Traffic Flow Theory and Simulation

V.L. Knoop

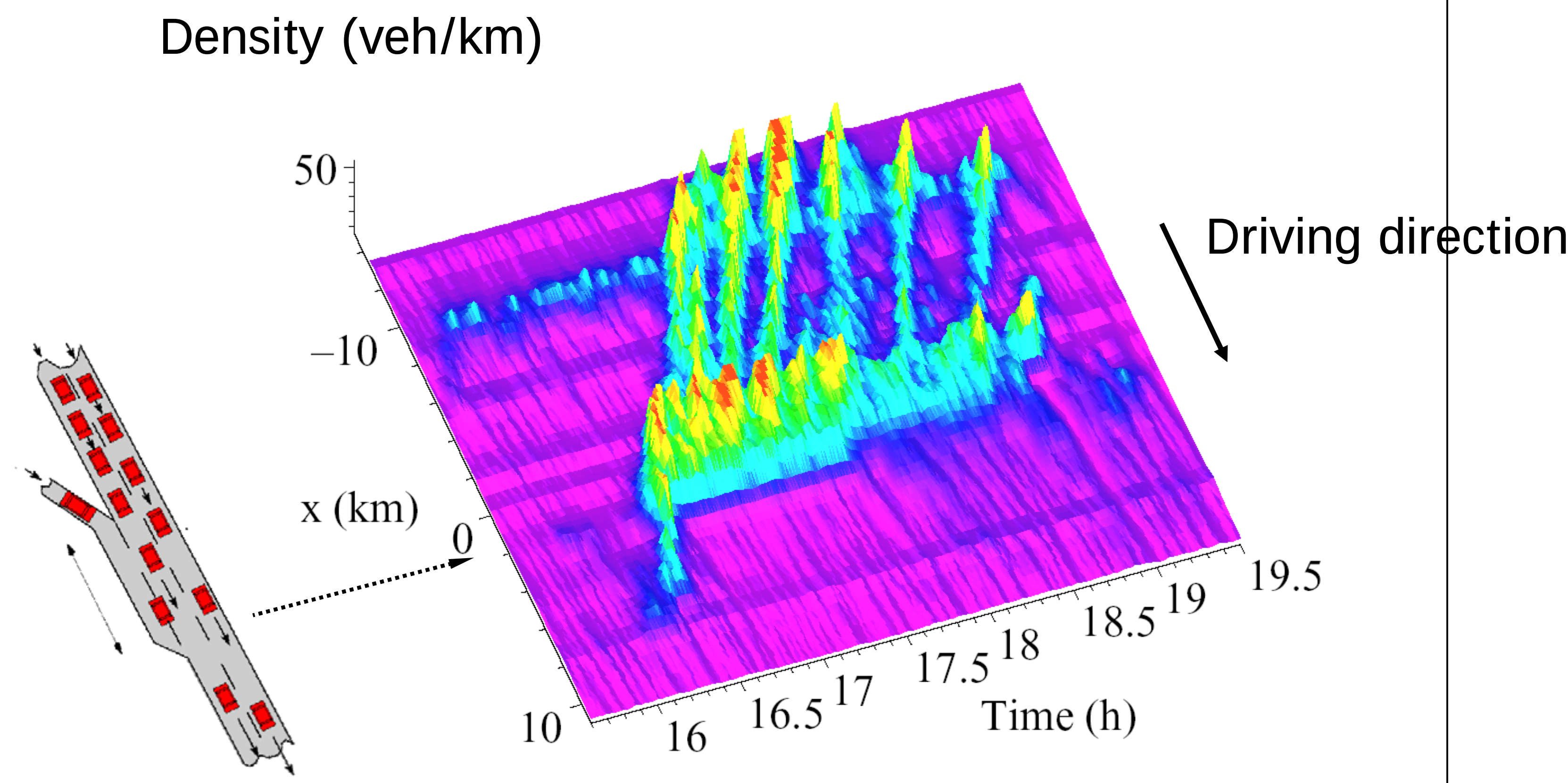
Lecture 11
Lateral Driving Behaviour

Lateral driving behaviour

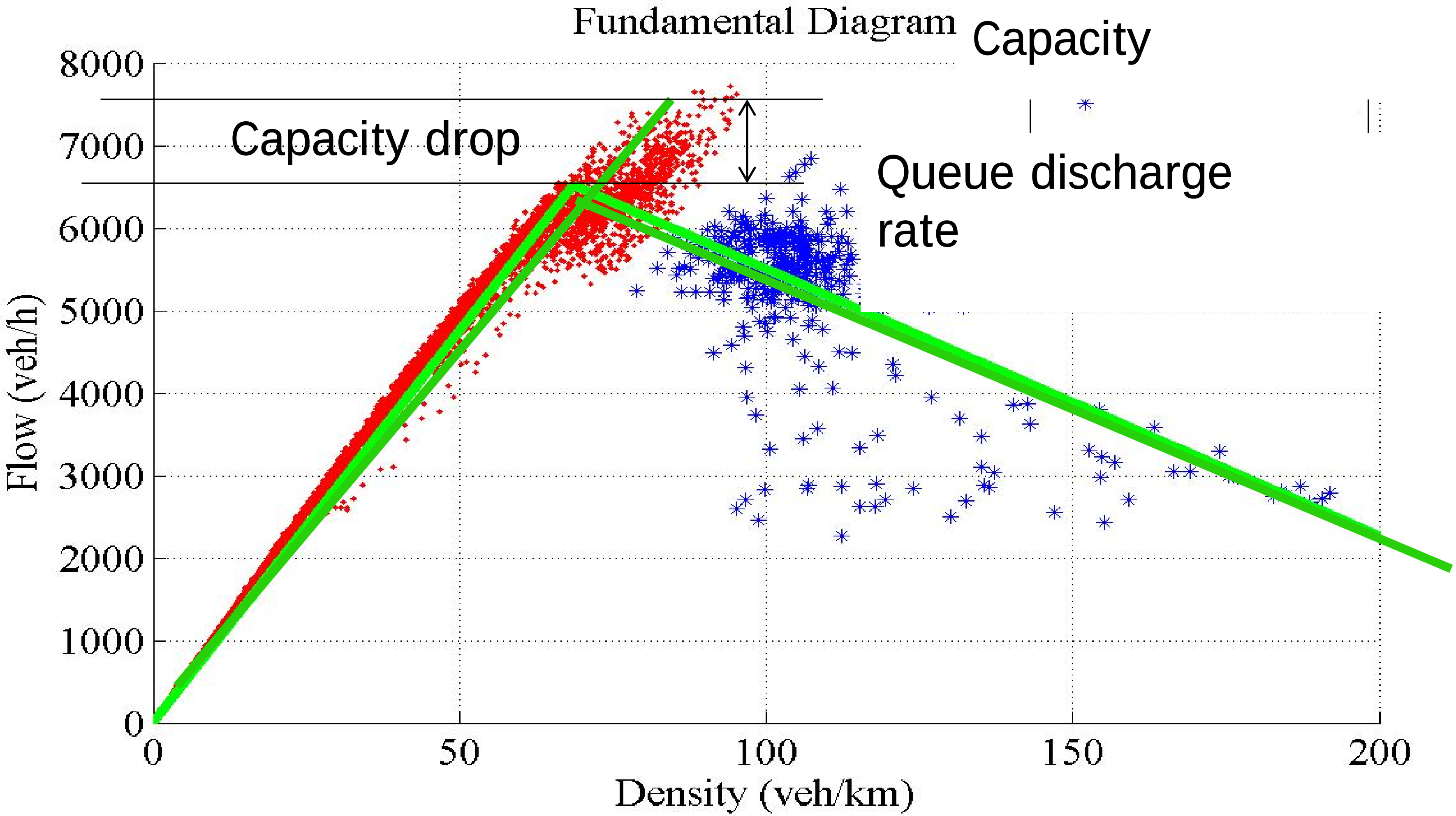
Victor L. Knoop

24-3-2014

Three phase traffic flow theory



Capacity drop



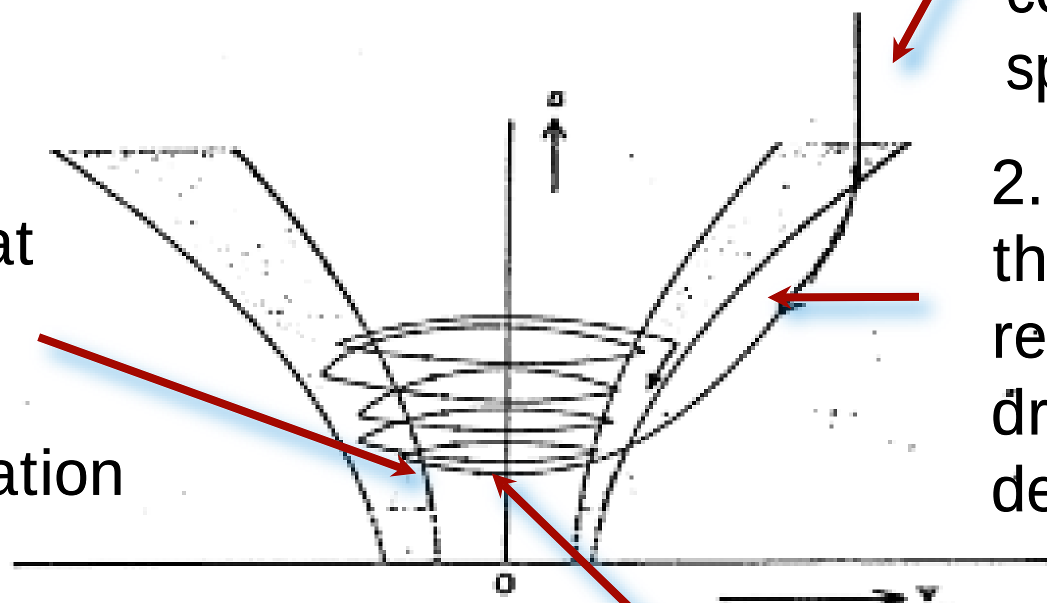
Principle by Wiedeman

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



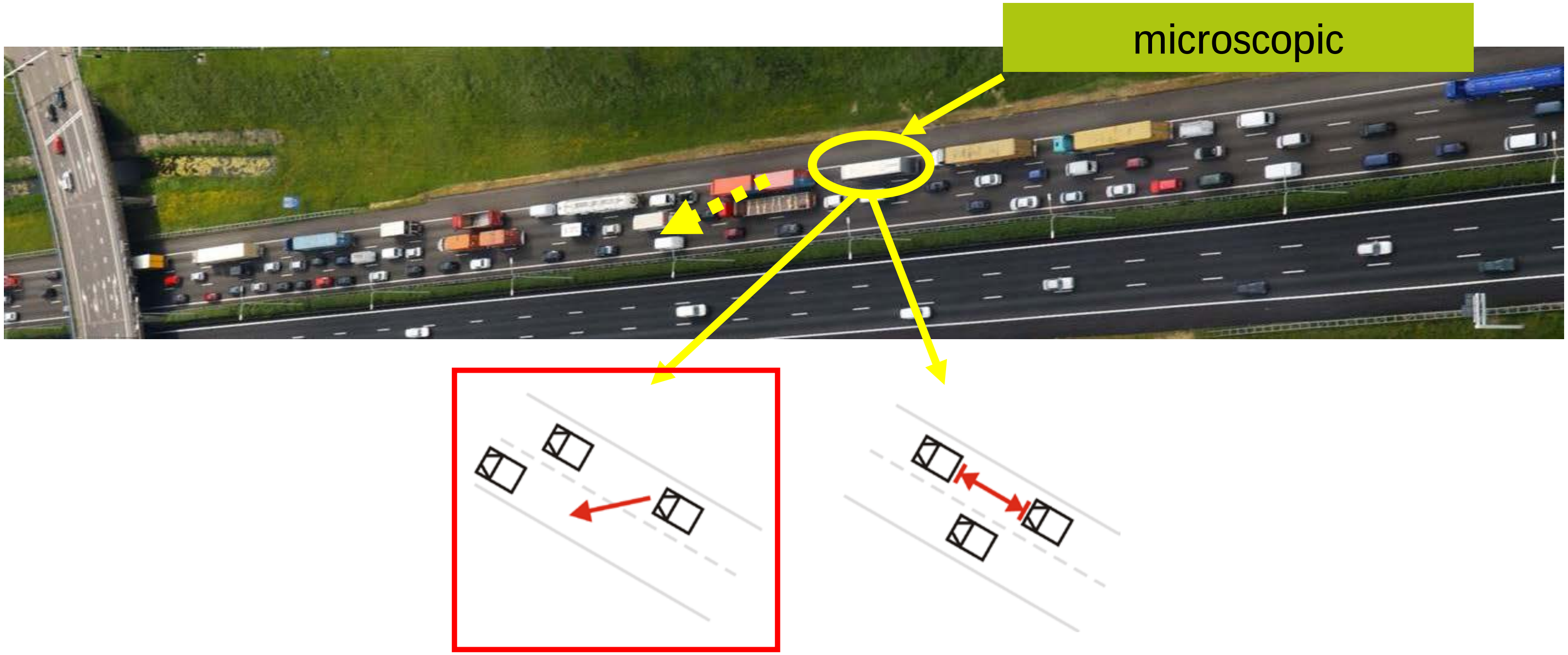
$V_{follower} < V_{leader}$

$V_{follower} > V_{leader}$

Agenda – After today, you can

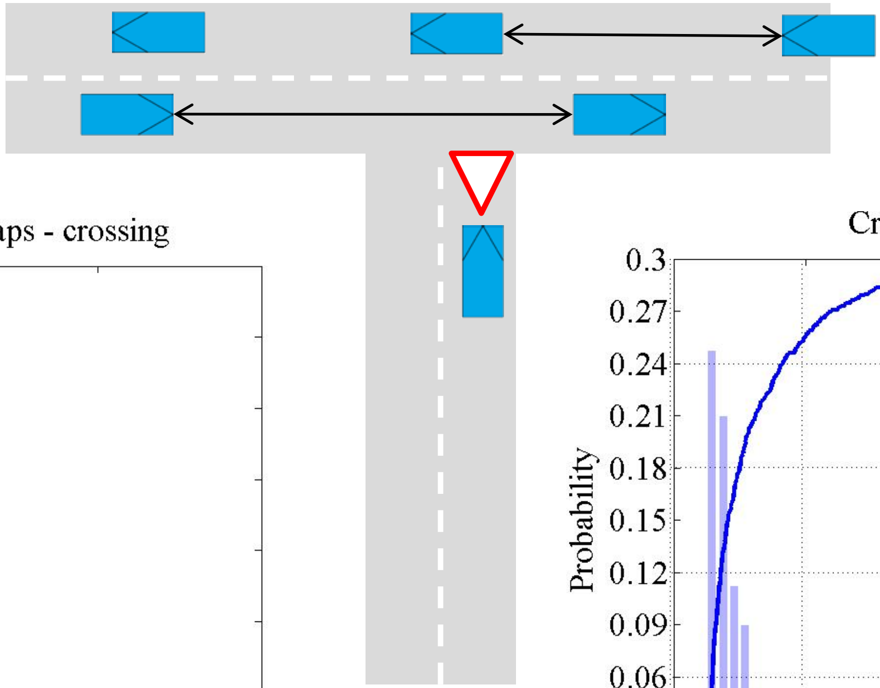
- ... differentiate between courtesy, mandatory and desired lane changes
- ... explain gap acceptance theory and comment on measuring critical gaps
- ... comment on the principles of the Mobil lane change model (equations will be given)
- ... comment on lane selection theories
- ... comment an analyse lane distributions
- ... comment on merging
- ... describe the principle of relaxation

