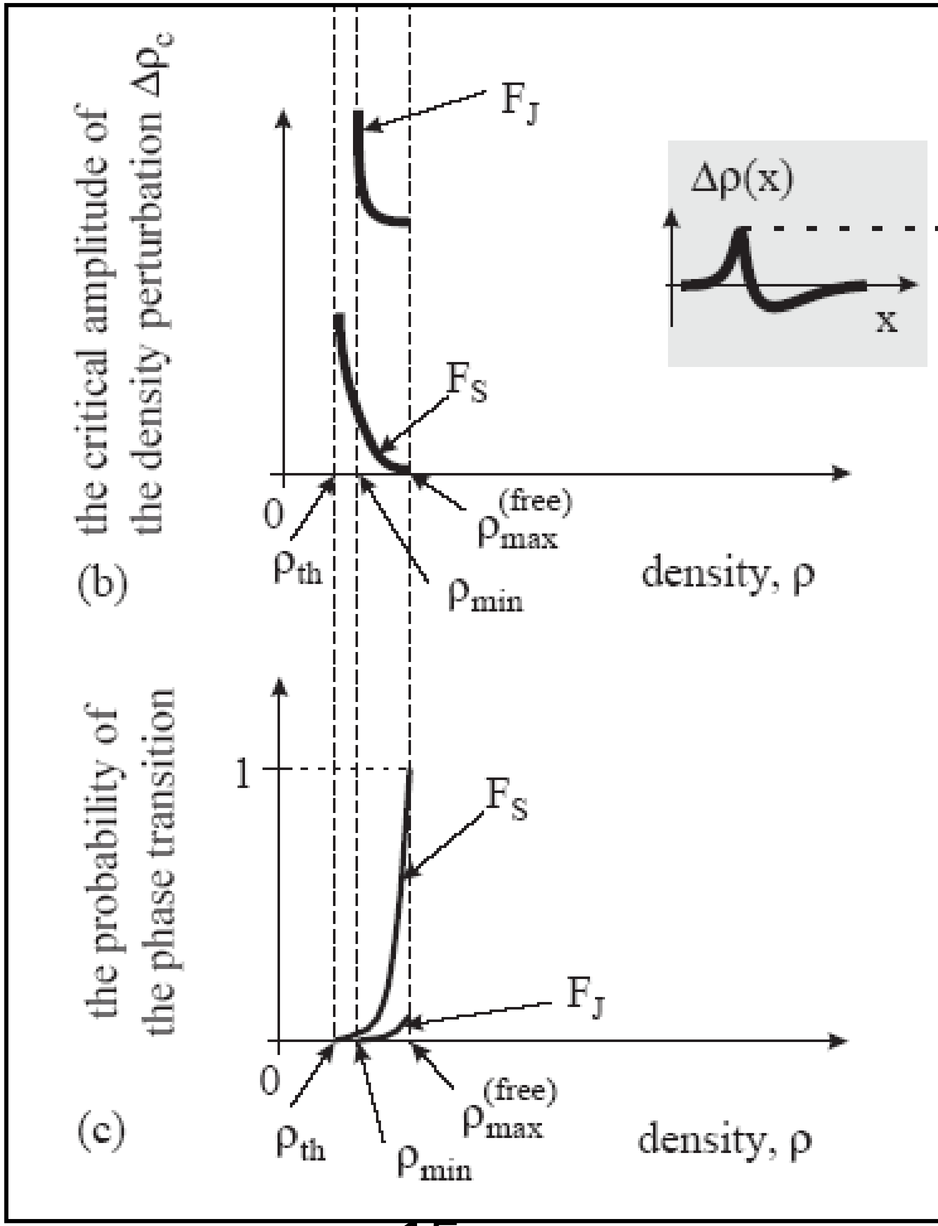
Traffic theory of Kerner



Phase-transitions

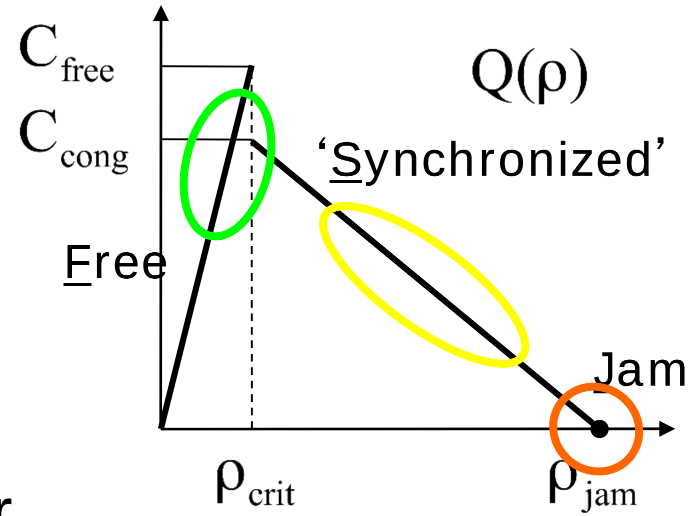
- Minimum distubance needed for breakdown

- Probability of breakdown



Modeling breakdown probability:

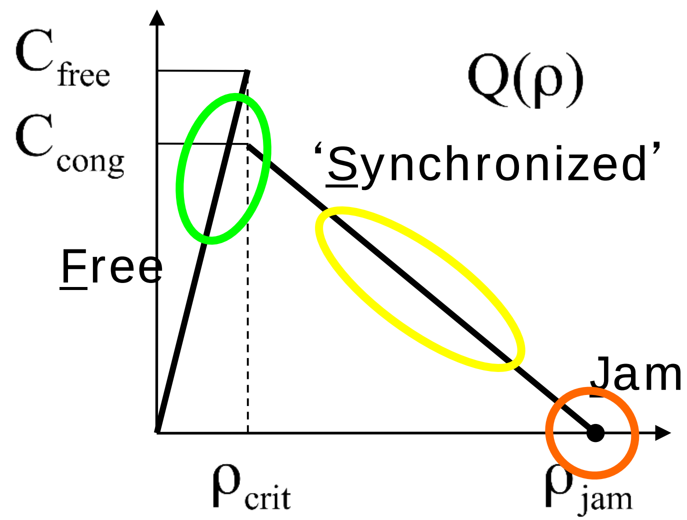
- Let a breakdown probability move with a characteristic curve
- Breakdown probability P grows with rate π over time
- P can pertain to a F-S ($P=P_{FS}$) or a S-J transition ($P=P_{SJ}$)
- Question: how can we find the speed of the characteristic curves (i.e., curves with the same traffic properties)?



Modeling breakdown probability:

- LWR 1st order model for density 〉 :

$$\frac{\partial \rho}{\partial t} + c(\rho)\frac{\partial \rho}{\partial x} = 0 \quad \text{where} \quad c(\rho) = \frac{dQ}{d\rho}$$



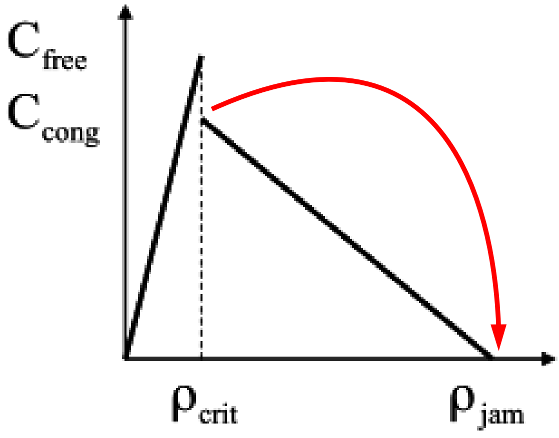
- Dynamics of phase-transition probability P:

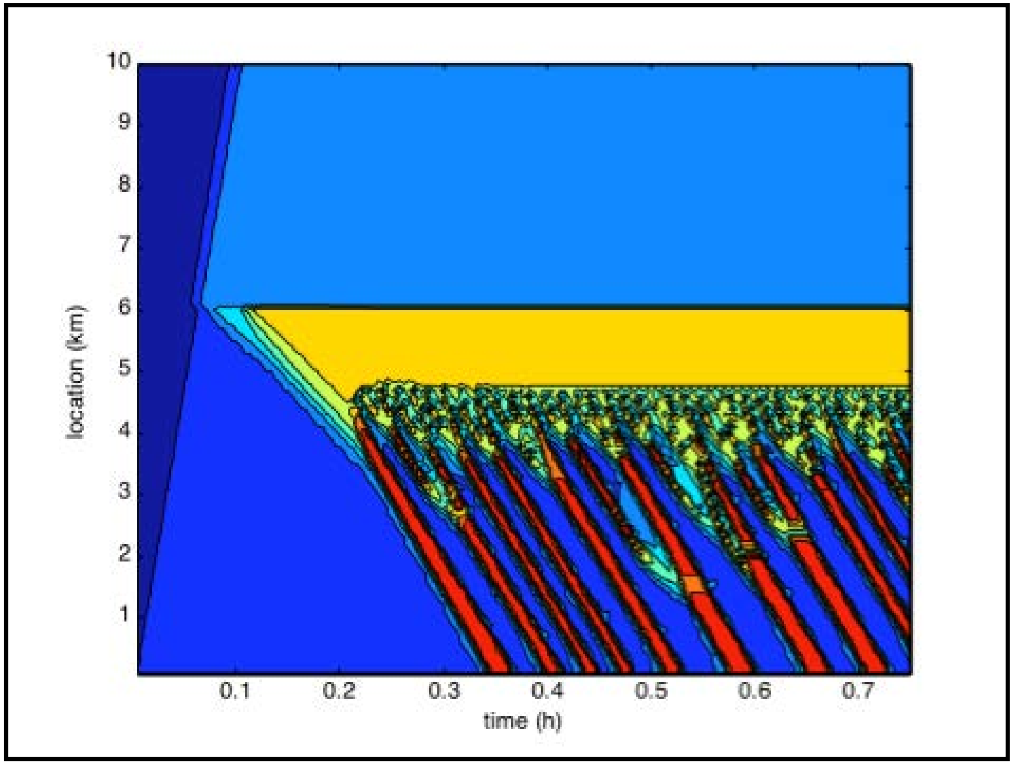
$$\frac{\partial P}{\partial t} + c(\rho)\frac{\partial P}{\partial x} = \pi(\rho, P)$$

□□ denotes the rate of change in phase-transition probabilities

Synchronised flow => WMJ

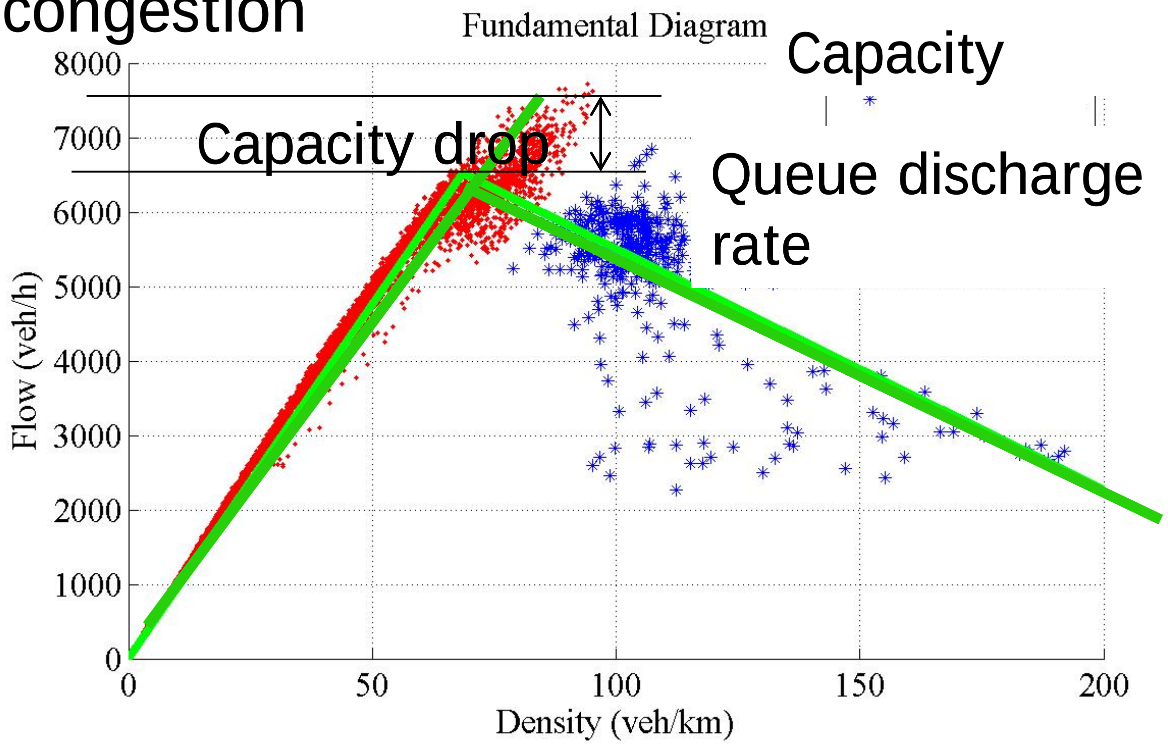
- Assume that S-J transition occurs when $P_{SJ} > 0.5$
- Spontaneous jump in the FD:





Capacity drop

- Typically, no bottleneck location, so no direct measurement
- Construct fundamental diagram with congested points from downstream congestion



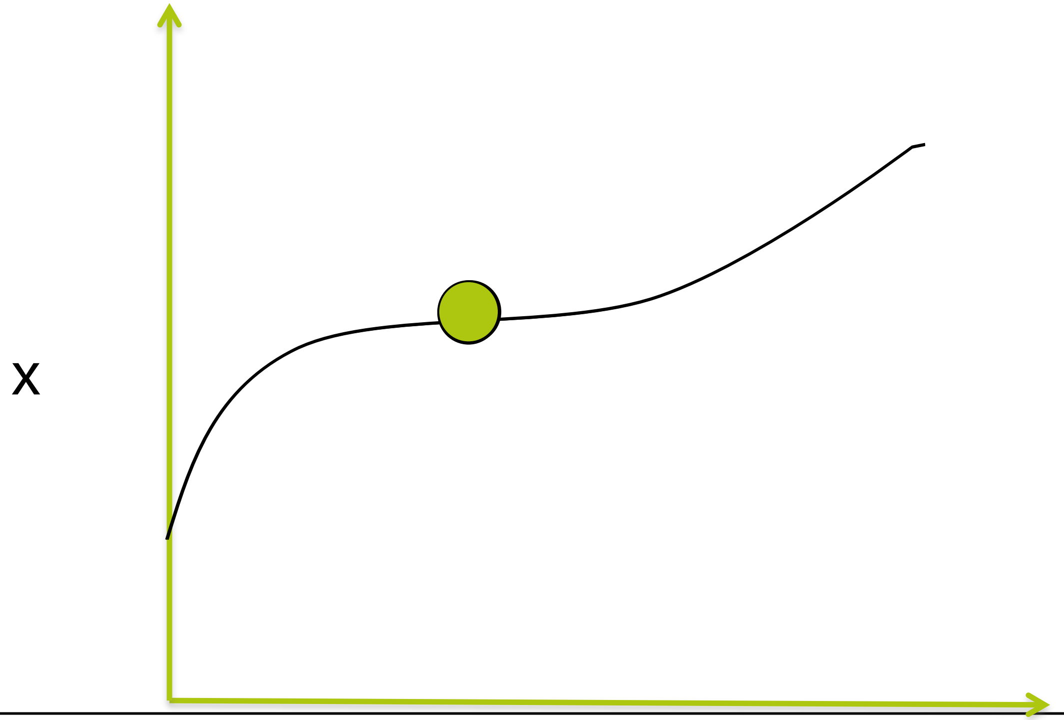
- Capacity drop!
- free flow capacity is higher than congested capacity
- Inverse-lambda fundamental diagram => queue outflow