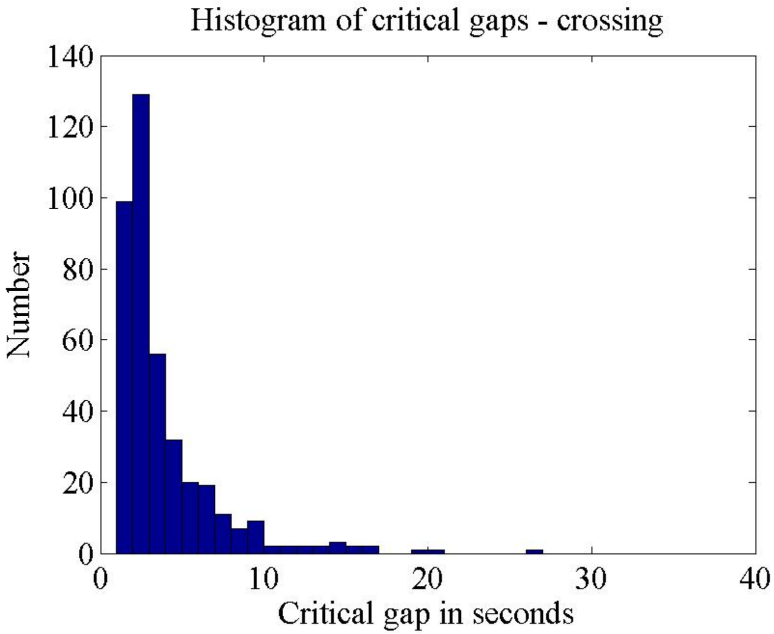
Driving tasks

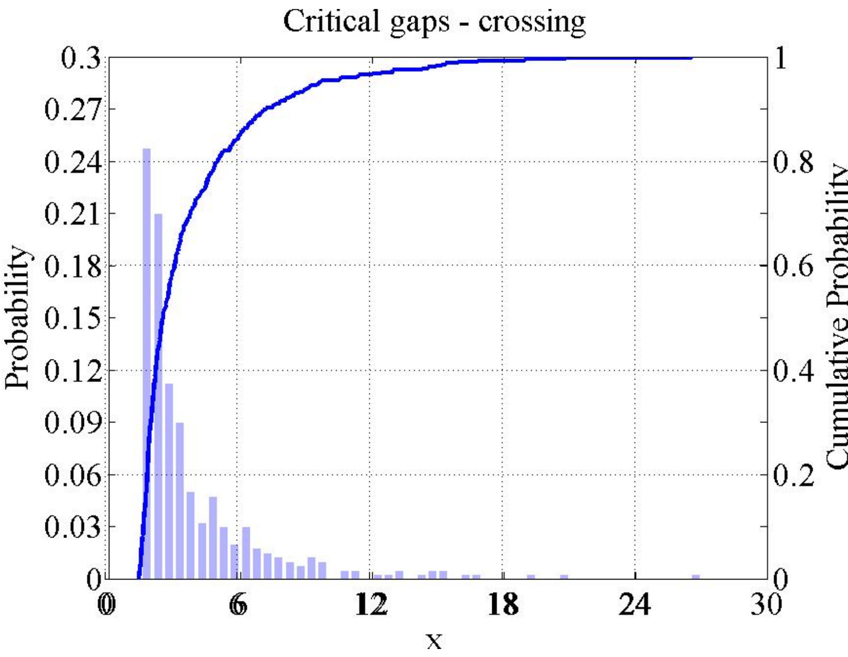


GAP ACCEPTANCE THEORY

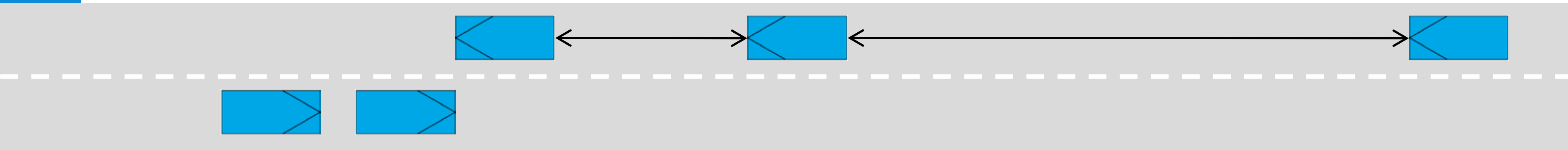
Gap acceptance - concept

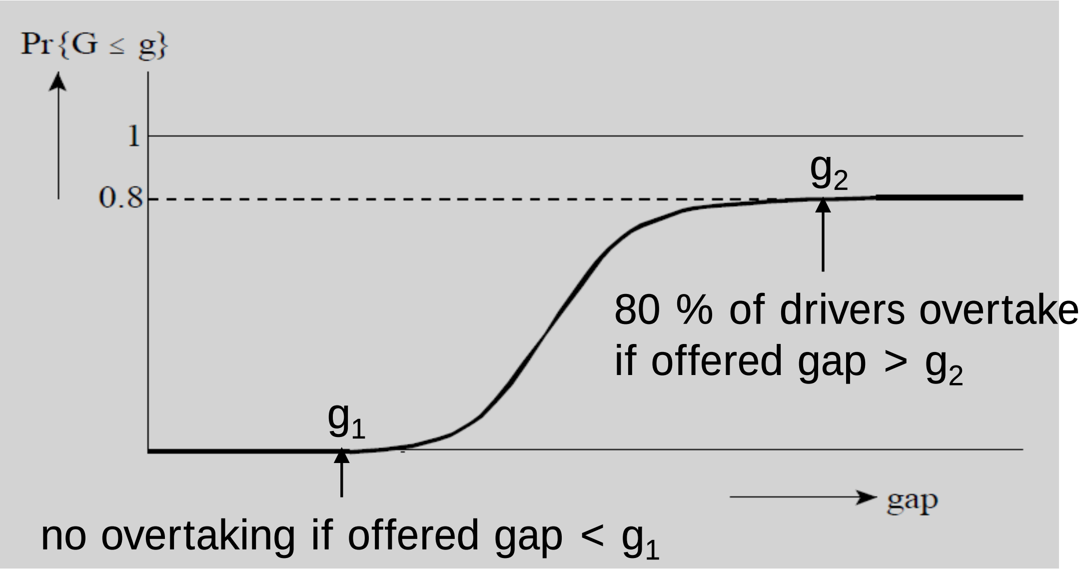




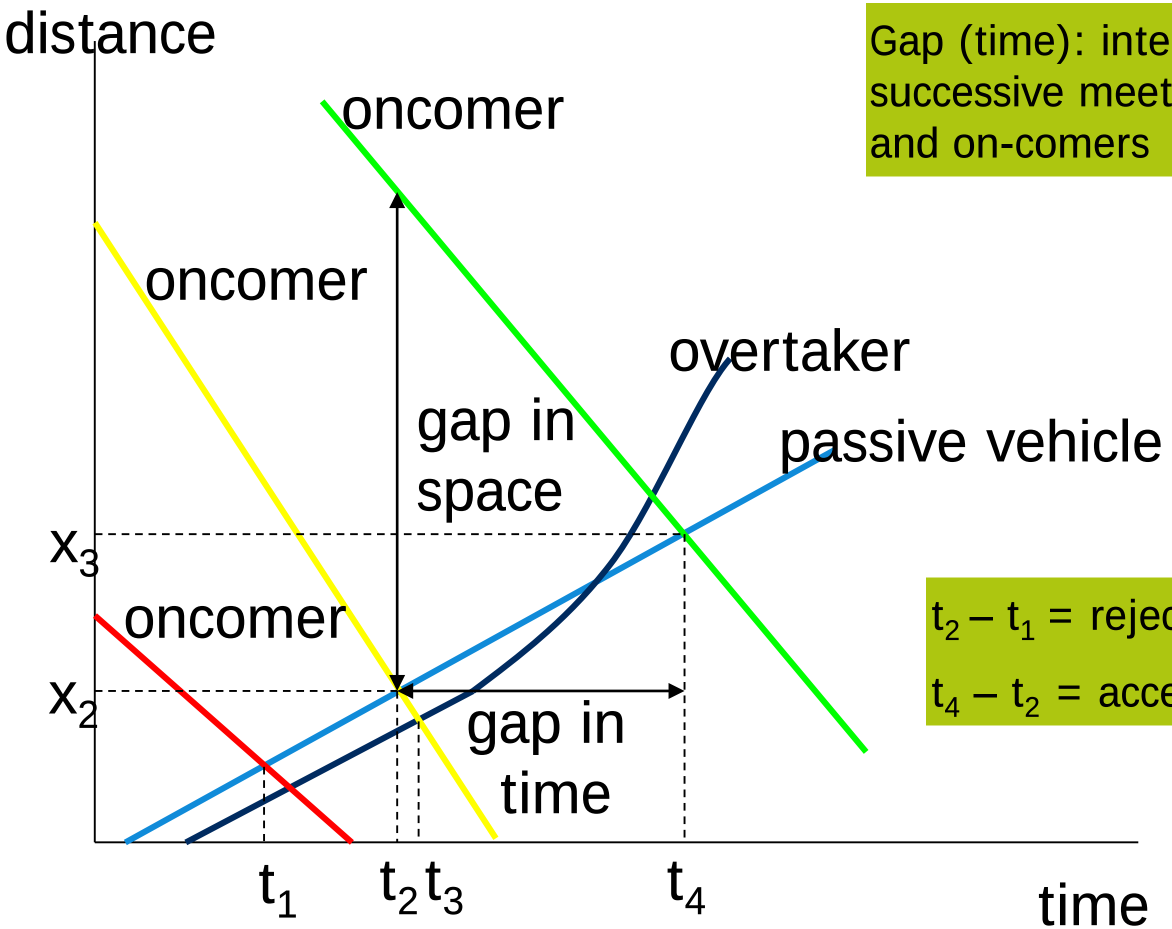


Gap acceptance for overtaking (1)





Overtaking in time and space



Gap (time): interval between 2 successive meetings of passive vehicle and on-comers

$t_2 - t_1$ = rejected gap

$t_4 - t_2$ = accepted gap

Gaps – theory vs practice

- Gap in time is not completely usable for overtaking
  - nett gap starts at t_4, when oncomer meets overtaker
  - overtaker has to be back on right lane **before** t_3 to prevent a collision

Overtaking critical gap depends on....?

Critical gap distribution

- One measures gap-accepance. Comparing the distribution of the accepted gaps to the critical gap distribution, one finds:
  A) The critical gaps are longer than the measured gaps
  B) The measured gaps are shorter than the critical gaps
  C) If one does enough measurements, they are equal

Application using the critical gap

- Model for ‘one driver at a time’ manoeuvres (e.g. a car crossing an intersection: single queue/server system)

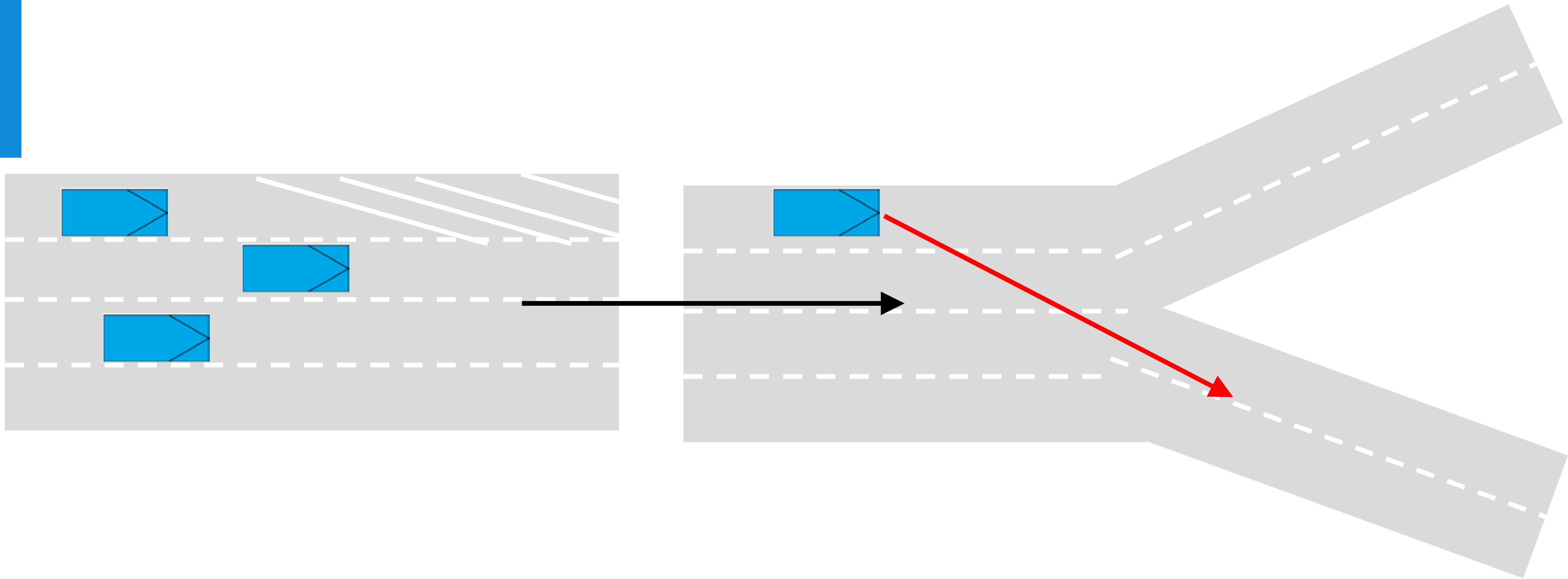
- Simple model gap acceptance process for ‘fixed’ critical gap
  1. Draw critical gap c_i from distribution F(c)
  2. Draw offered gap g_j from offered gap distribution
  3. If $g_j > c_i$, then gap is accepted; go to 1
  4. If $g_i < c_j$, then gap is rejected; go to 2