WIEDEMAN PRINCIPE (ACTION POINTS)

Recap car-following models

- A car-following model describes the position or speed or acceleration of a follower from a leader's trajectory
- Prediction model
- $a(t-t_r)=f(dx,v)$

Newell's car-following model



Action point models

- The assumption of continous and perfect operation is unrealistic

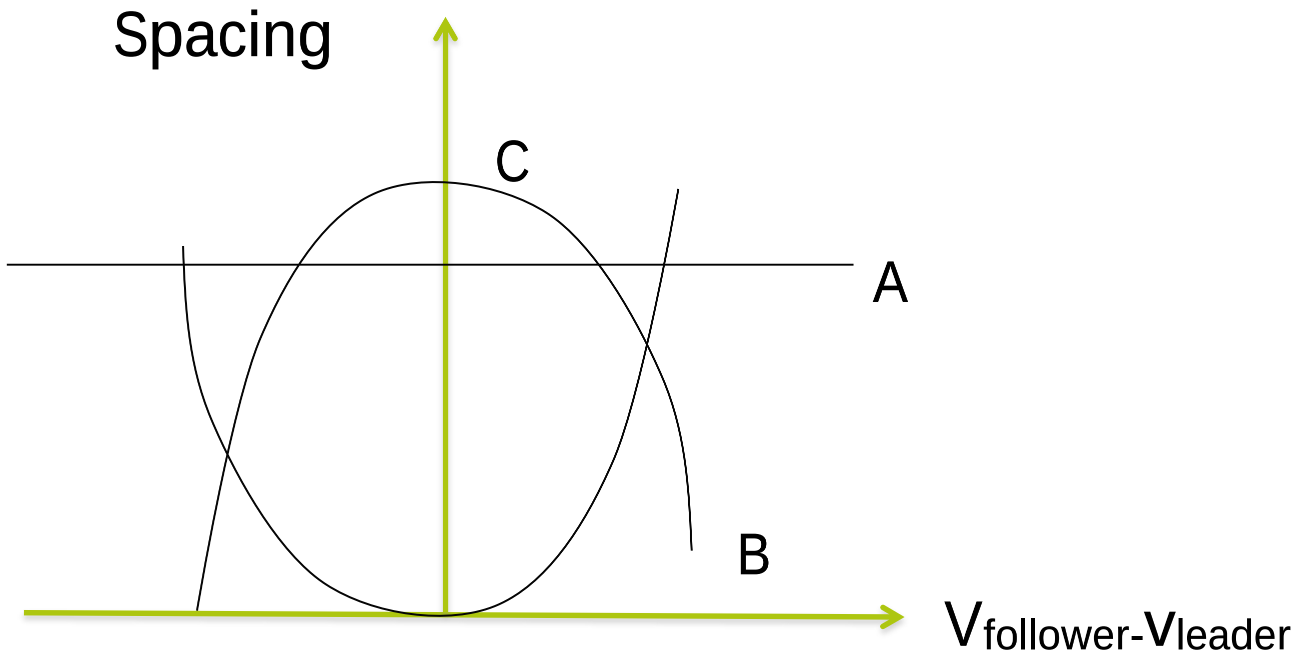
- Why?

Photo by wikipedia / CC BY SA

Photo by Svetlanochka

Perception thresholds

- People do not notice small speed differences at large distances
- What are observation thresholds?



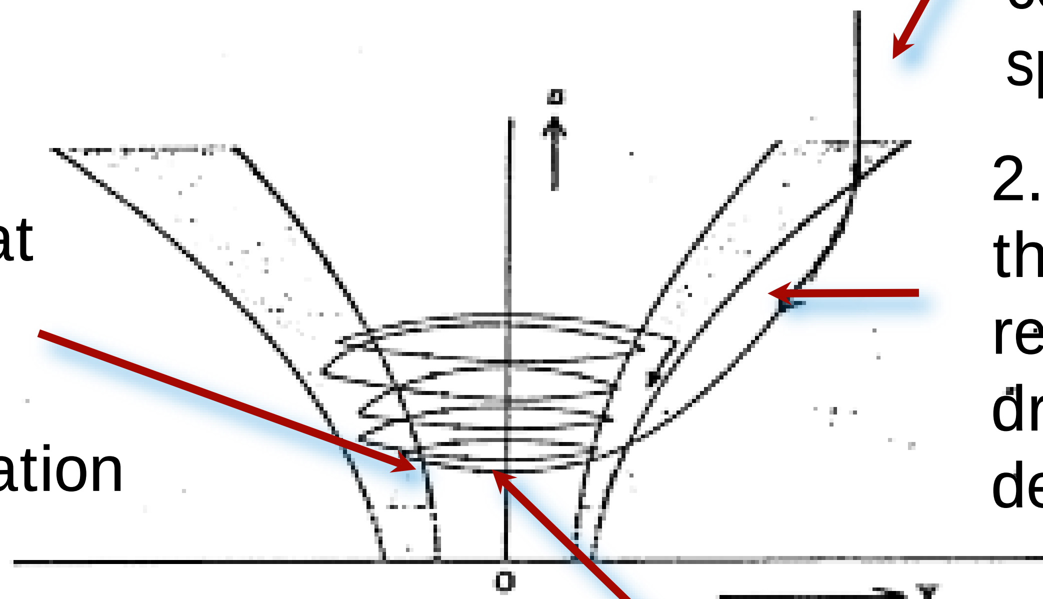
Principle by Wiedeman

1. A follower with a speed larger than the leader approaches with constant relative speed

2. When the threshold is reached, the driver decelerates

3. Deceleration until Δv=0

4. No notice that driver over-deceleraties, so relative acceleration



$v_{follower} < v_{leader}$

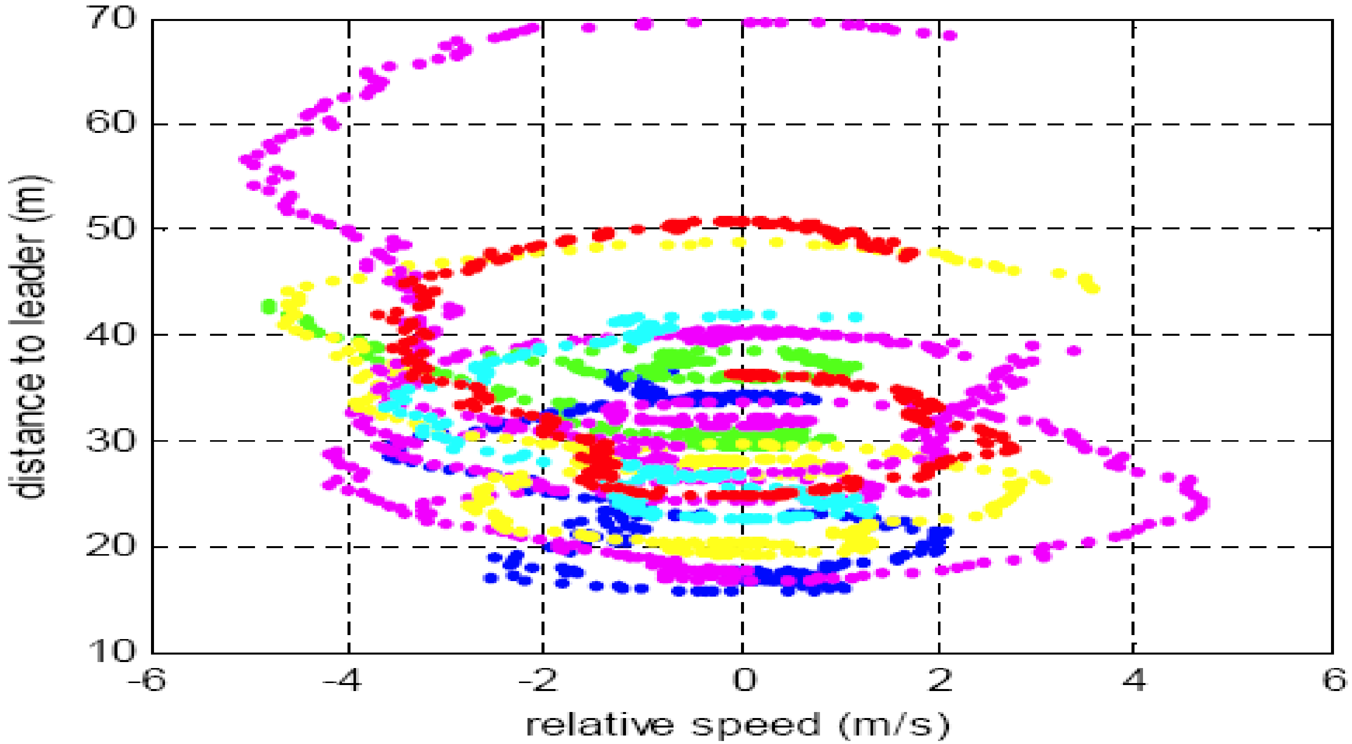
$v_{follower} > v_{leader}$

Wiedeman: a second thought

- Wiedeman principle is not a car-following model

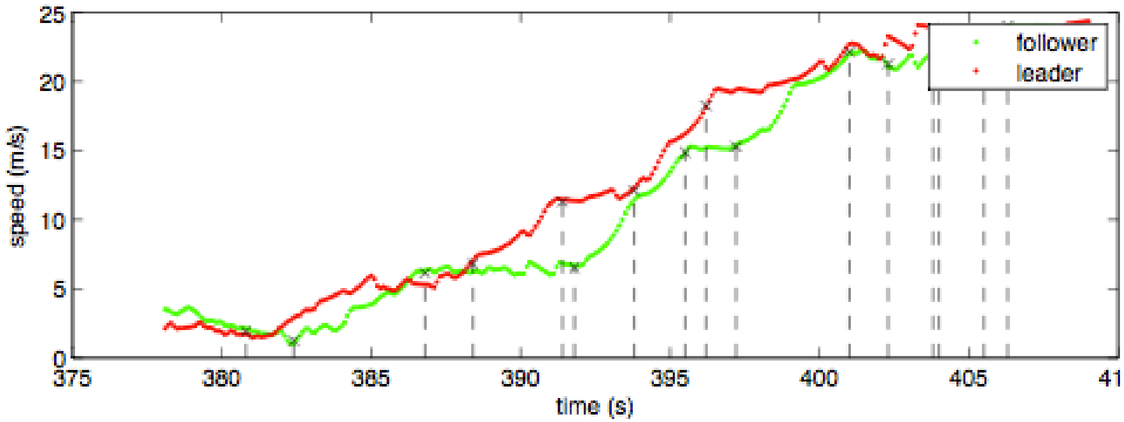
  => why not

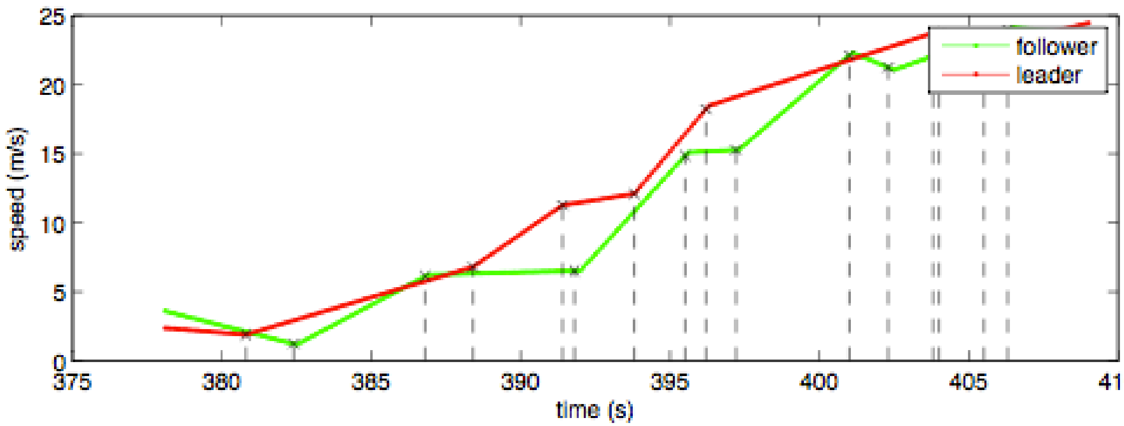
Wiedman plot for data



Finding action points

- Action points not so bad compared with real-life data
- Where are the action points located?

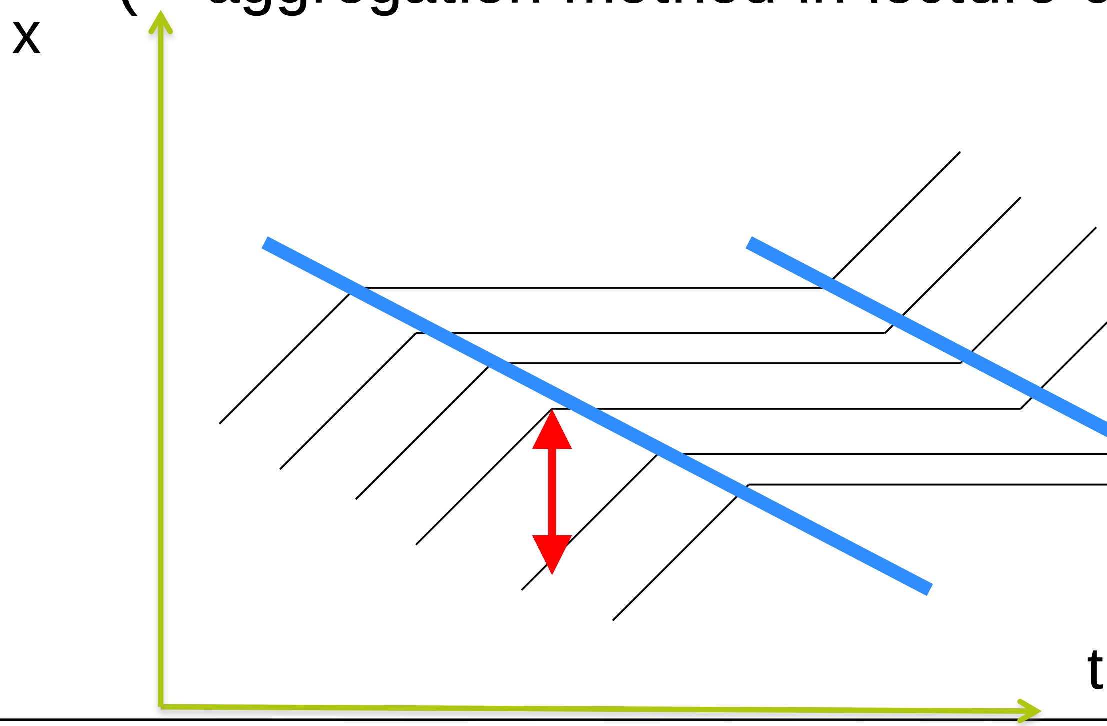




Location of action points

Further problems

- Evaluation points:
  For behavioral results: analysis along wave speeds
  (~ aggregation method in lecture 6) => why?



CELLULAR AUTOMATA MODELS

Cellular automata models

- roadways are divided into small cells with a constant length of Δx ~5-10 m
- these cells are either occupied by one vehicle or not;
- Speeds are also discretised:
  v=i*dx/dt, with i=0, 1, 2 ...
- Small Δx might improve accuracy, but speed advantage lost

Cellular automata models

- Updating of the vehicle's dynamics is achieved through the following car-following rules:
  - Acceleration: if a vehicle has not yet reached his maximum speed v_{max}, and if the lead vehicle is more than one cell away: $v=v+1$
  - Braking: if a vehicle driving with a speed v has a headway of Δj with $\Delta j<v$ then the speed of the vehicle is reduced to $(\Delta j-1)$;

- Randomisation;

MEASURING DRIVING BEHAVIOUR

Measurement techniques

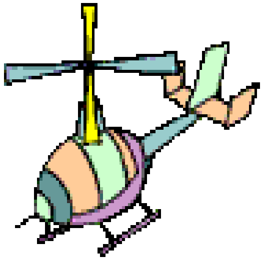
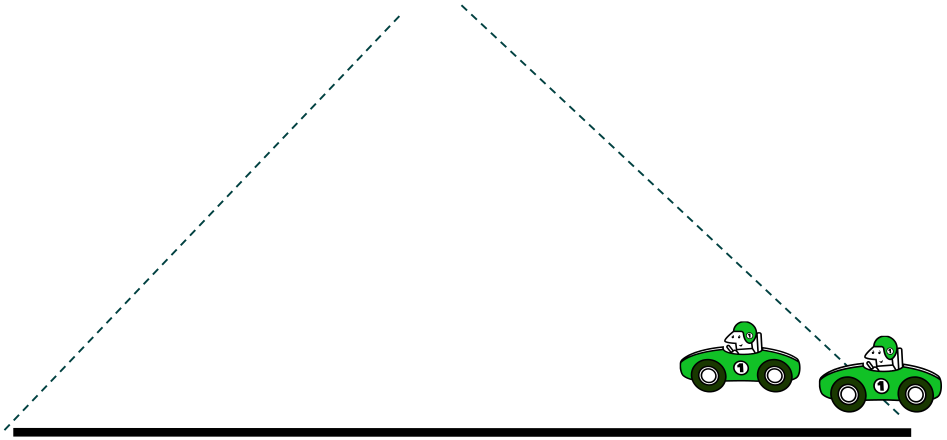
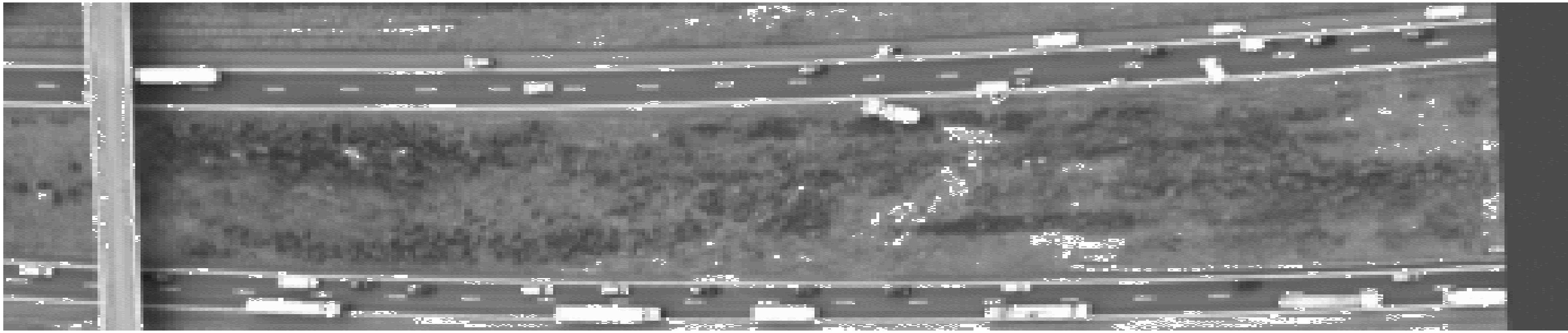


Photo by Theo Linkie



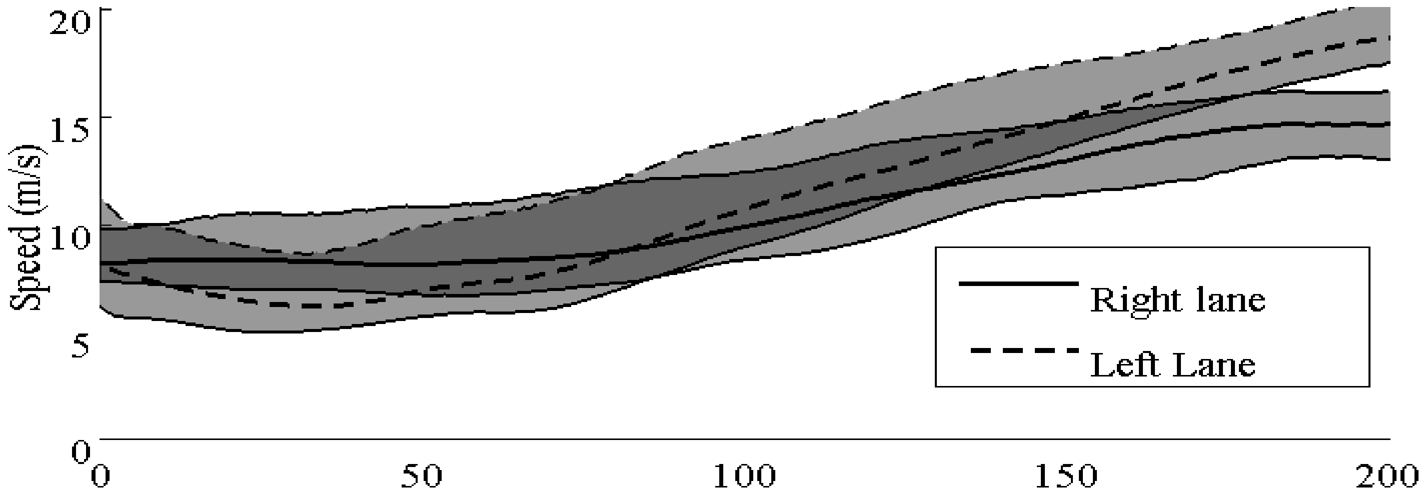
- High quality: 1 pixel = 30 cm
- Stretch of ca. 300 meter
- Recording frequency: 15.1 Hz

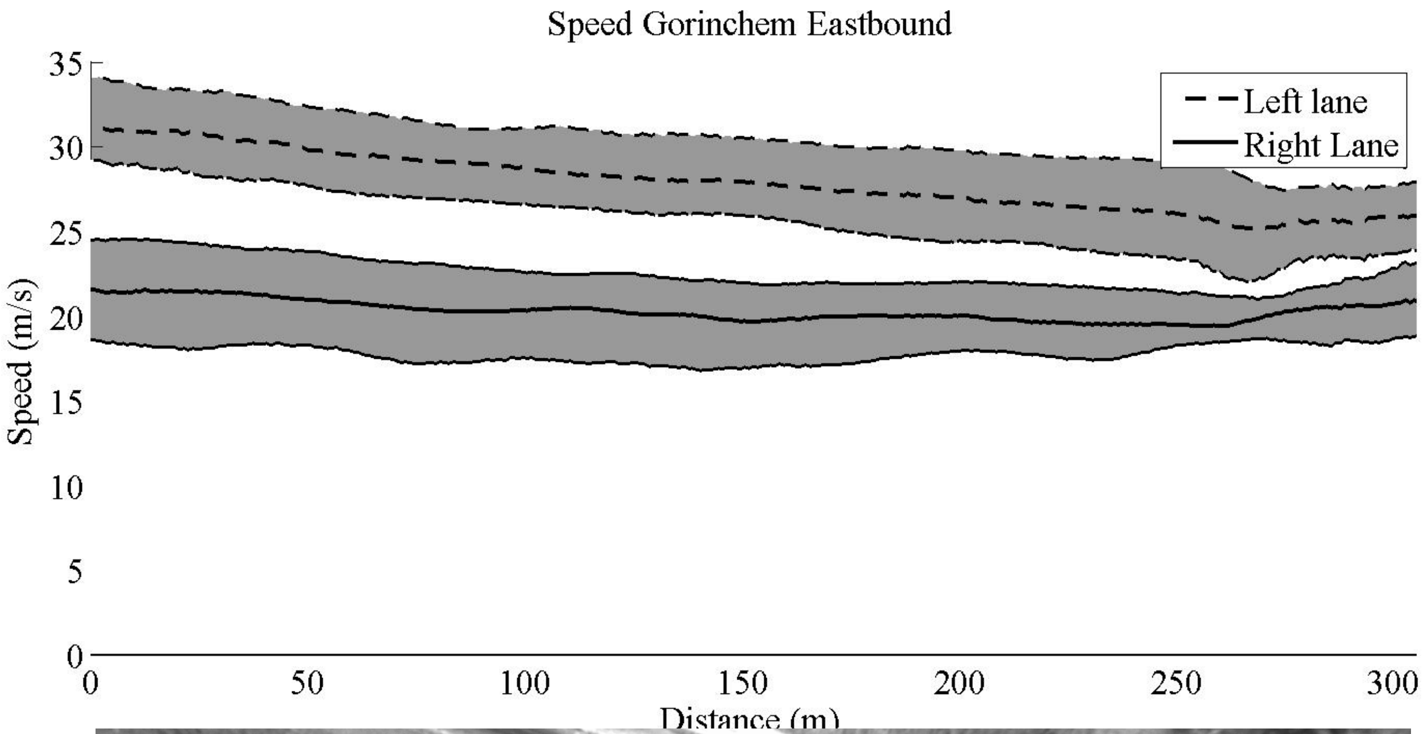
Accident Apeldoorn



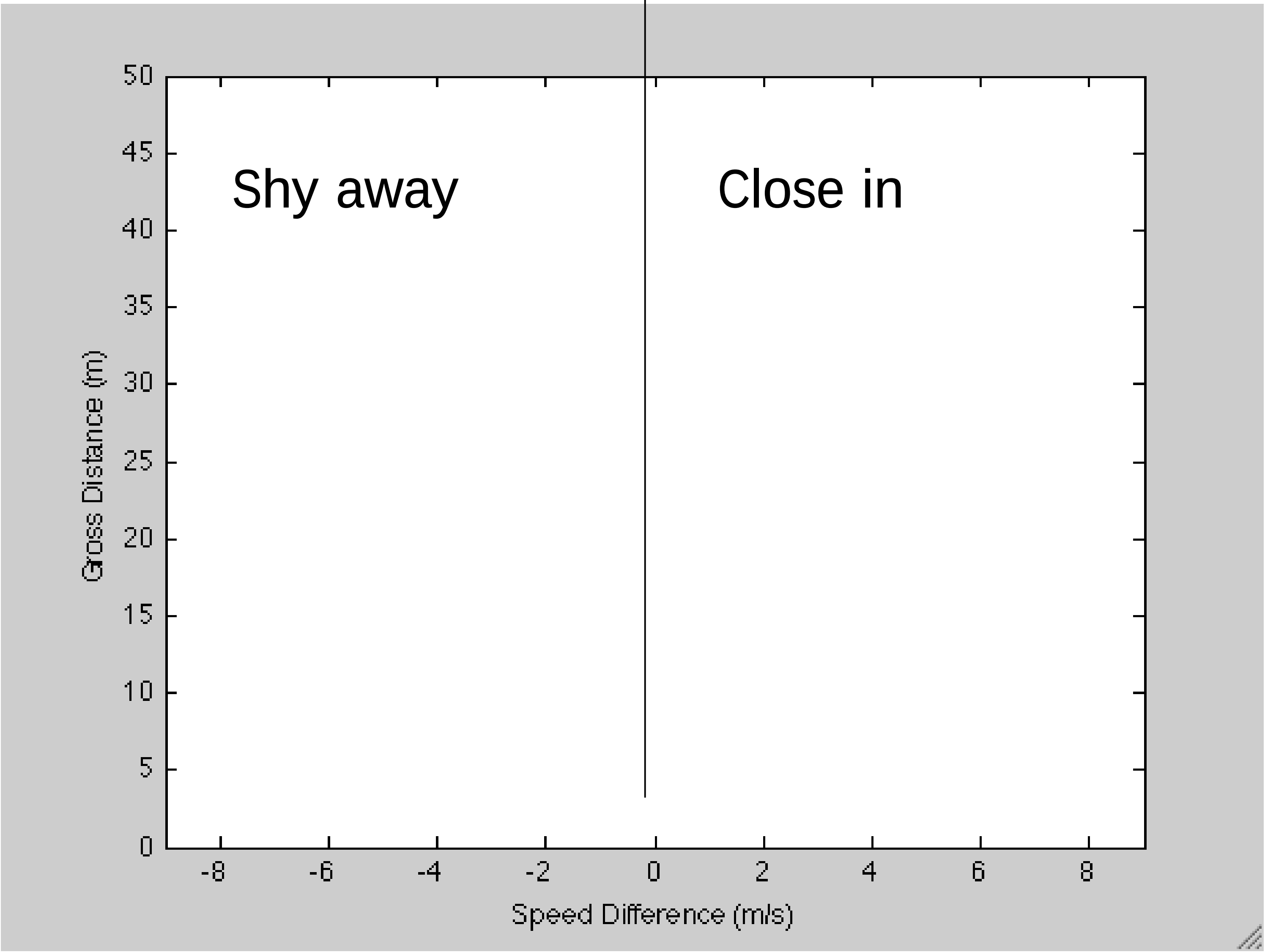
Accident Gorinchem

Speeds




Speed Gorinchem Eastbound
Left lane
Right Lane
Speed (m/s)
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
Distance (m)

Wiedeman principle in practice



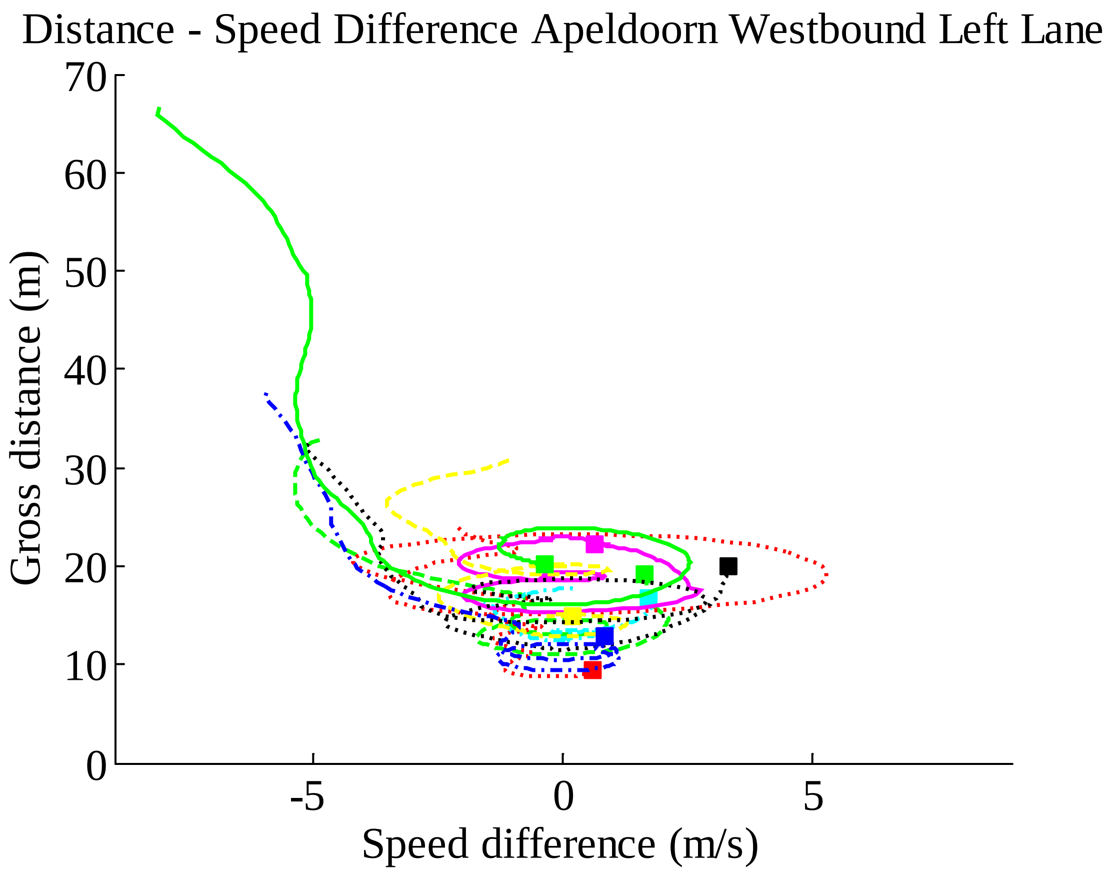


Photo by TU Delft


Source: unknown

CALIBRATING A CAR-FOLLOWING MODEL

Car-following model

$$s^*(v) = c_4 + c_5 v$$

$$\dot{v}(t + \tau_r) = \min\left\{\begin{array}{c} c_1 \Delta v(t) + c_2\left(\Delta x(t) - s^*(v)\right) \\ c_3\left(v^* - v(t)\right) \end{array}\right\}$$