MOTORWAY LANE CHANGING

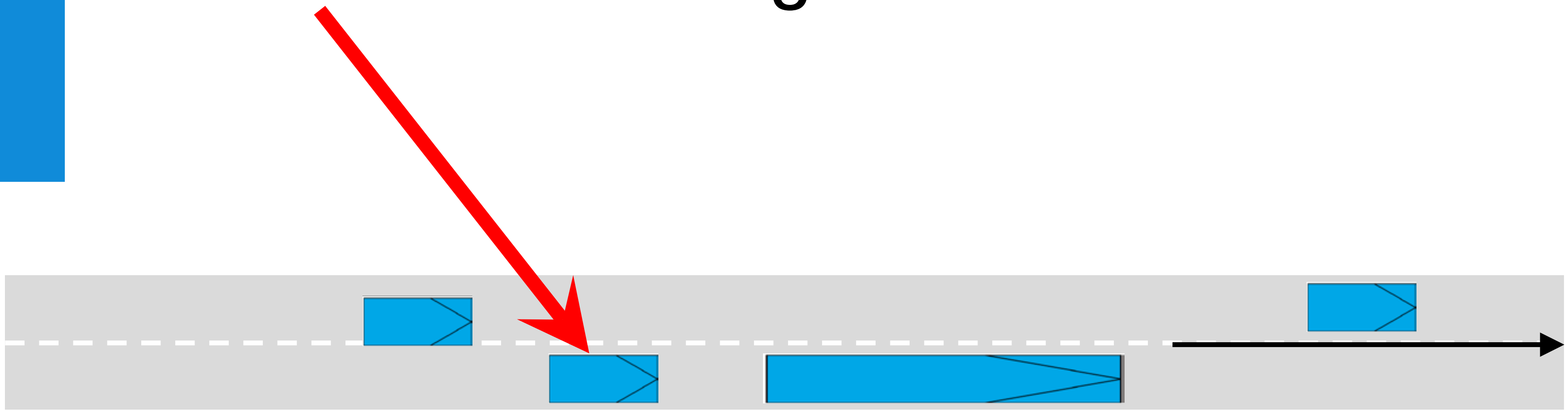
Motorway Lane Changing

- 3 types of lane changing
  - Mandatory
  - Desired
  - Courtesy

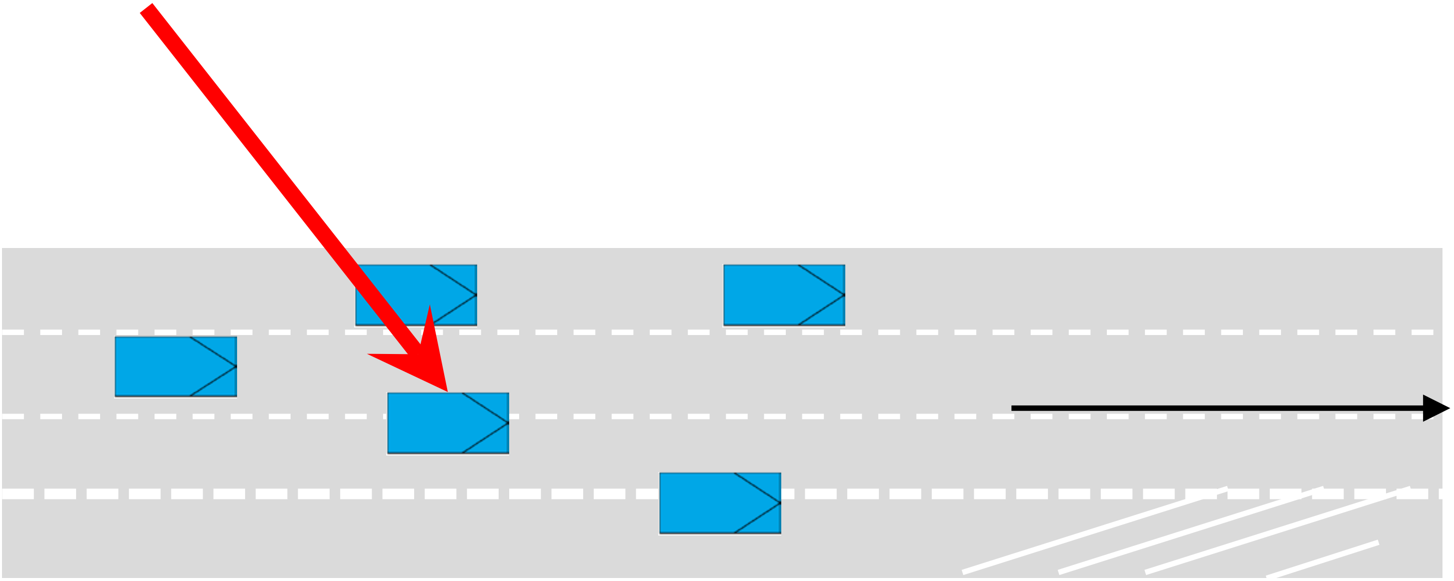
Mandatory lane changes



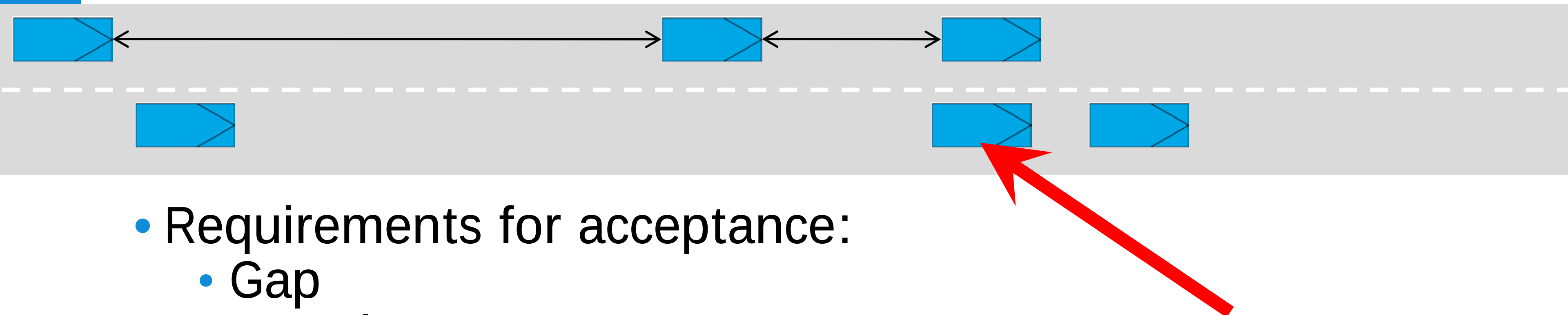
Desired lane changes



Courtesy lane change



Gap acceptance for overtaking (2)



- Requirements for acceptance:
  - Gap
  - Speed
  - Speed of future follower
  - ....

LANE CHANGE MODELS

Models & observations

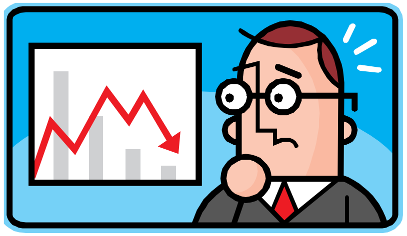
- Many lane changing models
- Problem in observation:
  no reasoning, only events
- Events: willingness x probability
- All models are wrong
  (but some are more wrong than others)
- Calibration?

One model in detail: MOBIL

- Model by Helbing, Treiber, Kesting
- Based on **utility**

Utility concept

- From economics
- People do whatever gives them highest payoff
- Include error in perception
- => Compute utility U_i for each option i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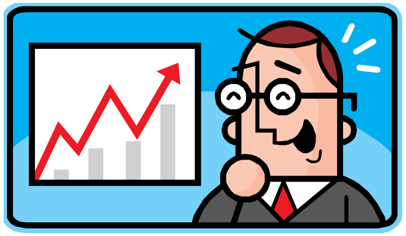
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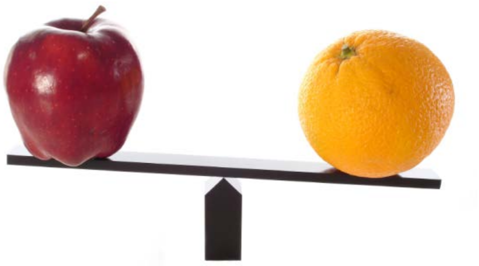
Example of utility

- Comparing apples and oranges:

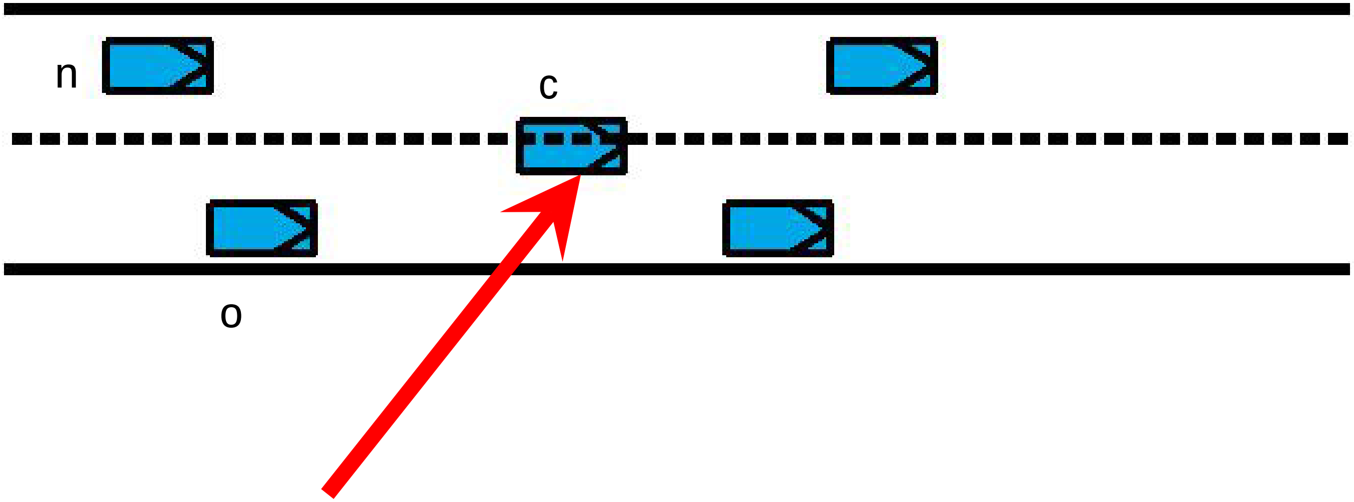


Source: Unknown

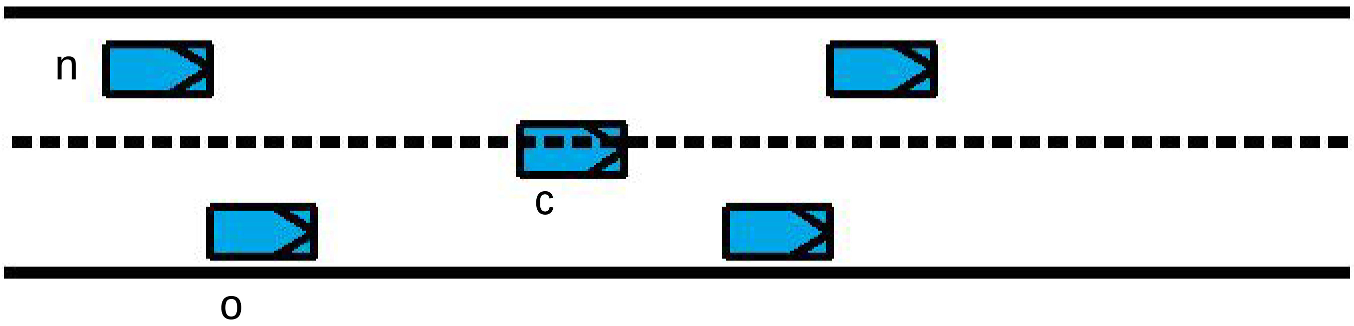
- E.g., U=a*price [E] +b*vitamins [g]+ c* age [days] + ε
  - a<0
  - b>0
  - c<0
- Buy product with highest utility

Mobil

- Minimising Overall Braking Induced by Lane changes
- Consider accelerations of 3 vehicles



Mobil: decision



- Acceleration trade-off

$$\tilde{a}_c - a_c + p\,(\tilde{a}_n - a_n + \tilde{a}_o - a_o) > \Delta a_{th}$$

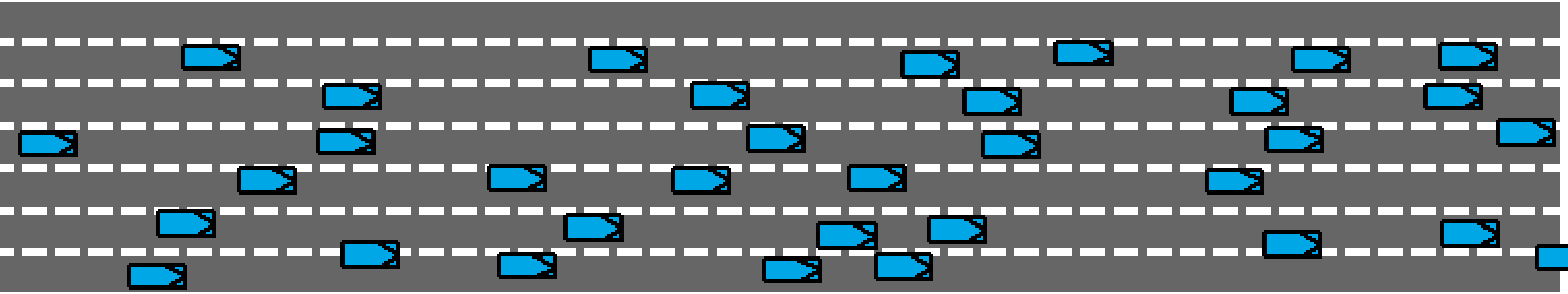
Own benefit Benefit n Benefit o "Cost of changing lane"

Adding European driving rules

- Restrict acceleration in right lane: $a^{eur}_{right}=\min(a_{right}, a'_{left})$
- Introduce a preference for the right lane: Threshold + bias towards right lane
- R => L $\tilde{a}_c - a_c^{Eur} + p(\tilde{a}_n - a_n + \tilde{a}_o - a_o) > \Delta a_{th} + \Delta a_{bias}$
- L => R $\tilde{a}_c^{Eur} - a_c + p(\tilde{a}_n - a_n + \tilde{a}_o - a_o) > \Delta a_{th} - \Delta a_{bias}$

How to calibrate

- Number of lane changes?
- Lane distributions?
- Travel times?