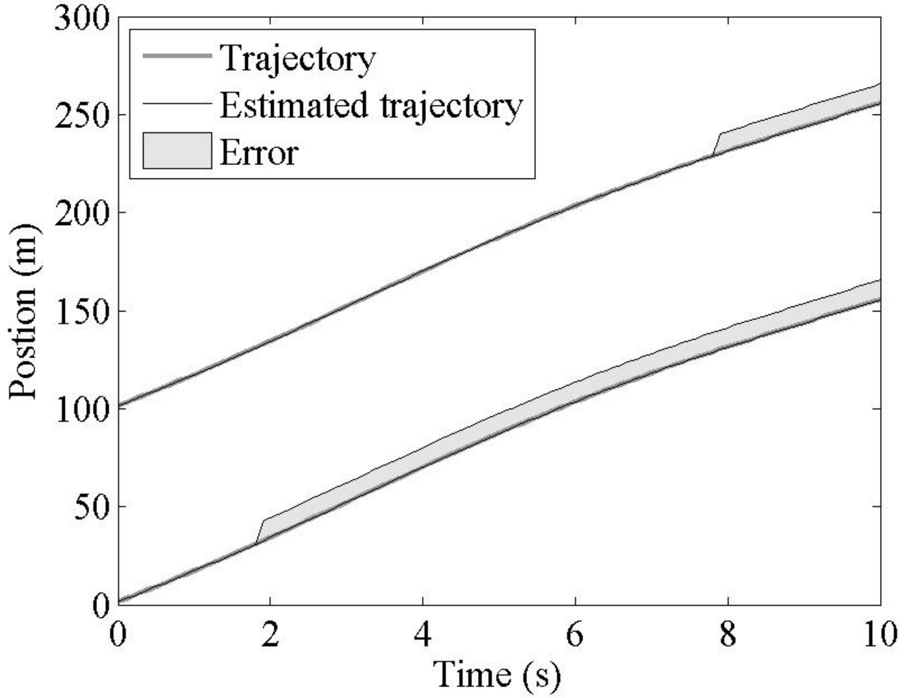
Calibrating parameters

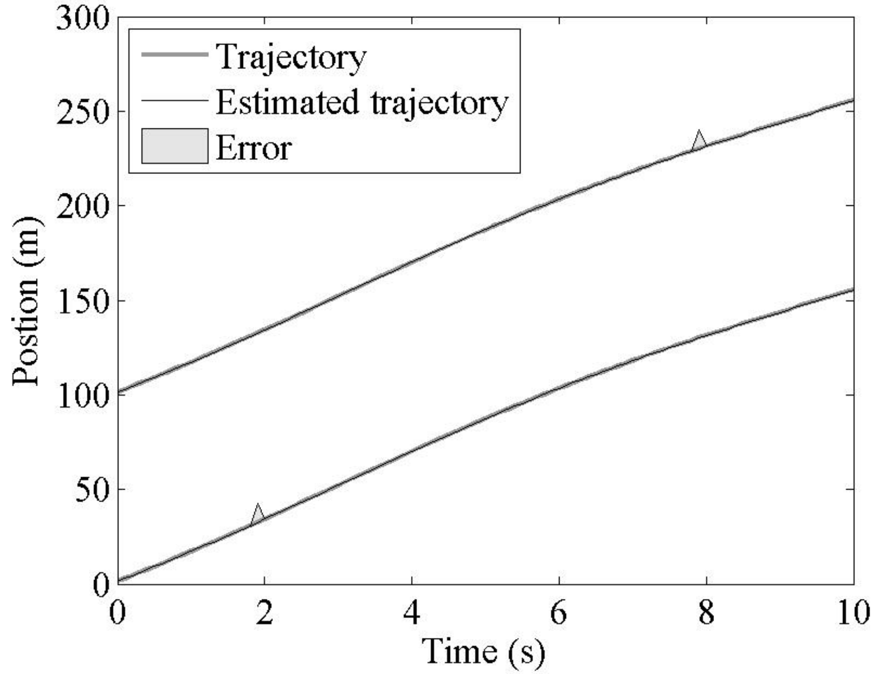
- Change parameters such that model predicts accurately trajectory of follower
- Input: trajectory of leader (or leaders)

- How?
- Simulate trajectory of follower with a certain parameter set
- Change parameters such that error is minimum
- Objective: speed and position
  => combination thereof

Combine speed and position

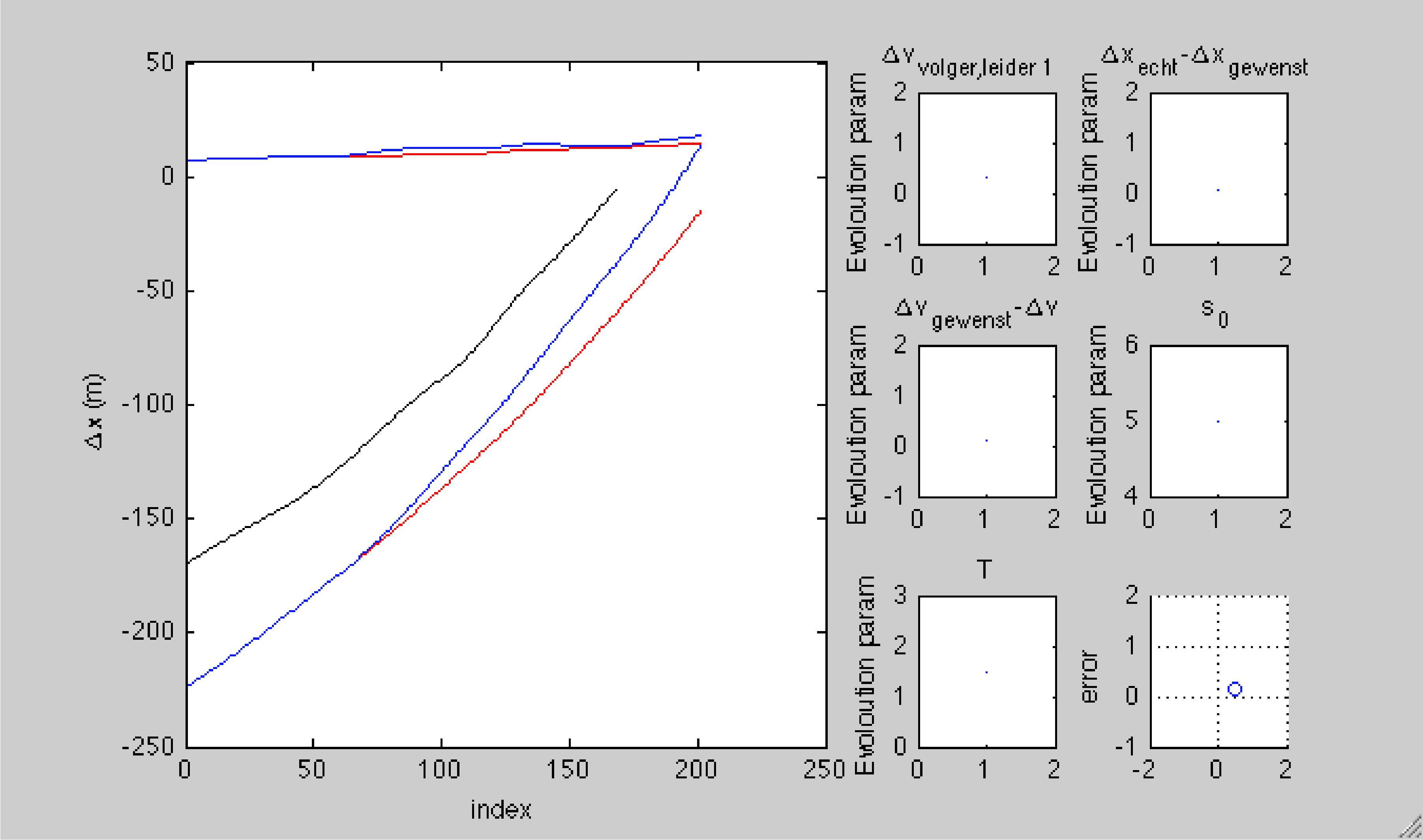
- Correlated
- Reset position each time step





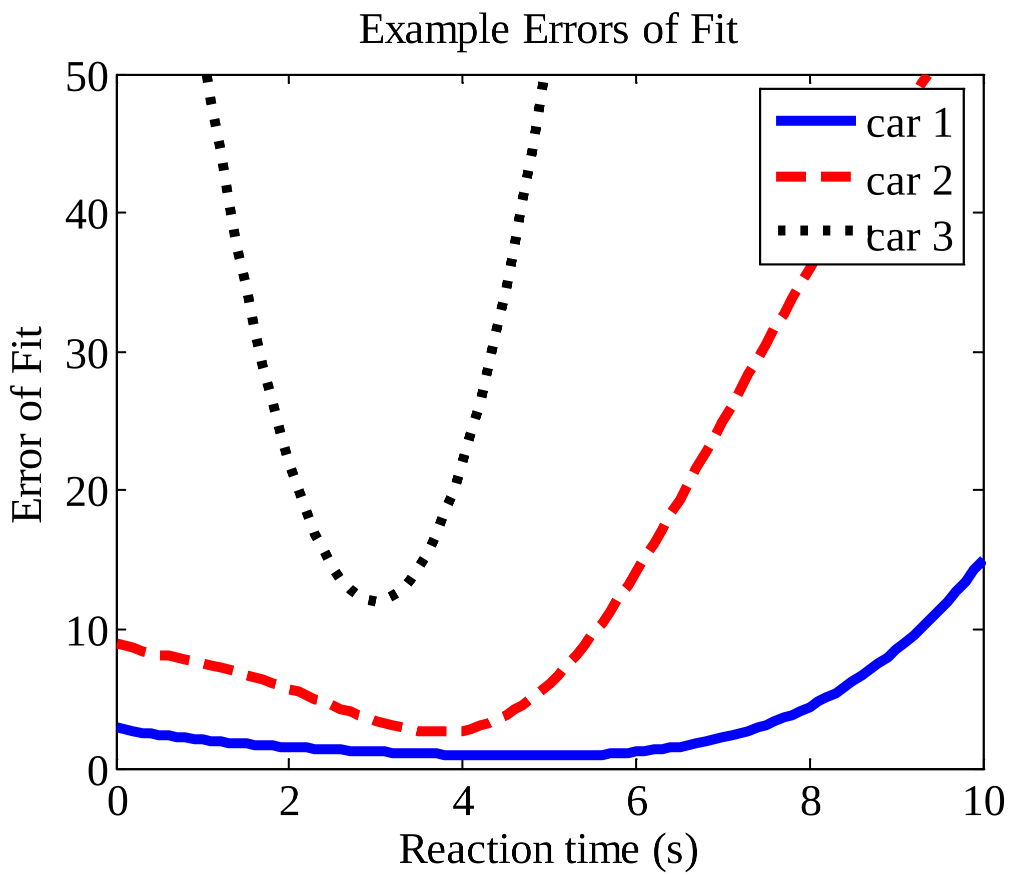
Car-following model

Acceleration at $t+t_{react}$ is function (model) of trajectory of leader



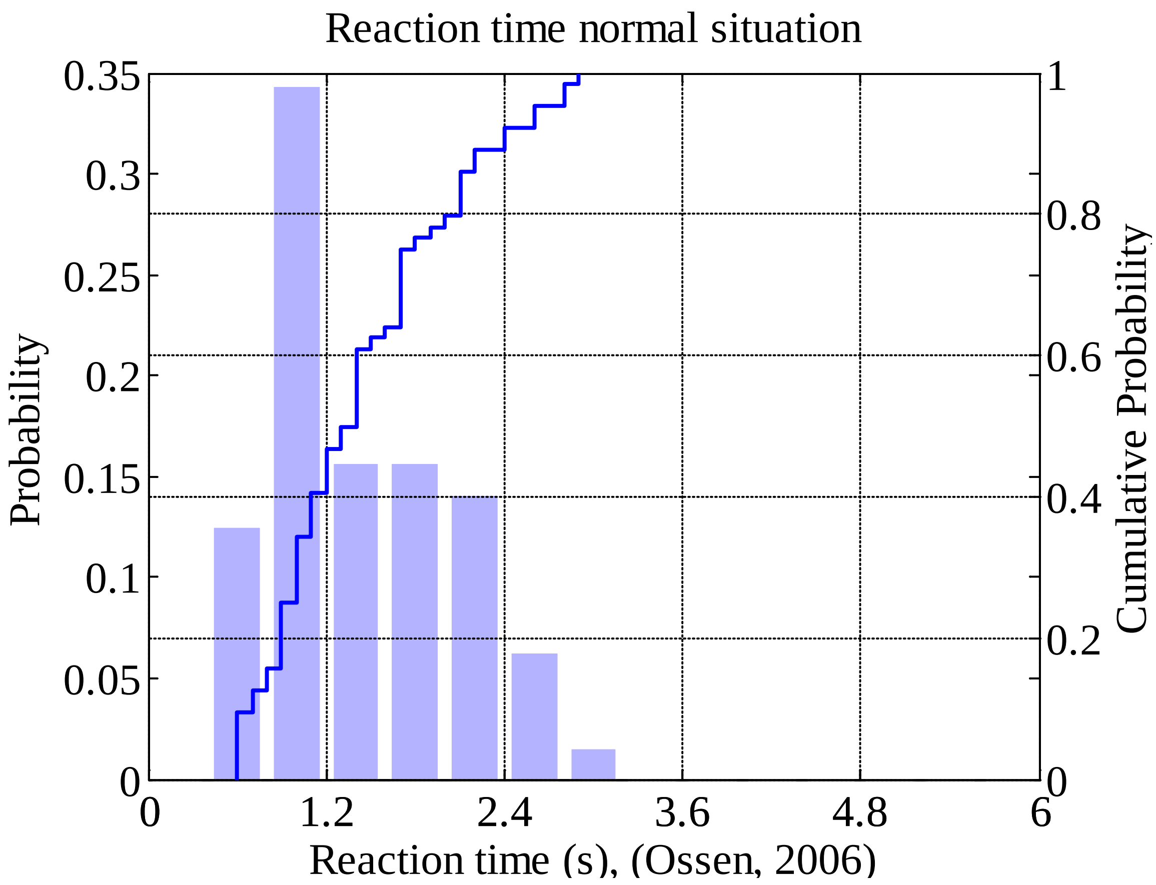
Sensitivity of parameters

- Some drivers better fitted than others
- More weight for parameters which are better known