Mandatory lane changes

- We do not know
- Engineers find a solution: Adapt the model!
- Usually: change model parameters until it looks OK

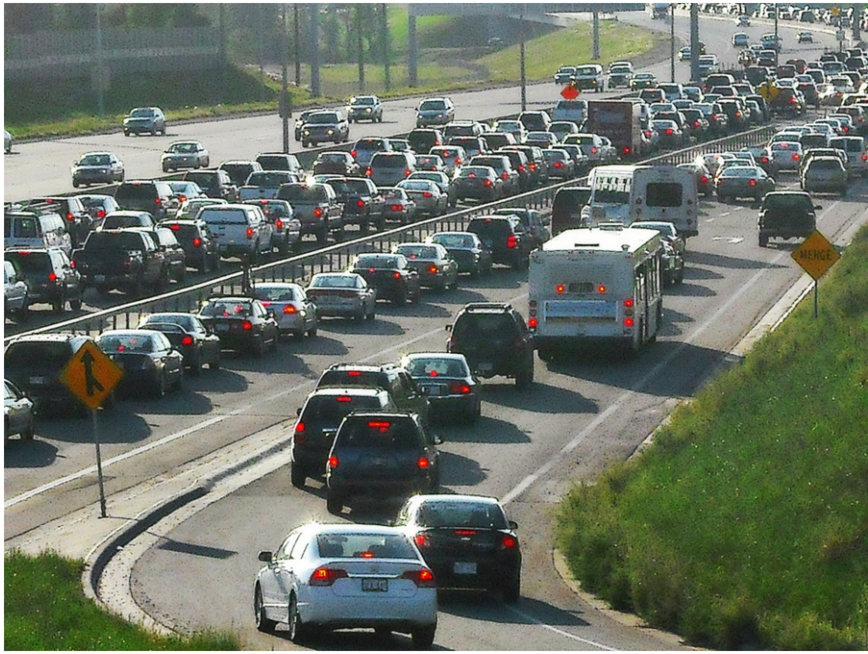


Photo by Breana Cronk

Problems of simulation programs

- Cars stuck: possible solutions
  - Stop cars until gap is there
  - Remove cars
  - Other direction (in case of wrong descision)
- Cars stuck at the on-ramp
  www.traffic-simulation.de
- Low-speed merging creating congestion

Implications of lateral behaviour

- Lane changes are important to for traffic flows
  - Lane distribution
  - Disturbances
- But it is very difficult to model them correctly

After this hour, you can

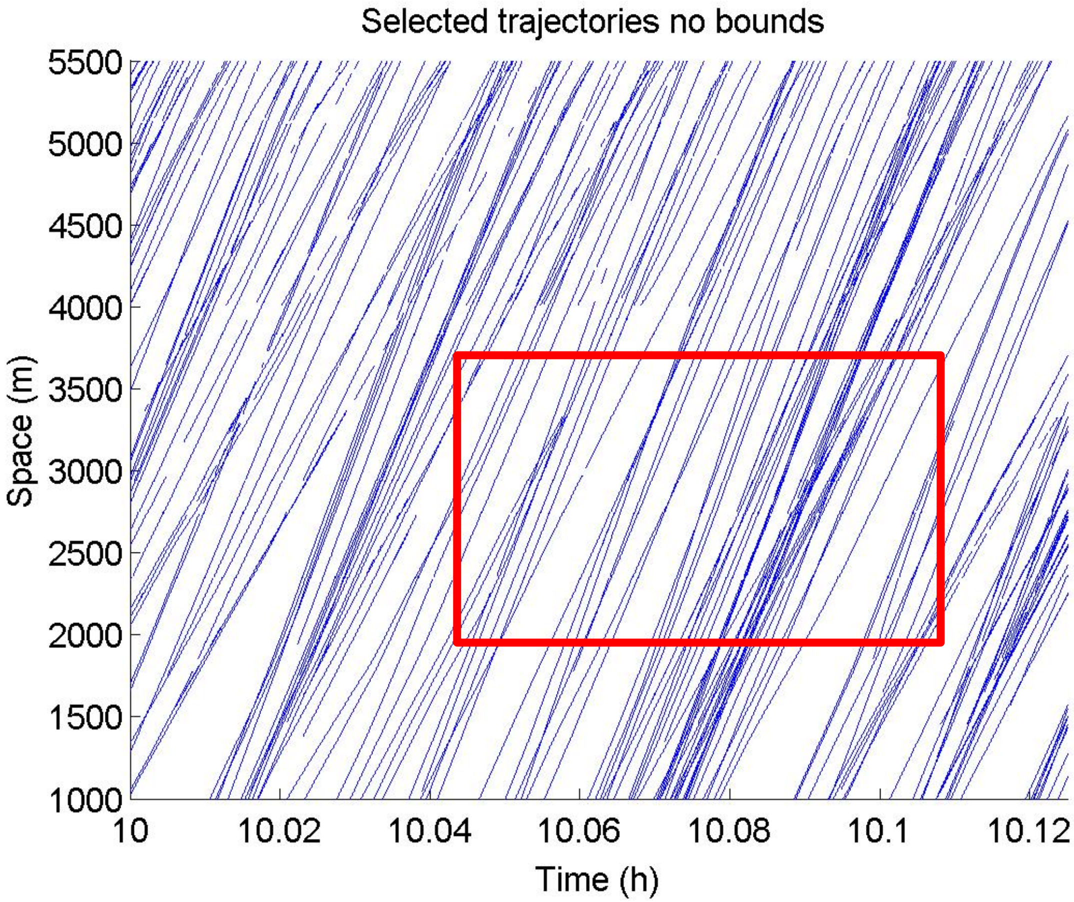
- ... differentiate between courtesy, mandatory and desired lane changes
- ... explain gap acceptance theory and comment on measuring critical gaps
- Comment on the principles of the Mobil lane change model (equations will be given)

Coffee question....

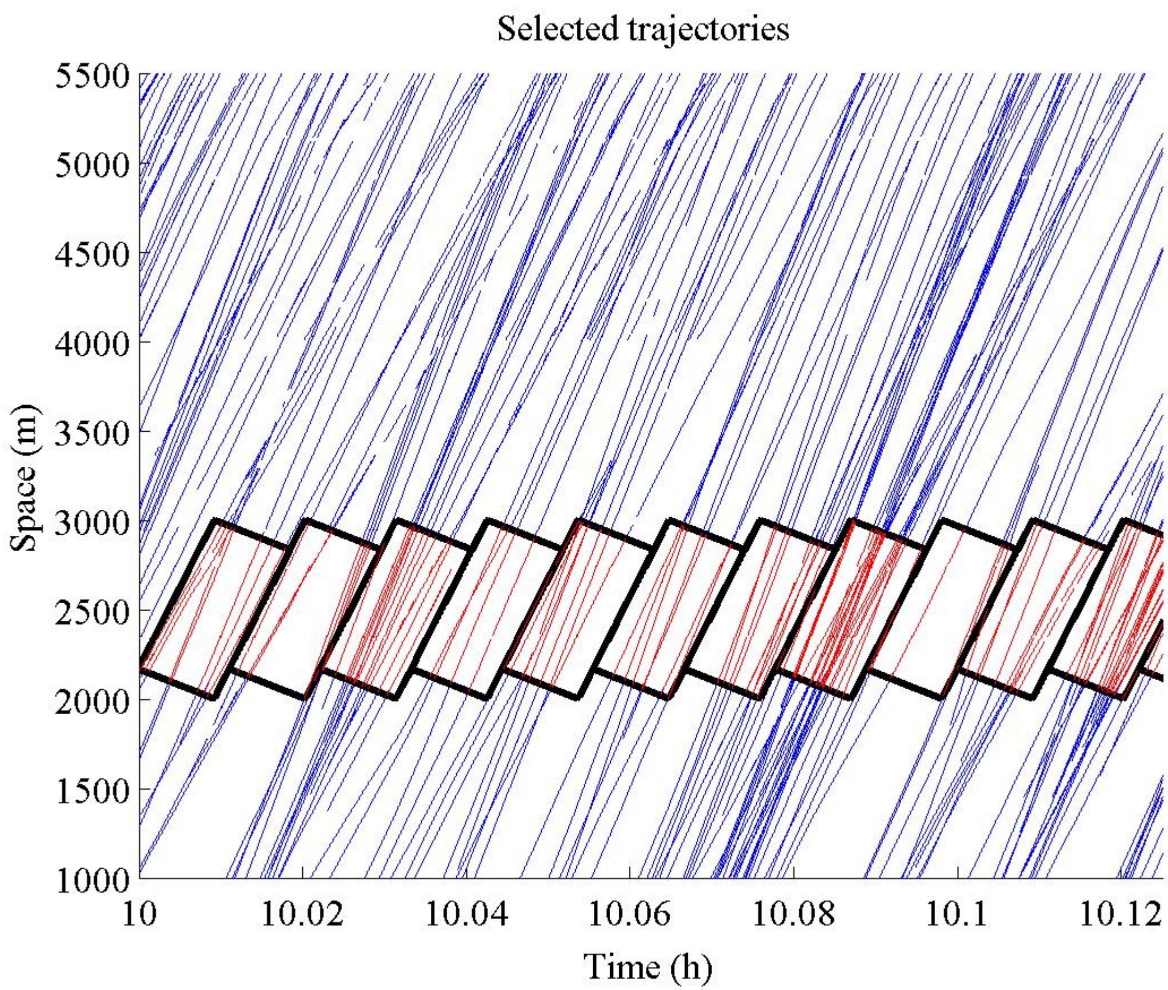
- Lane changes are discrete events (i.e.,...)
  What is the best way to express the number of lane changes (and what is the most constant?)

- Different formulation:
  What would your reply be to my question: how many lane changes are there?