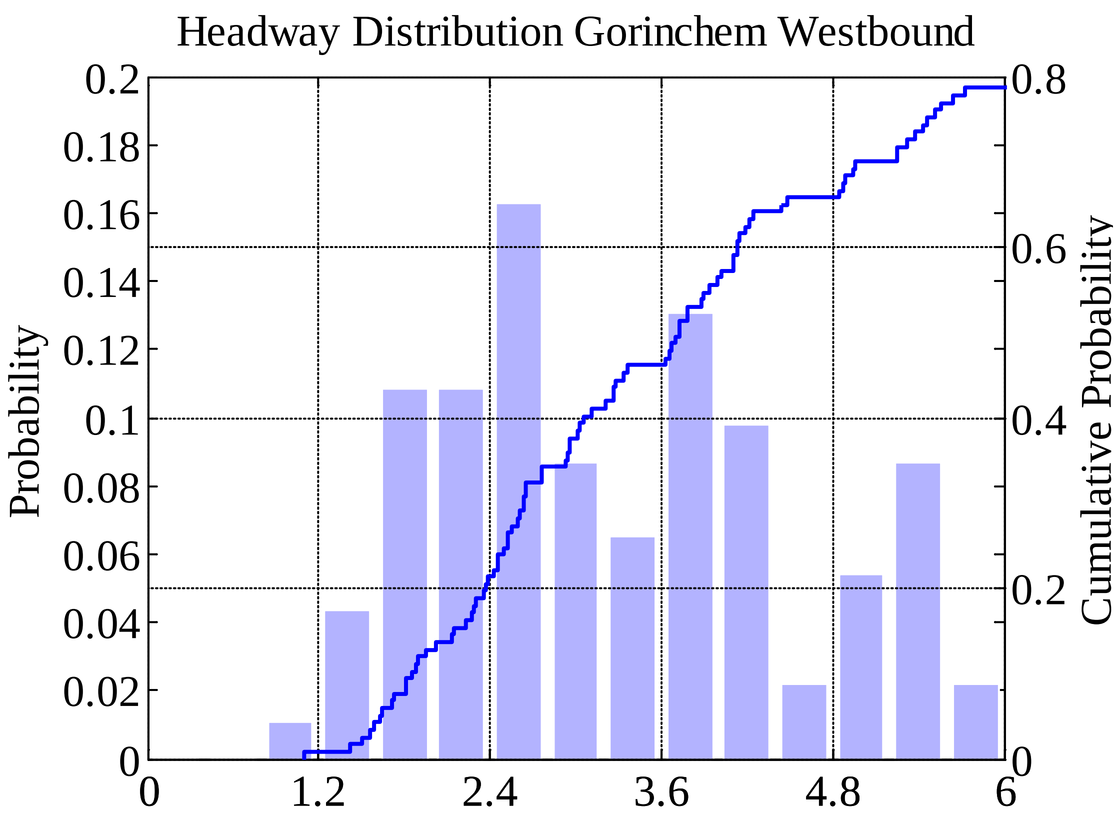


IMPLICATIONS OF PARAMETERS

Bi-modal reaction time distribution

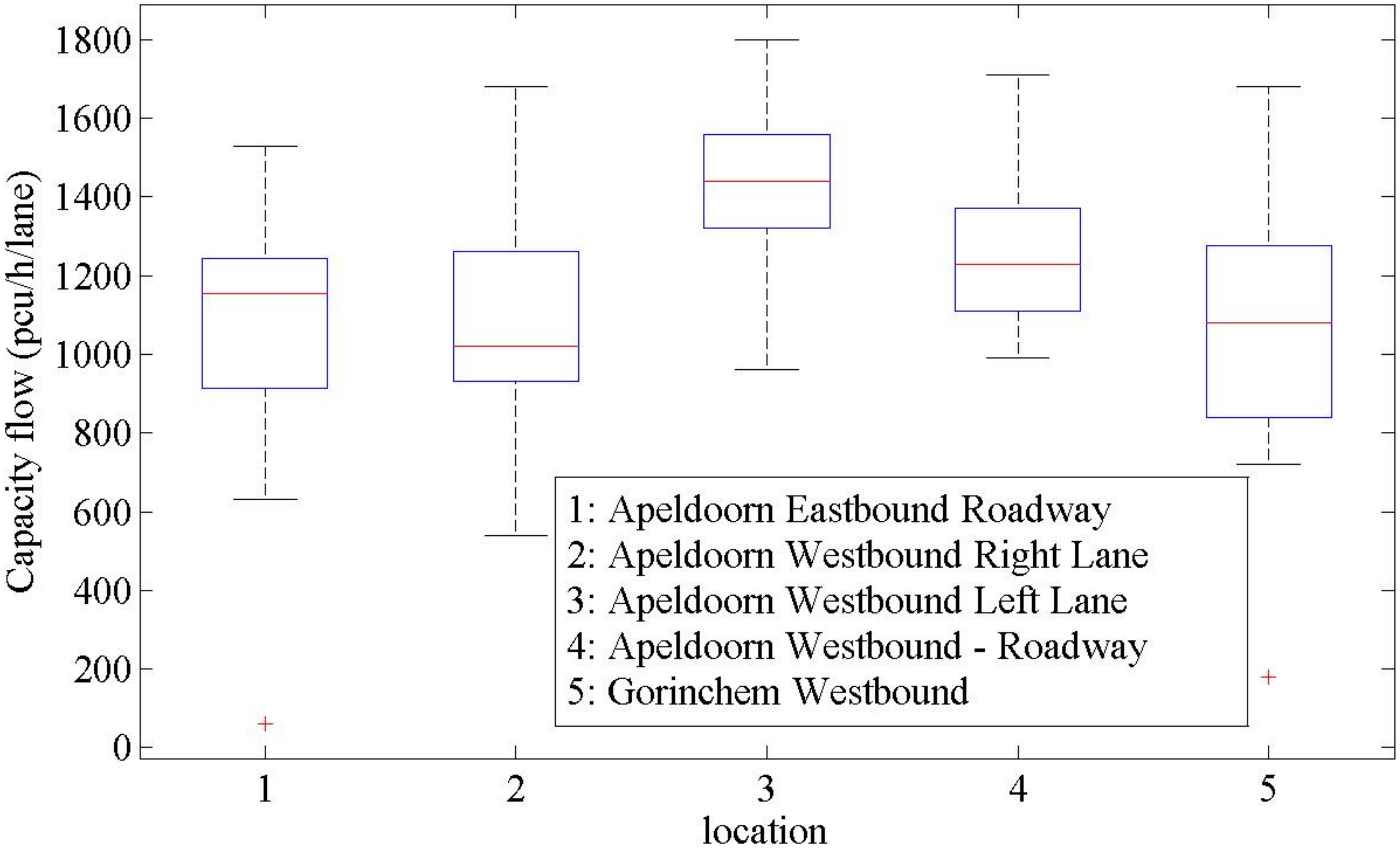


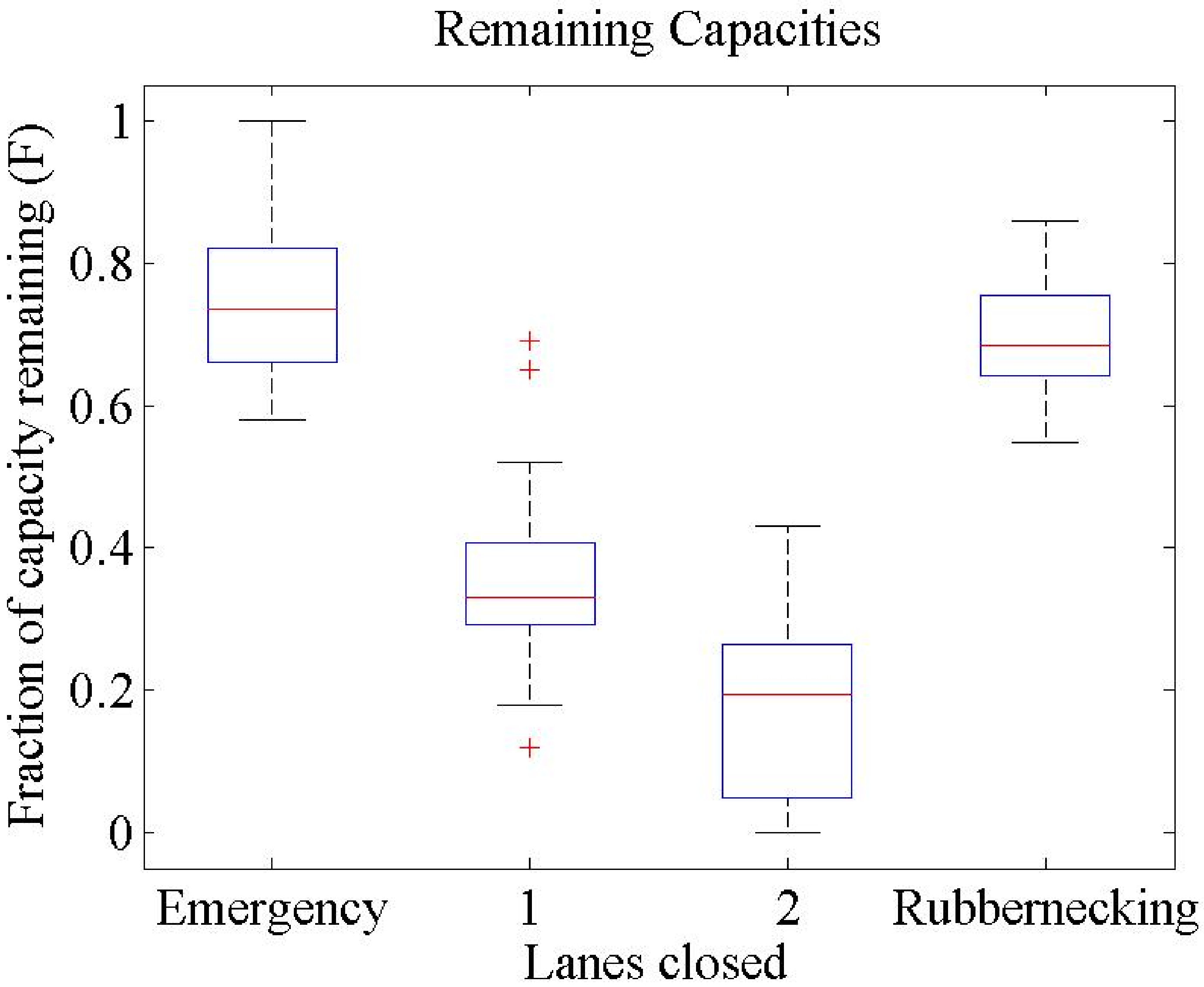
Headways



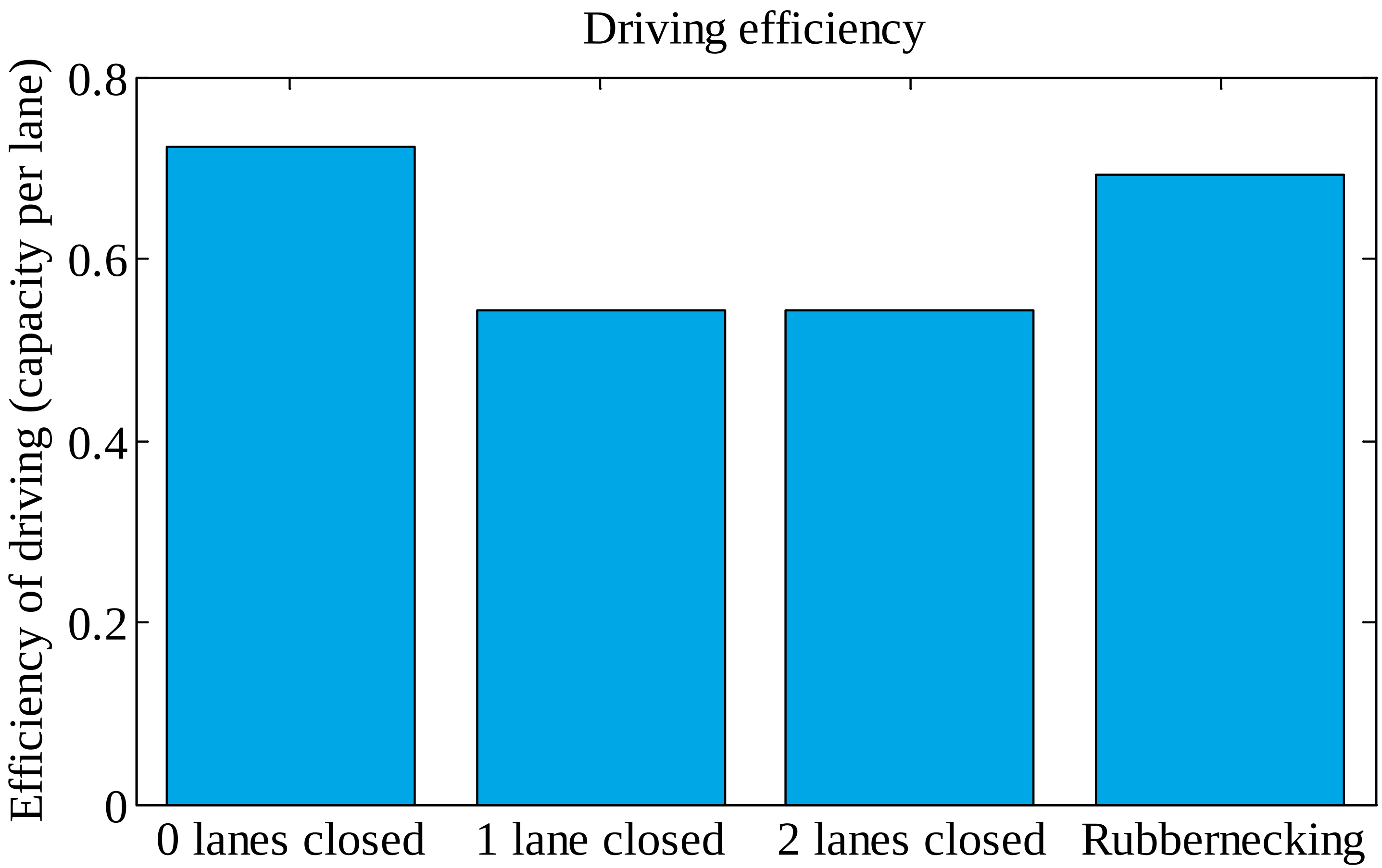
Headway Distribution Gorinchem Westbound
Probability
Cumulative Probability
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.8
0.6
0.4
0.2
0
0
1.2
2.4
3.6
4.8
6

Outflow capacity 30% lower




Remaining Capacities
Fraction of capacity remaining (F)
1
0.8
0.6
0.4
0.2
0
Emergency
1
2
Rubbernecking
Lanes closed