Dependencies

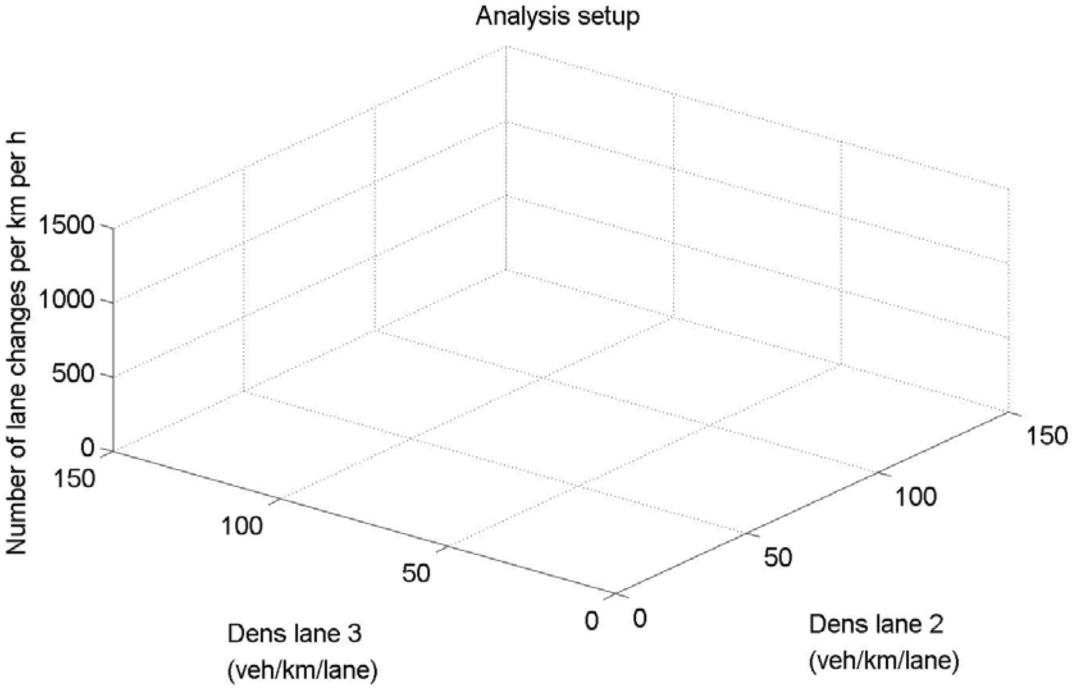


Parallelograms / Rhomboid

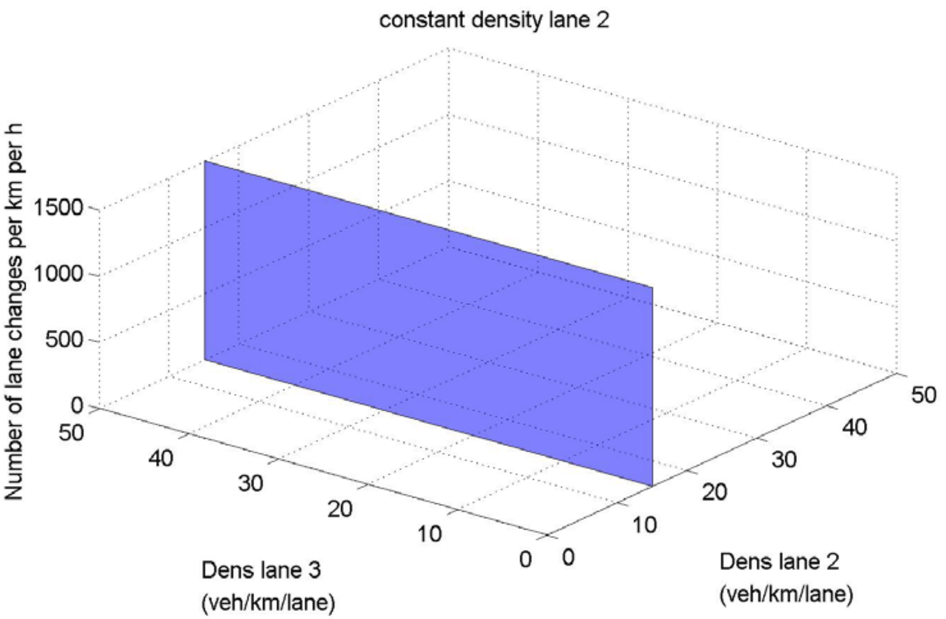


Setup of analysis

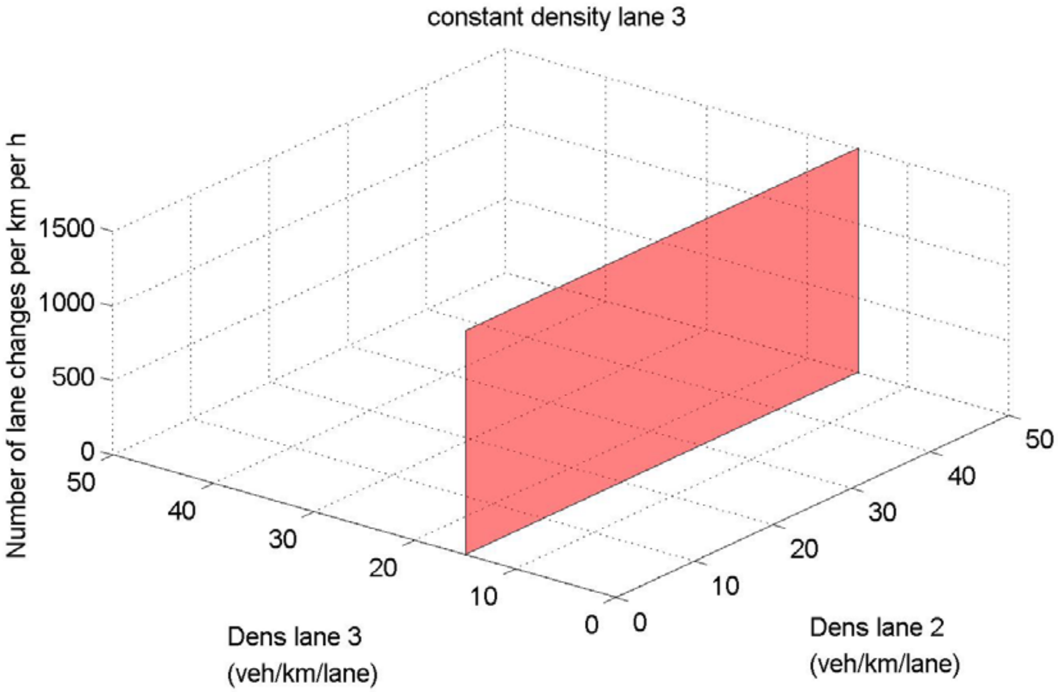
- Separate densities in origin lane and destination lane