Efficiencies



=> Driving behaviour considerably influences capacities

EXERCISE

Effect of Incident Management

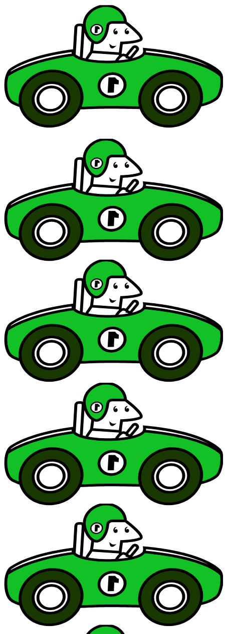
- Reduction of incident handling time
- 1 of 3 times to be shortened by 2 min:
  - Until arrival (1 lane blocked, 15 min)
  - Working on roadway (2 lanes blocked, 30 min)
  - Working on emergency lane (0 lanes blocked, 15 min)

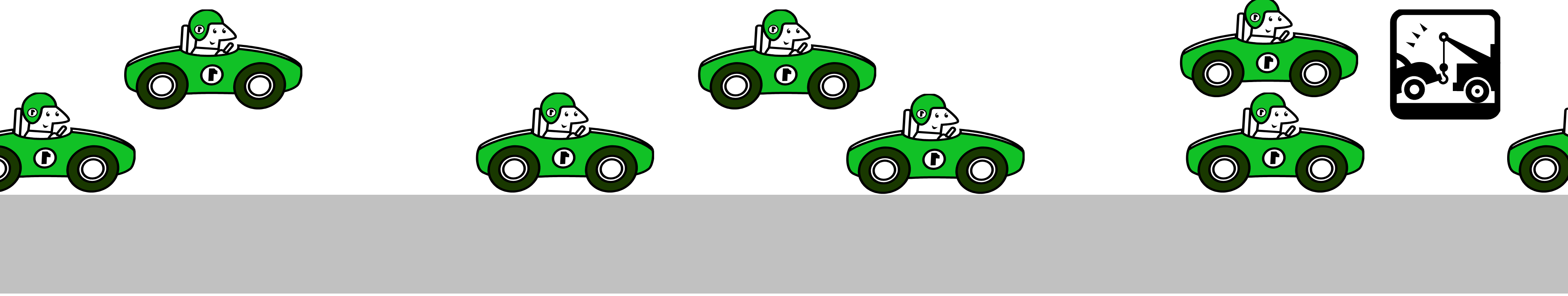
Source: unknown

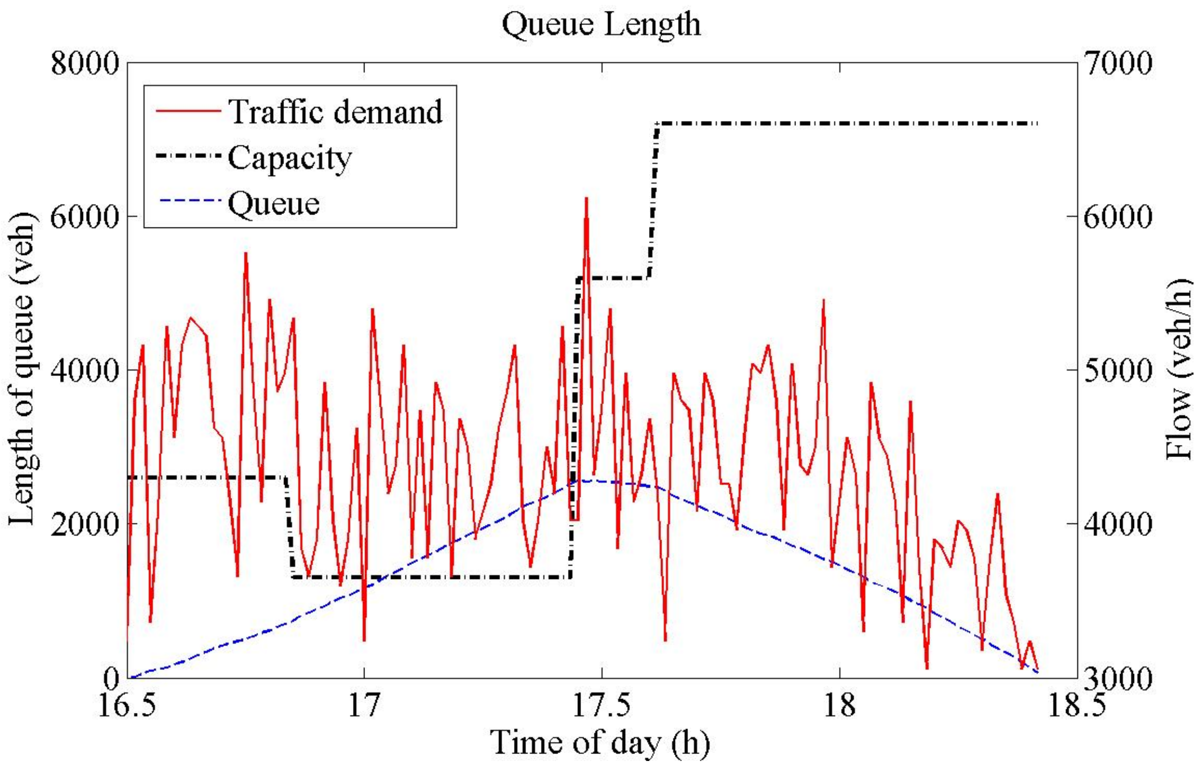
- Use capacities from previous slides
- Which reduction reduces incident delays most?

Vertical queuing model

- Simple modeling:
  - No change in demand
  - No route choice change
  - Vertical queuing
- Use a non incident day







- You should be able to calculate the blue line based on the red and the bale line

- # Exam formulation:

A three lane motorway has a capacity of 7000 veh/h, and a constant demand of 3000 veh/h. An accident at t=0 blocks 1 out of 3 lanes. After 15 minutes (phase 1), recovery workers arrive (start of phase 2). In order for them to work safely, an extra lane is closed. After 30 minutes of working, the wreck is moved to the hard shoulder (phase 3), where it stays for another 15 minutes (after which the road is completely opened again, phase 4). The lane capacities are the same. Due to changed driving behavior, the capacity per (open) lane reduces when something stationary is on the roadway. Research shows that the capacity of open lanes reduces by 50% if one of the driving lanes is blocked, and by 30% if a stationary object is present at the hard shoulder.

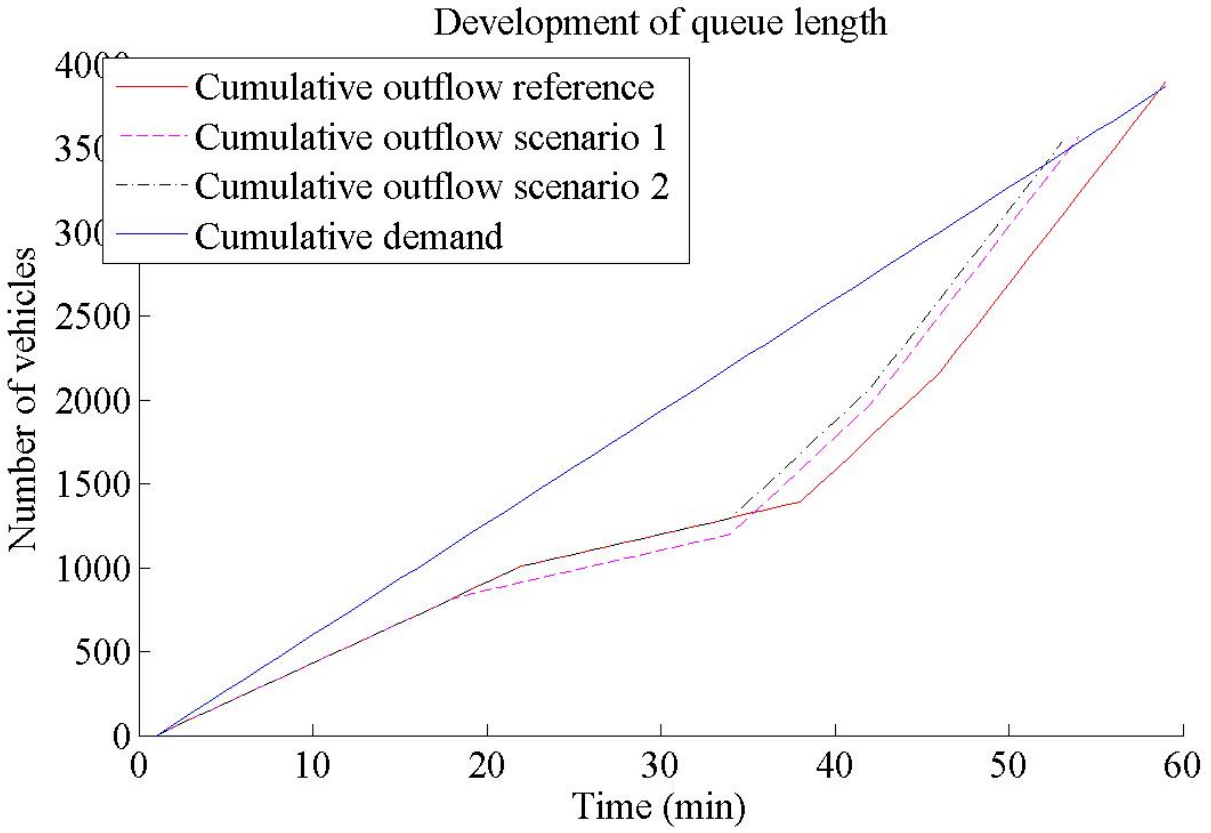
1. Explain from a behavioral point of view why the capacity reduces
2. Draw the cumulative curves for the situation at hand. Indicate the queue length in vehicles, and the total delay

Incident handling can be improved, and one of the phases 1-3 can be reduced by 2 minutes.

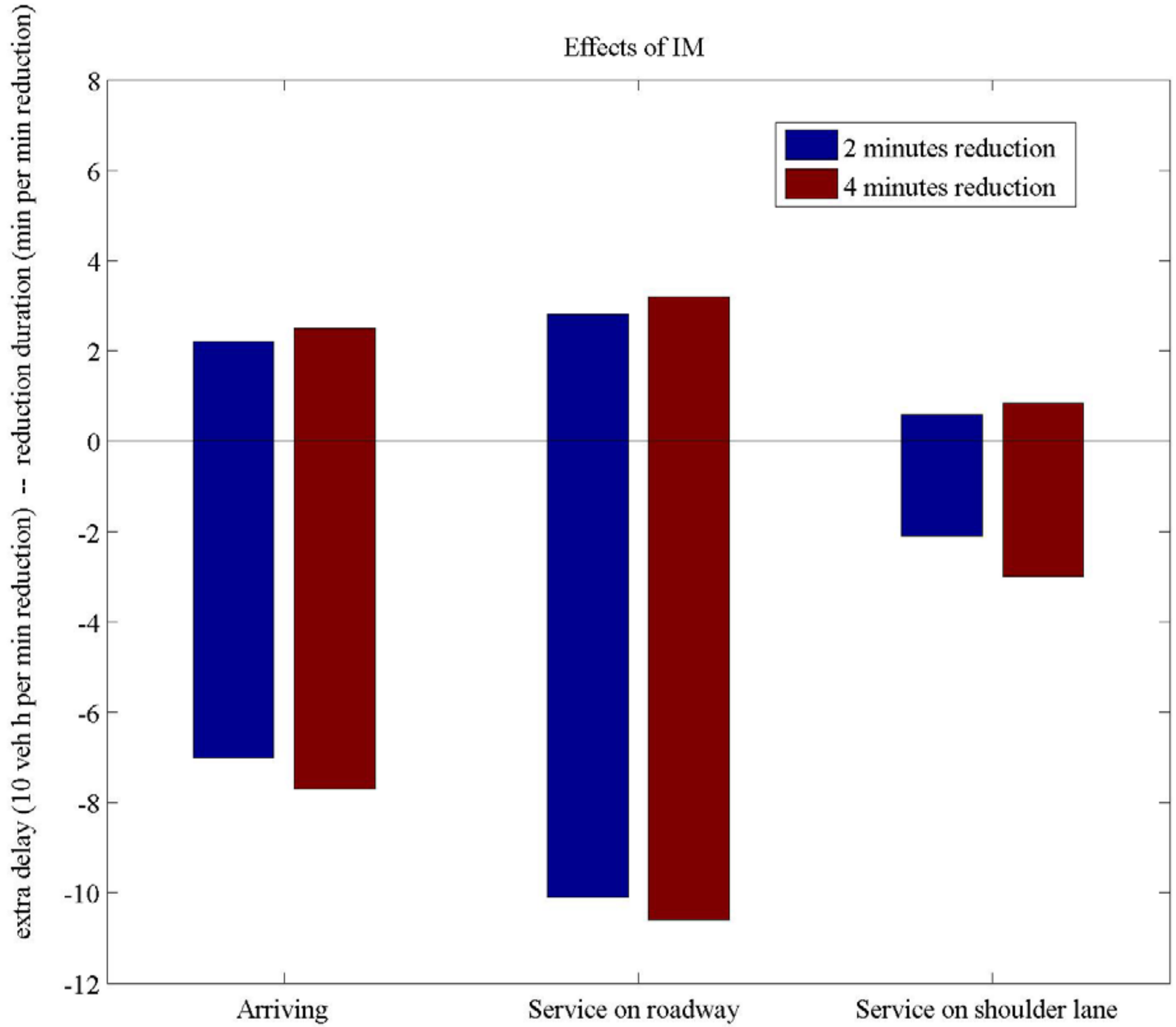
1. Which phase can best be shortend – why? Prove your solution with a calculation or a reasoning based on the cumulative curves.

Reducing the time of which phase helps most?

- Always: phase with lowest capacity (not: earlier phase!)