Guess – what is the influence of

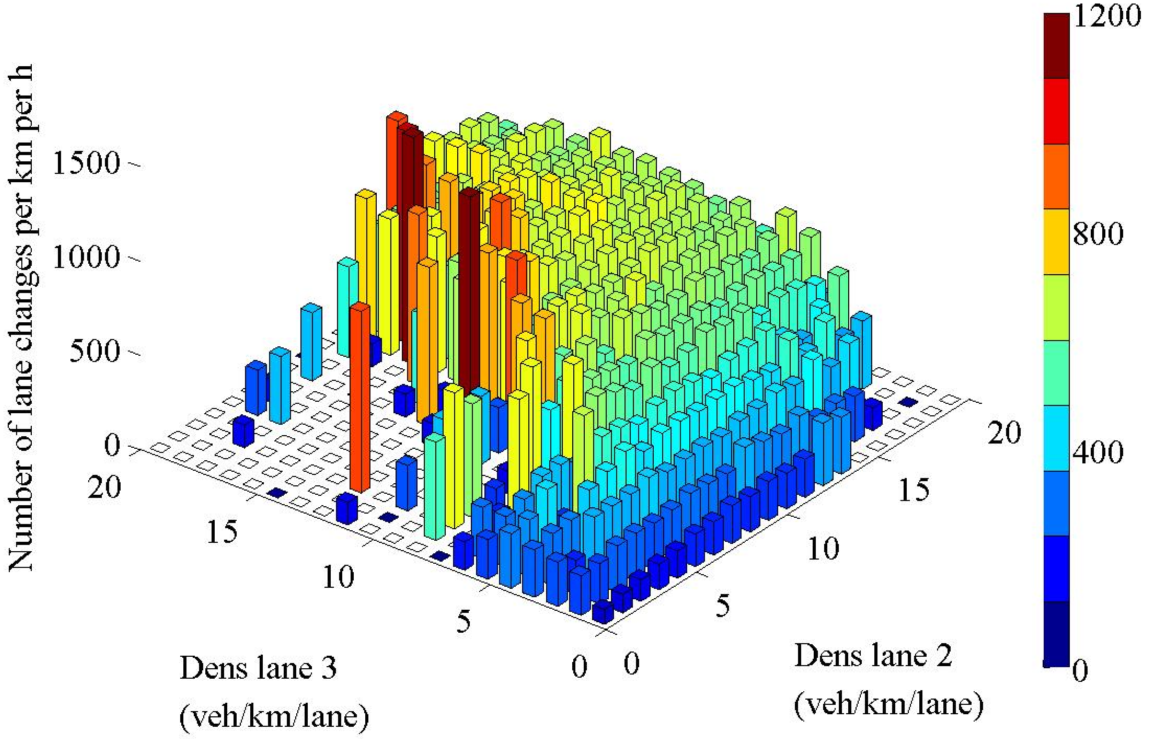


Guess – what is the influence of



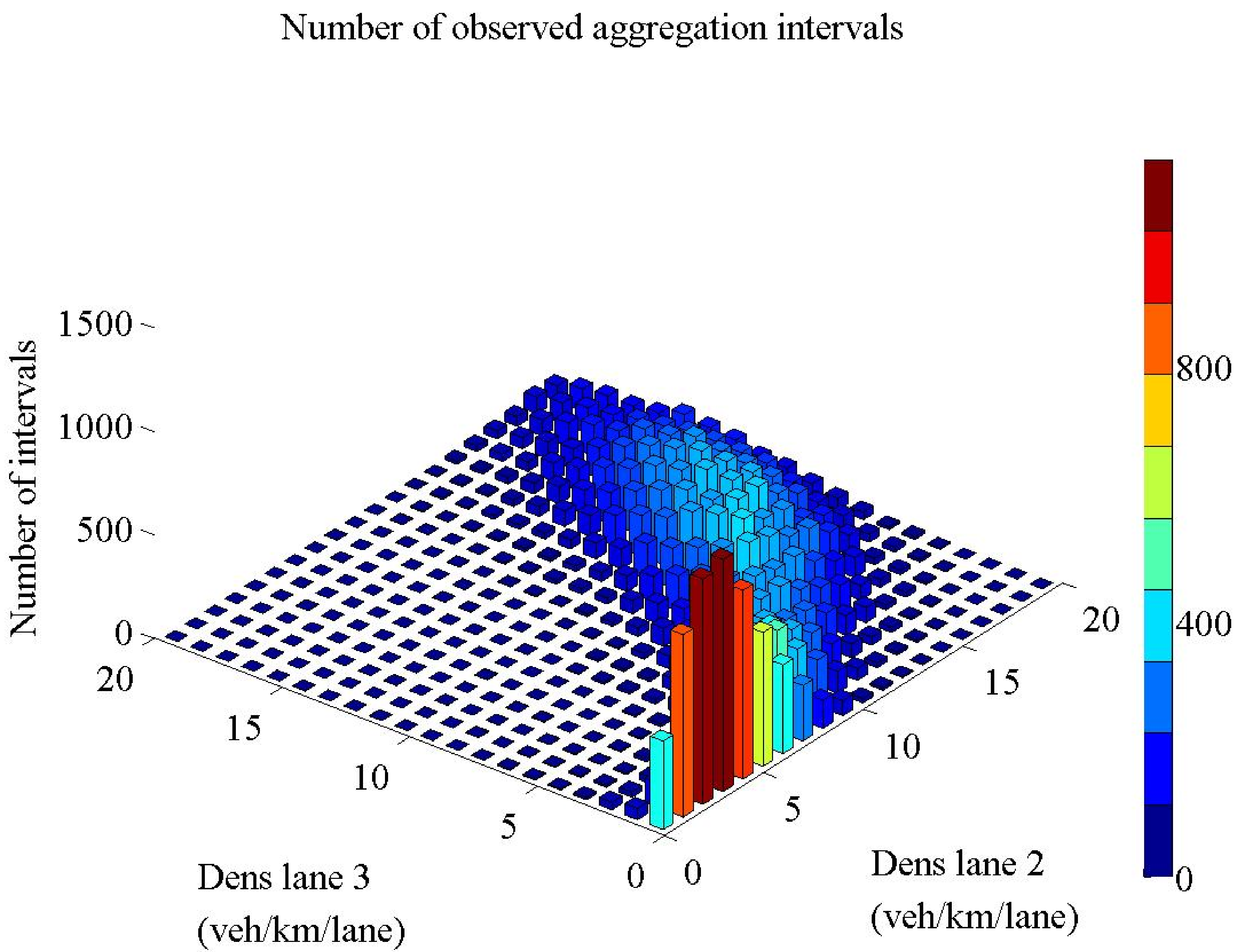
Lane changing lane 2 => 3

Experimental averge number of lane changes from lane 2 to 3

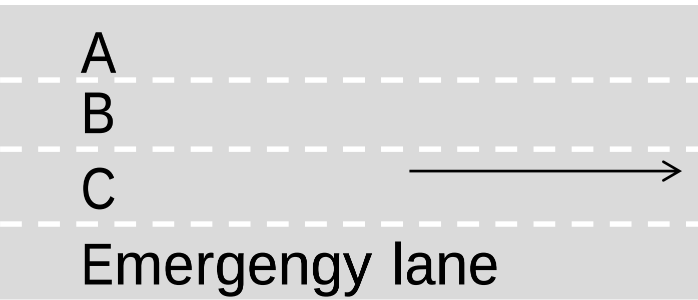


Explanations

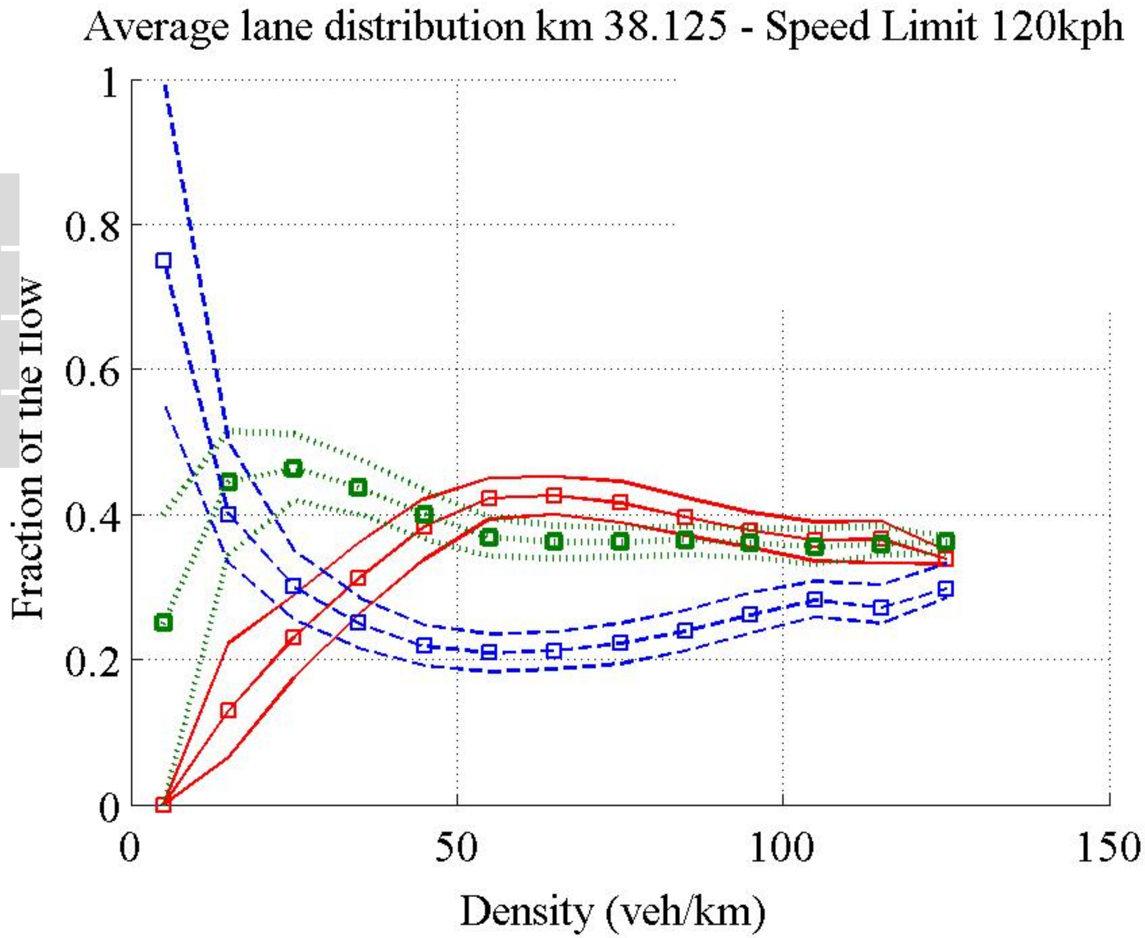
- Future conditions not included (drivers anticipate)
- Lane changes are induced by lane changes from the target lane (place swapping), which occur more frequently with higher target lane density
- Separation origin lane density and target lane density artificial
- Daganzo's theory of slugs and rabbits...


Number of observed aggregation intervals
Number of intervals
1500
1000
500
0
20
15
10
5
0
Dens lane 3
(veh/km/lane)
0
5
10
15
20
Dens lane 2
(veh/km/lane)
800
400
0

Flow distribution



Question: which lane corresponds with the blue line in the graph?



LANE SELECTION THEORIES

Slugs and Rabbits (Daganzo, 2002)

- Slugs:
  lower free speed
  right lane(s)

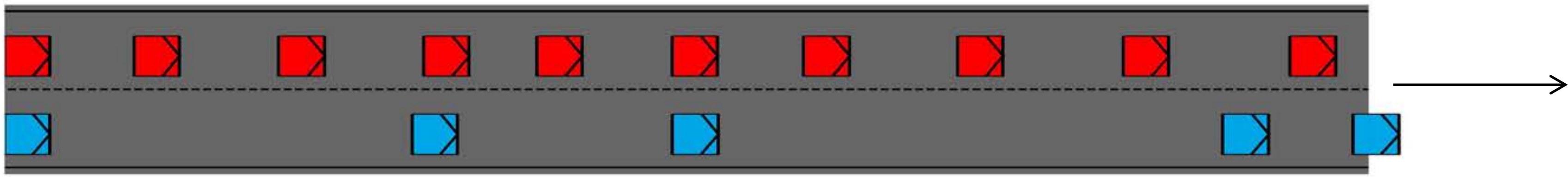
Photo by wikipedia / CC BY SA

Photo by Jonathan Dresner

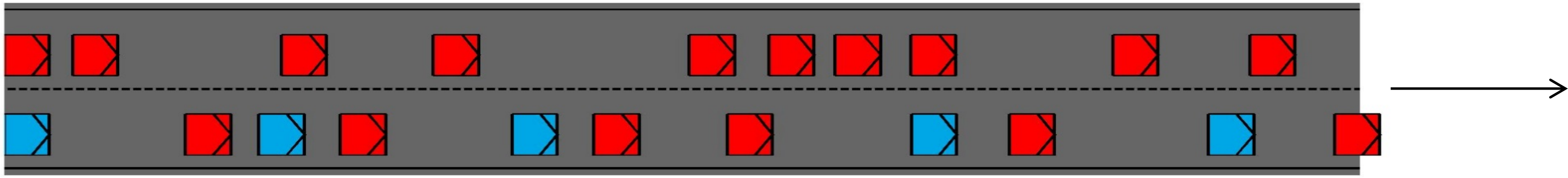
- Rabbits
  higher free speed
  left lane if that is faster than the right lane(s)

Two different regimes

- Two-pipe regime: slugs and rabbits separated

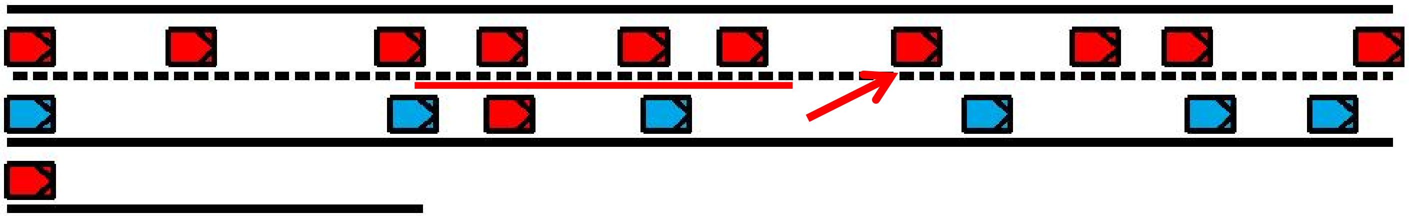


- One-pipe regime:
  slugs right lane and rabbits on both lanes
  equal speed (~Kerner: synchronised flow)



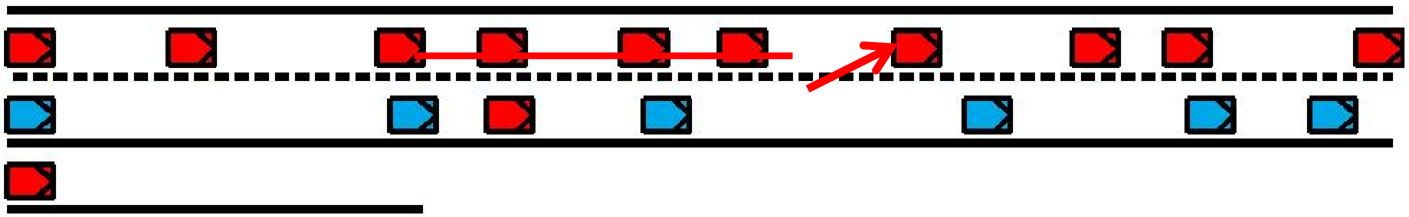
Slugs and rabbits – start of congestion

- Rabbits and slugs enter on-ramp
- Rabbits will not merge immediately into left lane