Numerical results

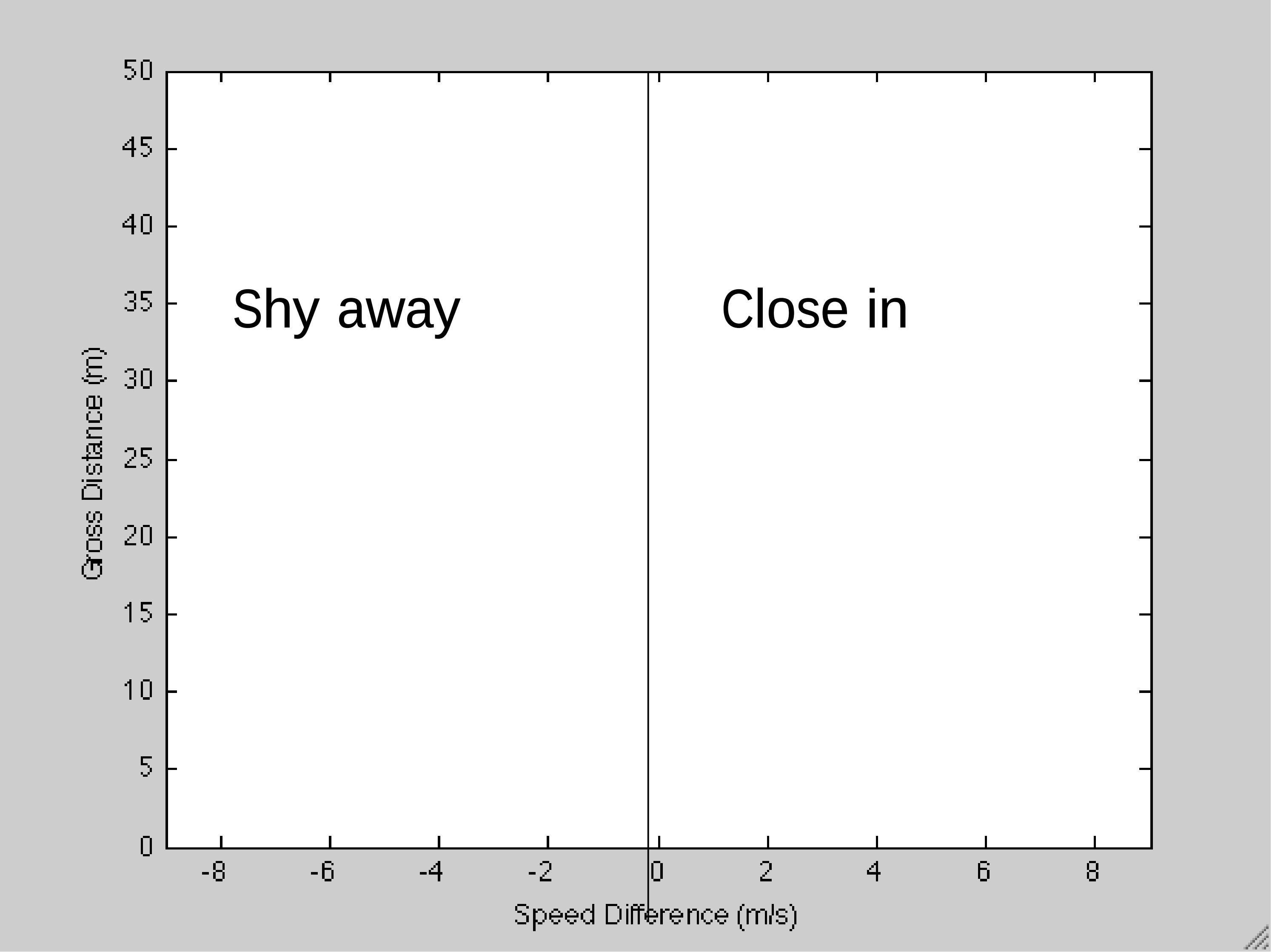


⇒ Effects of incidents
⇒ Incident management
⇒ Cumulative curves

Learning goals

- After today's lecture, you can:

1. Comment on Wiedeman's principle, draw diagrams
2. Explain what action point modeling is
3. Comment on the calibration of parameters of car-following behavior
4. Comment on the capacity, the capacity drop, and the queue discharge rate
5. Relate parameters of car-following models to macroscopic quantities (when possible...)
6. Make the exercise at slide 56


Shy away
Close in
Gross Distance (m)
Speed Difference (m/s)
0
5
10
15
20
25
30
35
40
45
50
-8
-6
-4
-2
0
2
4
6
8

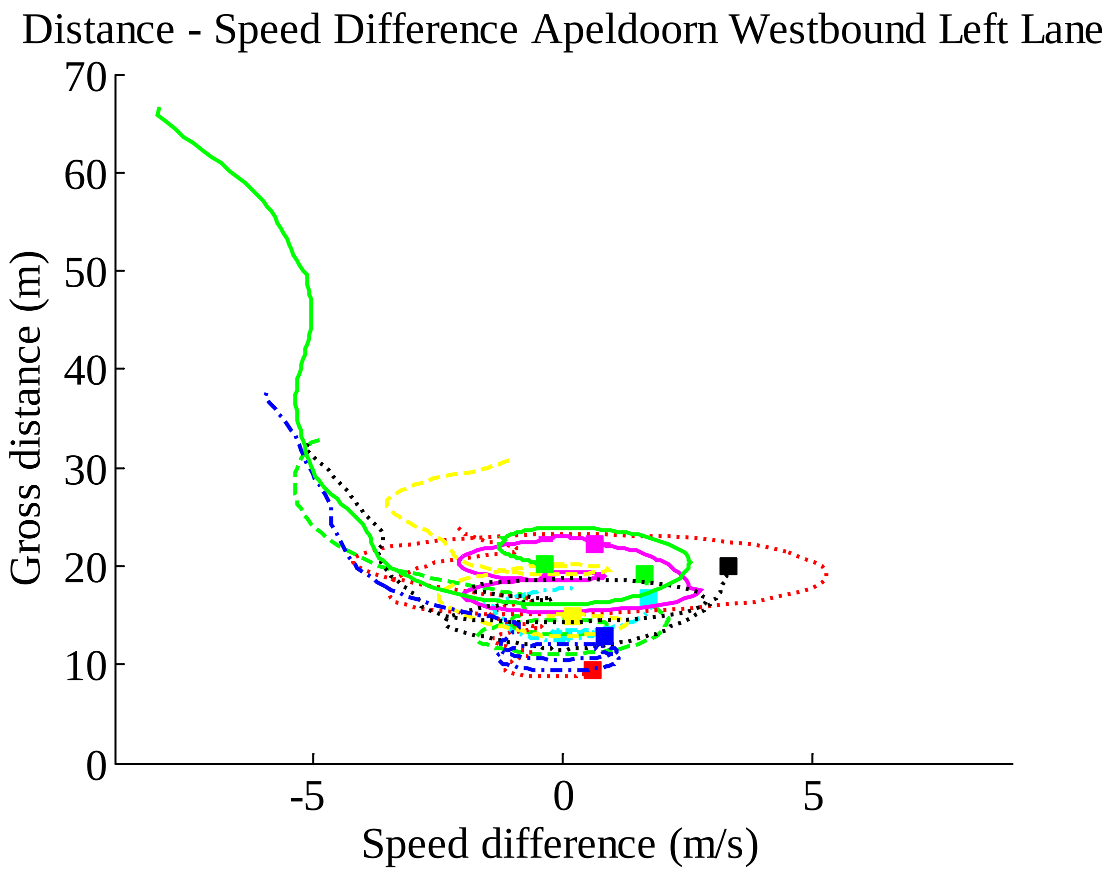


Photo by TU Delft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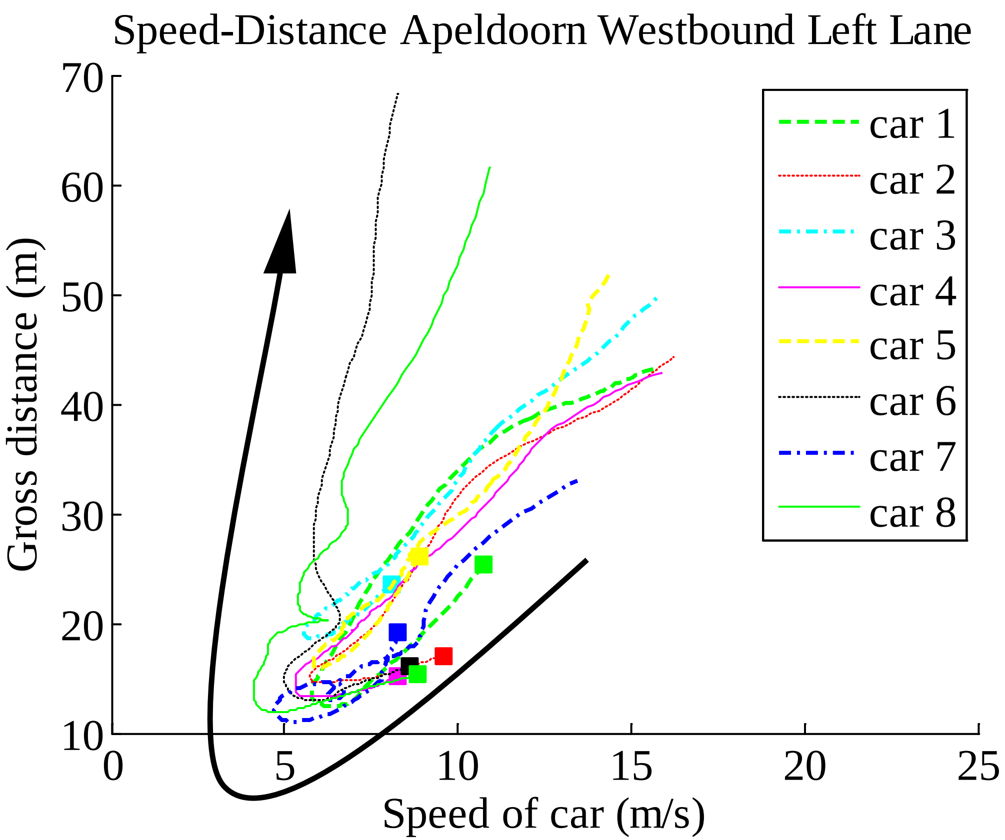
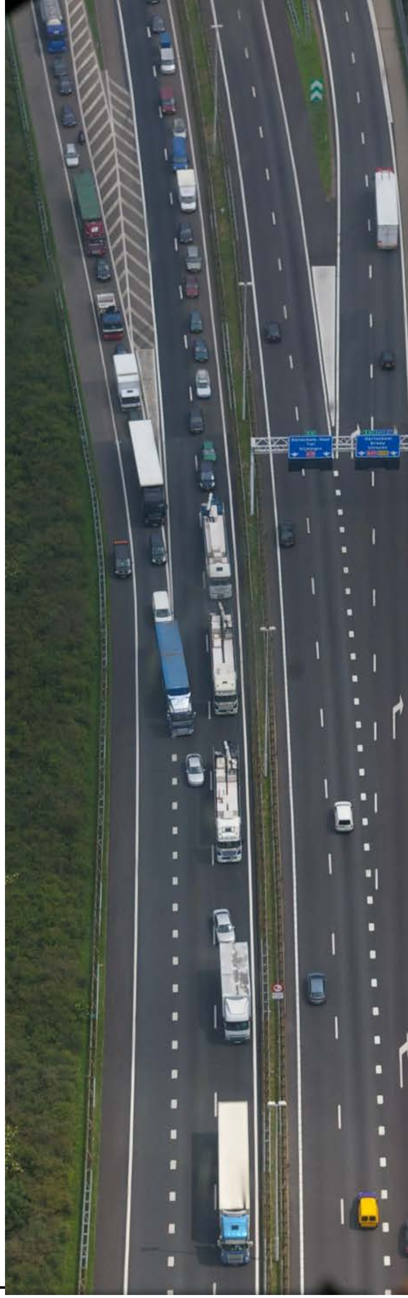
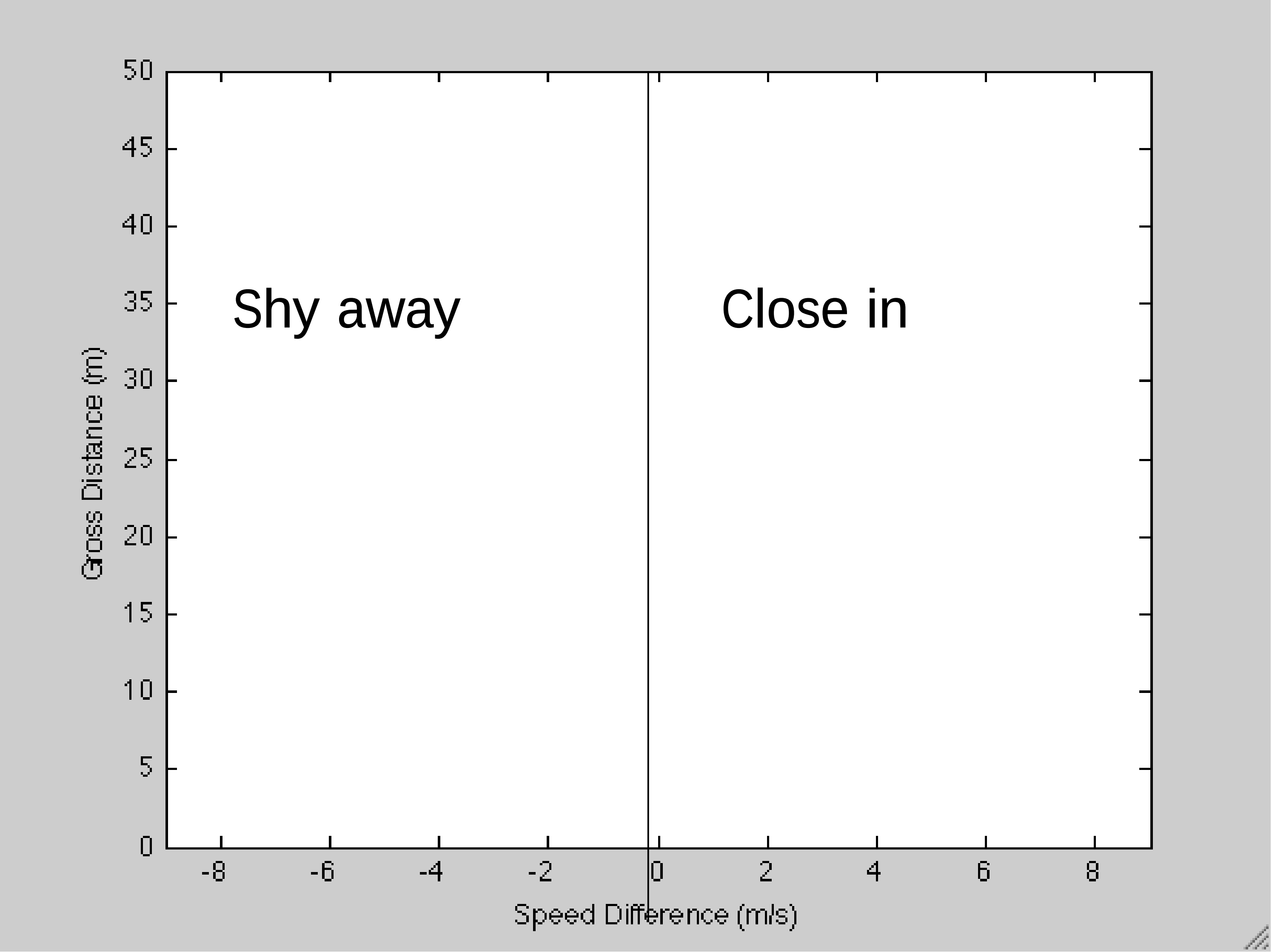

Speed-Distance Apeldoorn Westbound Left Lane
Gross distance (m)
Speed of car (m/s)
70
60
50
40
30
20
10
0
5
10
15
20
25
car 1
car 2
car 3
car 4
car 5
car 6
car 7
car 8




Shy away
Close in
Gross Distance (m)
Speed Difference (m/s)
0
5
10
15
20
25
30
35
40
45
50
-8
-6
-4
-2
0
2
4
6
8

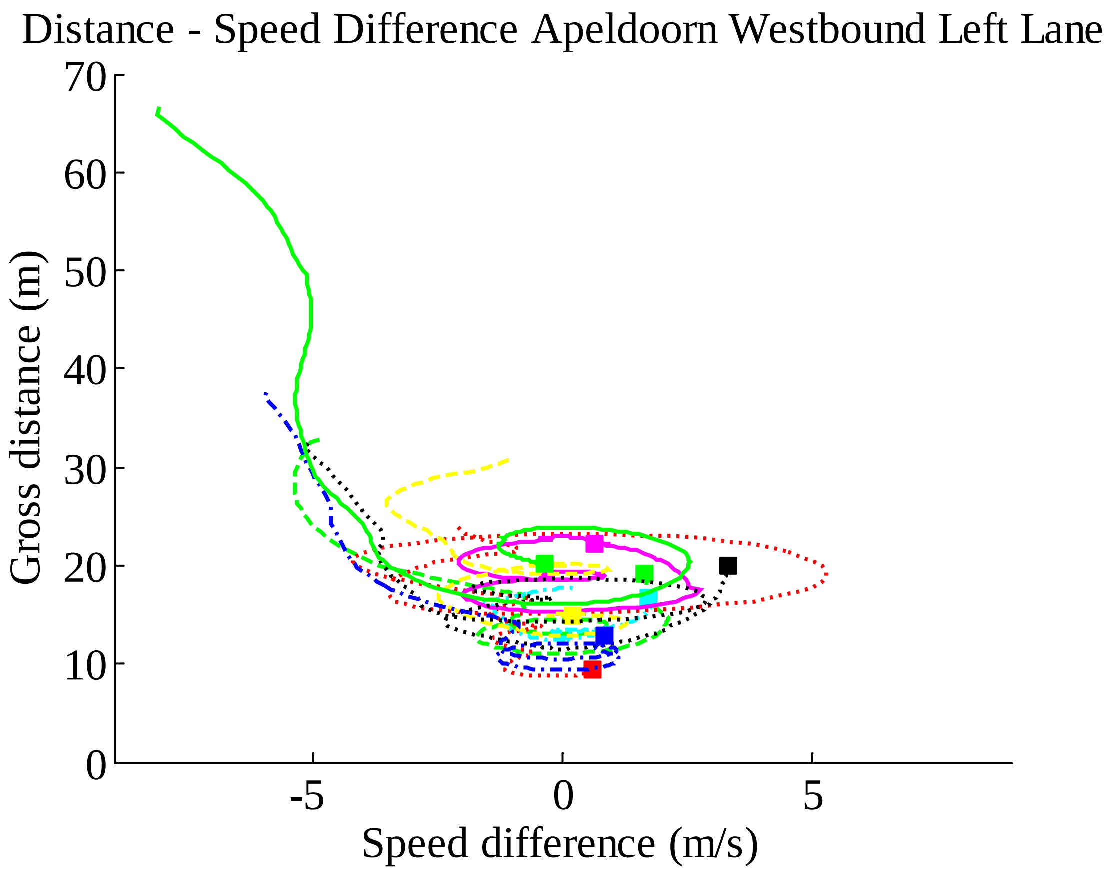


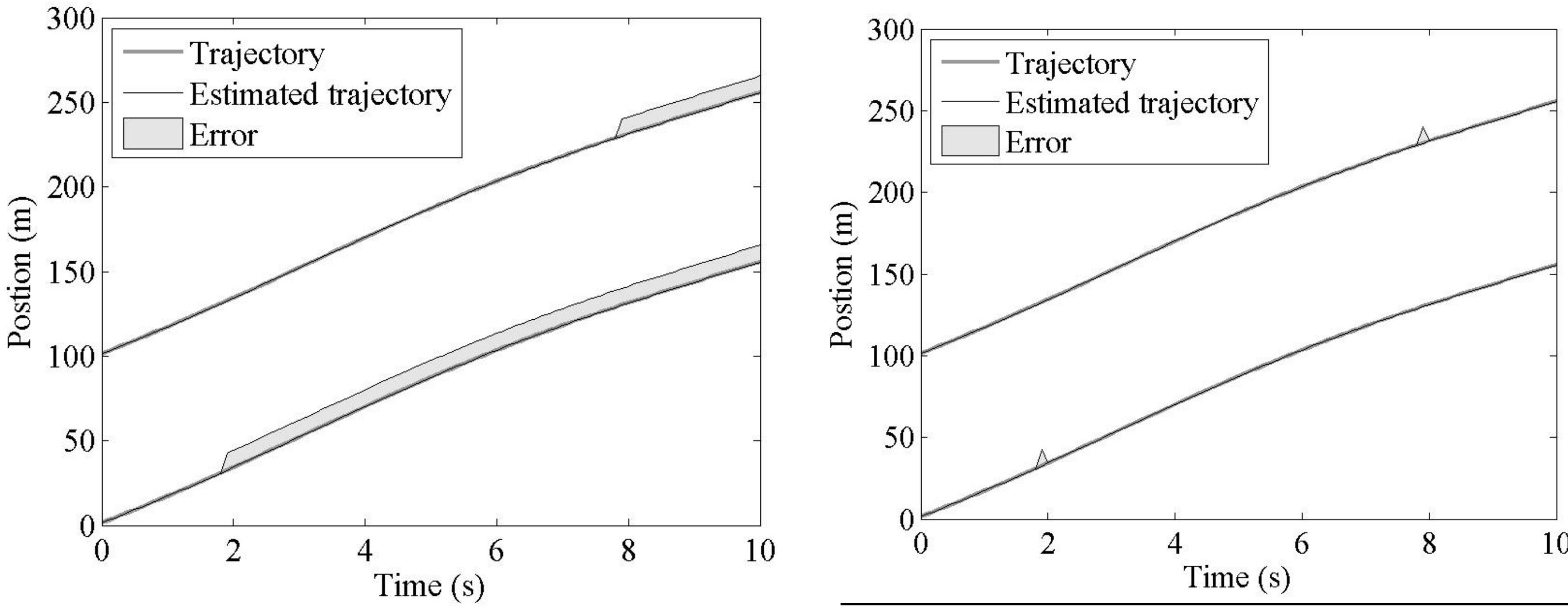
Photo by TU Delft

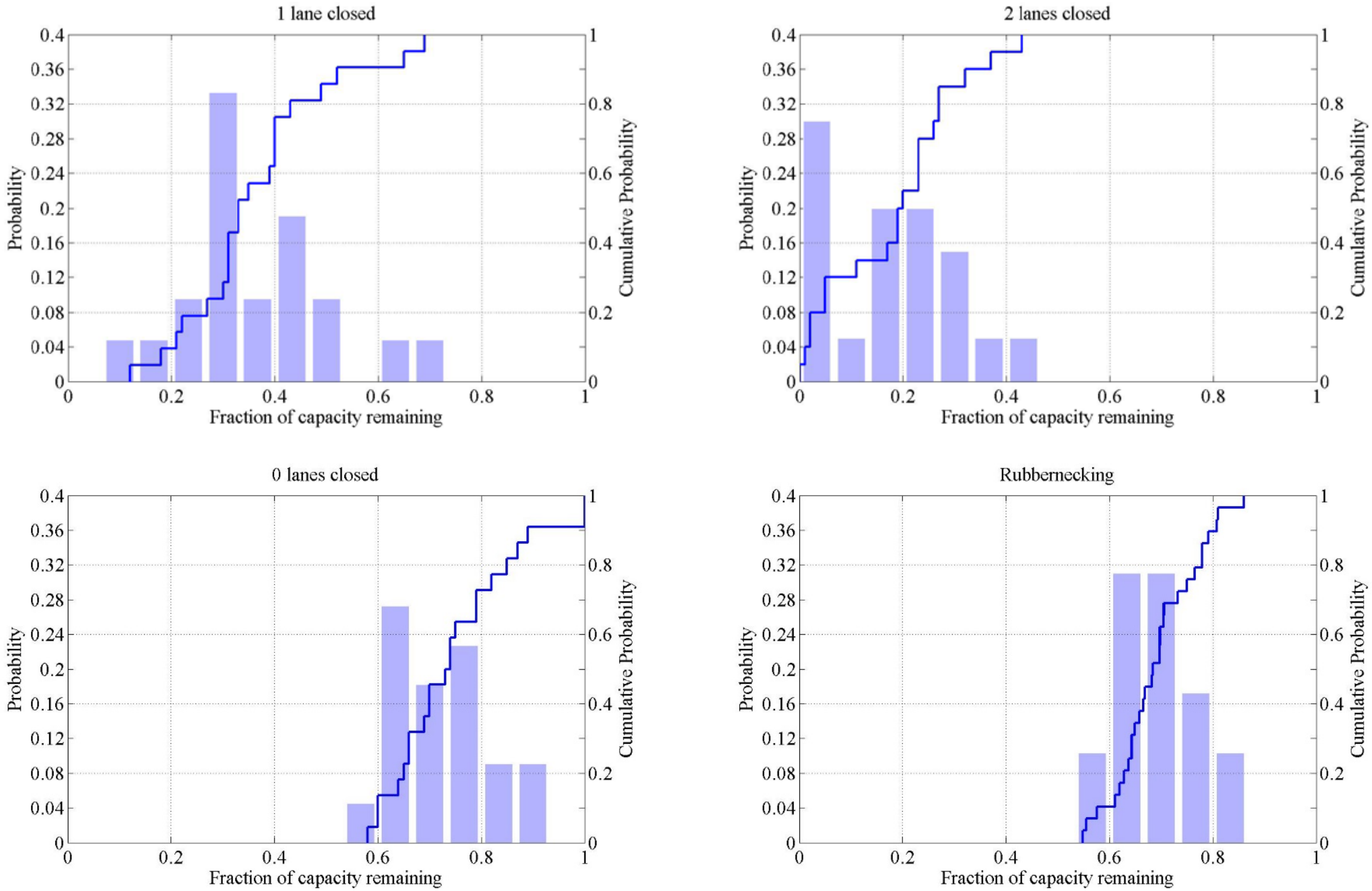
66

Source: unknown

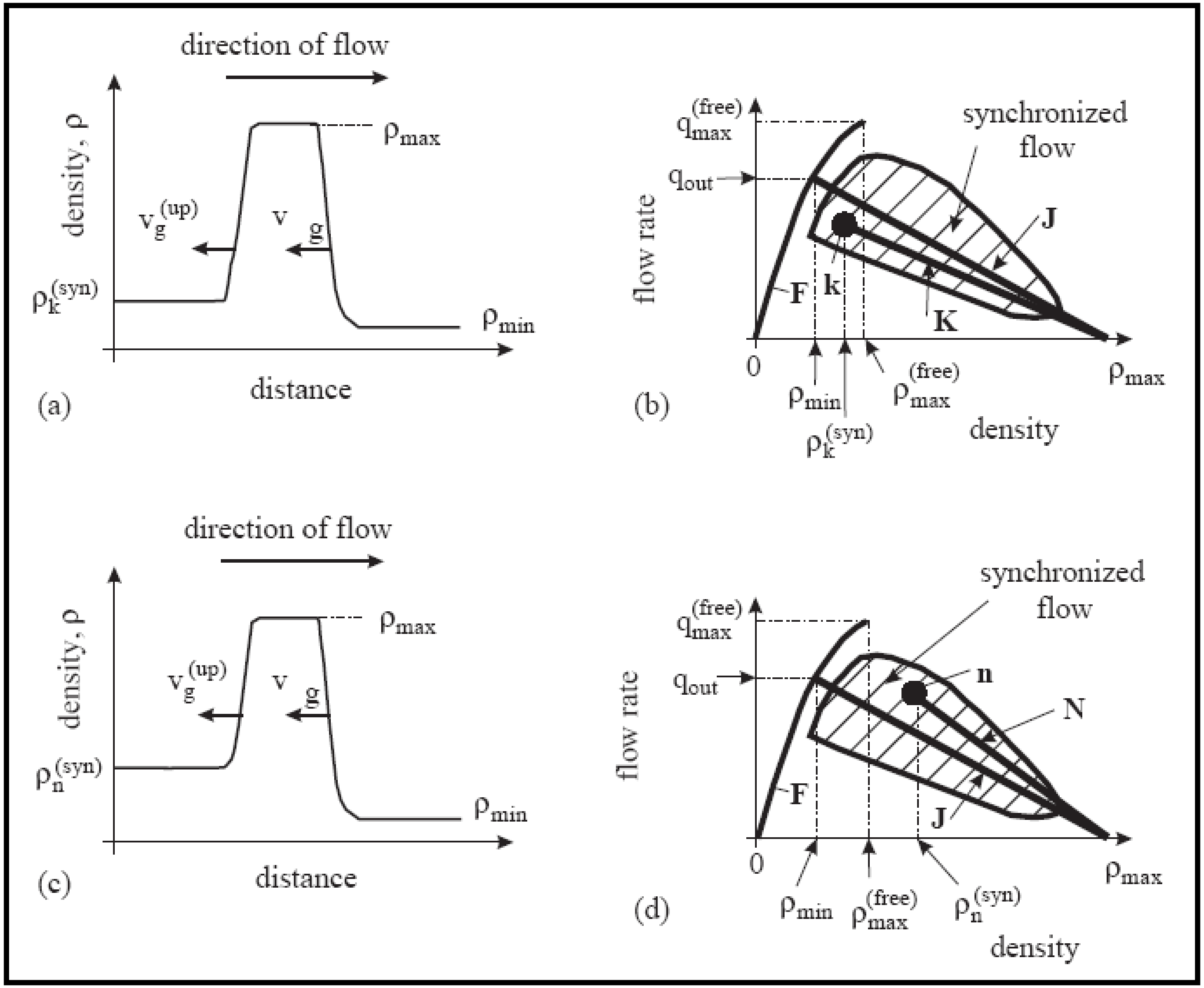
Combine speed and position

- Correlated
- Reset position each time step





1 lane closed
2 lanes closed
0 lanes closed
Rubbernecking
Probability
Cumulative Probability
Fraction of capacity remaining



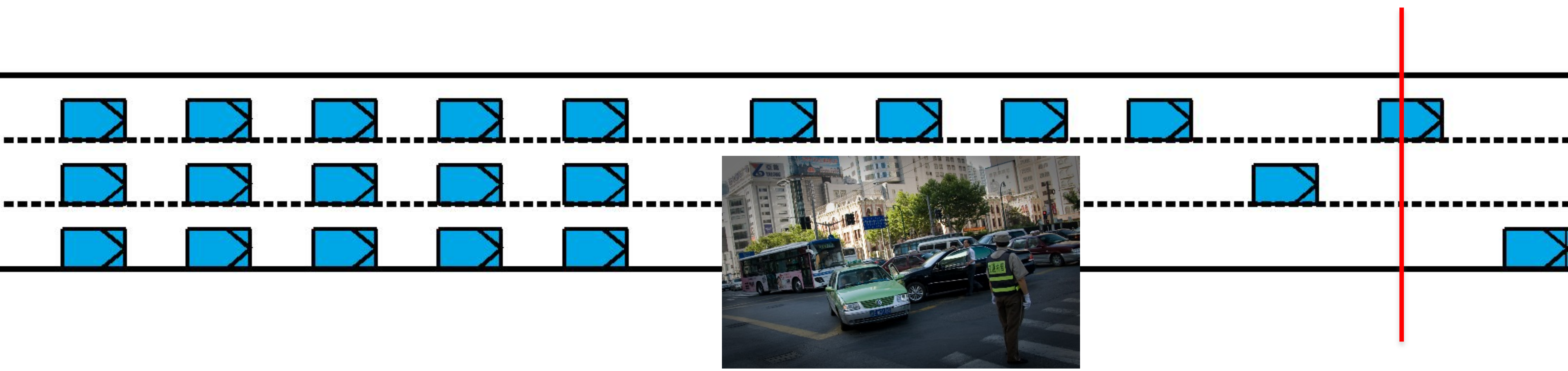
direction of flow
density, ρ
ρ_{max}
$v_g^{(up)}$
v
g
$\rho_k^{(syn)}$
ρ_{min}
distance
(a)
$q_{max}^{(free)}$
q_{out}
synchronized flow
flow rate
J
F
k
K
0
ρ_{min}
$\rho_{max}^{(free)}$
$\rho_k^{(syn)}$
ρ_{max}
density
(b)
direction of flow
density, ρ
ρ_{max}
$v_g^{(up)}$
v
g
$\rho_n^{(syn)}$
ρ_{min}
distance
(c)
synchronized flow
$q_{max}^{(free)}$
q_{out}
n
N
flow rate
F
J
0
ρ_{min}
$\rho_{max}^{(free)}$
$\rho_n^{(syn)}$
ρ_{max}
density
(d)

Macroscopic Approach

- Much more incidents can be studied
- Just possible to find the capacity...
  ... or capacity reduction?

Source: Unknown

Where to measure queue outflow?



Source: Unknown

=> Queue outflow

Methodology

- Find incidents which cause a queue
- Number of lanes available?
- $C_{incident}/C_{normal}$

Source: Unknown