Consequences of merging

- Oversaturation on left lane after lane change



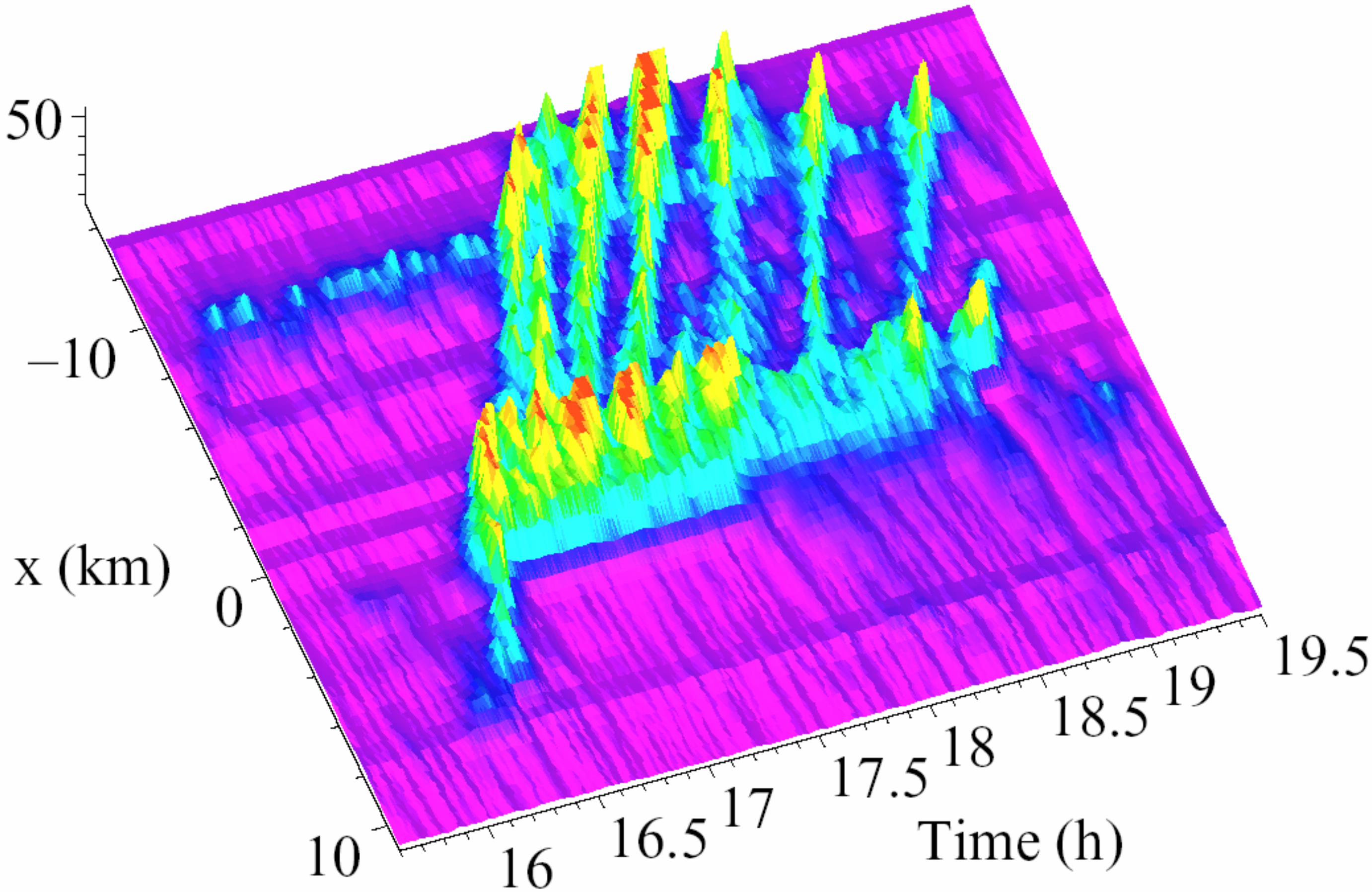
- Start congestion on left lane, downstream of ramp

Impact and consequences

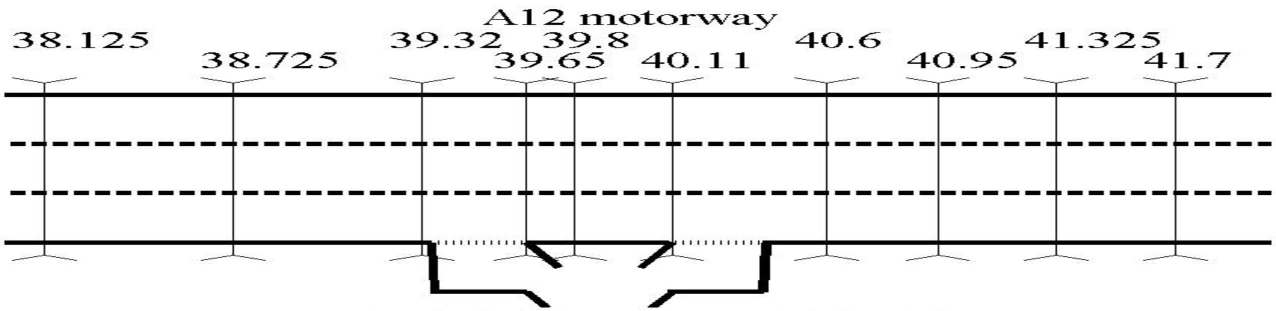
- Capacity drop
- Congestion start downstream of merge ("boomerang")
- Lane distribution uneven

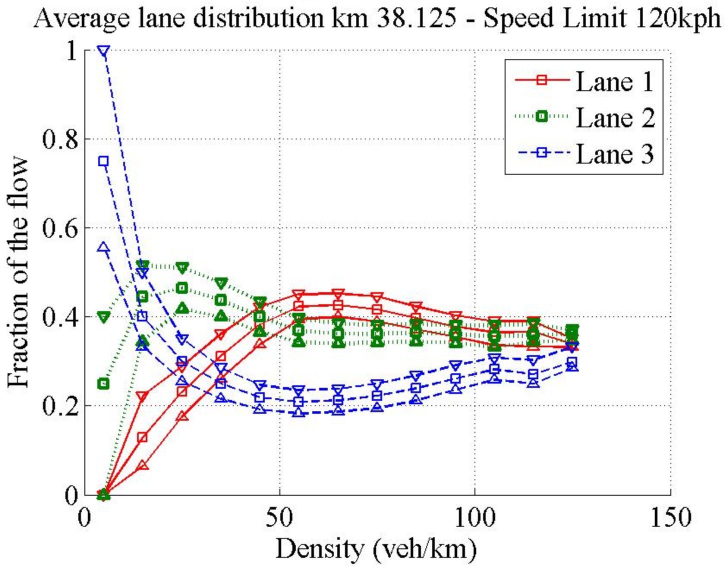
- All seen in practice!

Observed phenomena in traffic flow

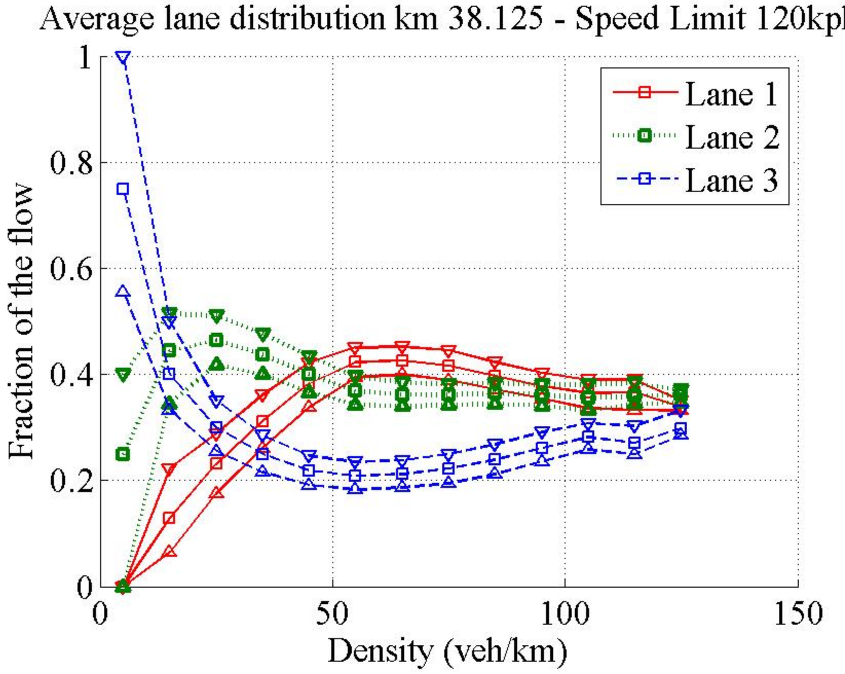


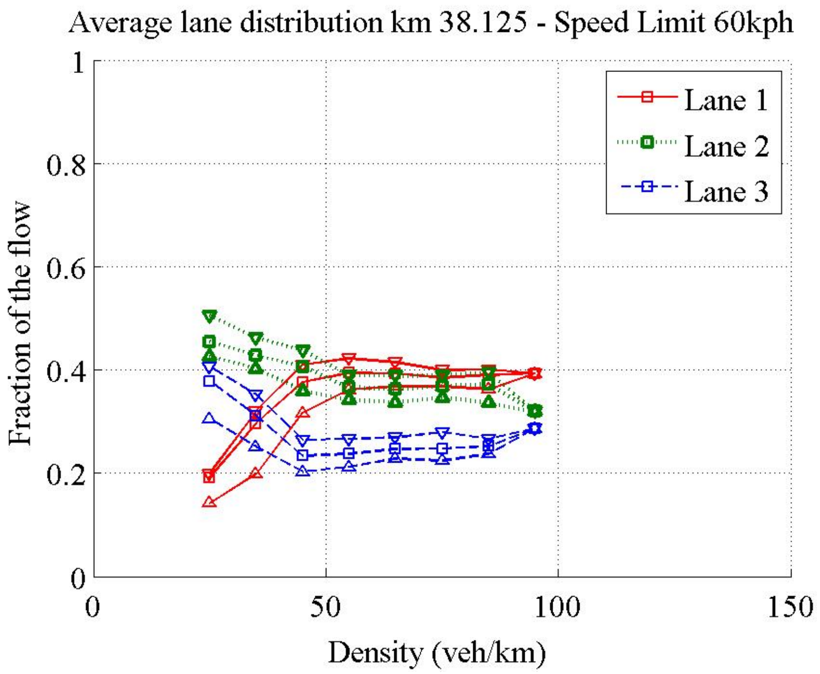
Lane Distribution





Influence of speed limit

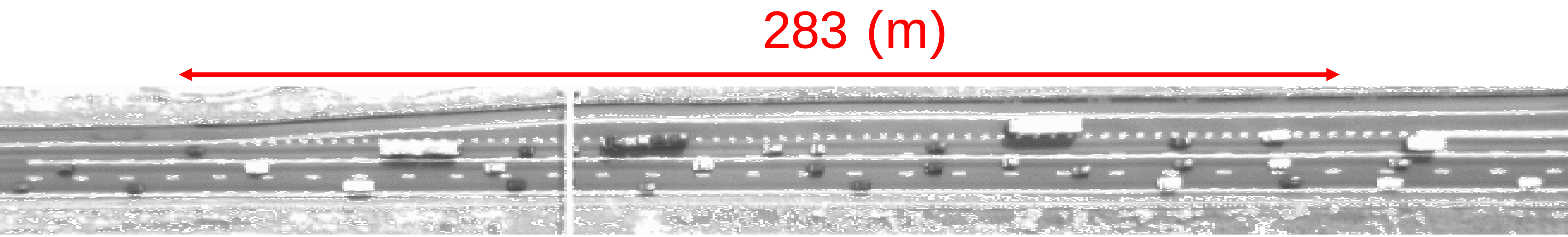




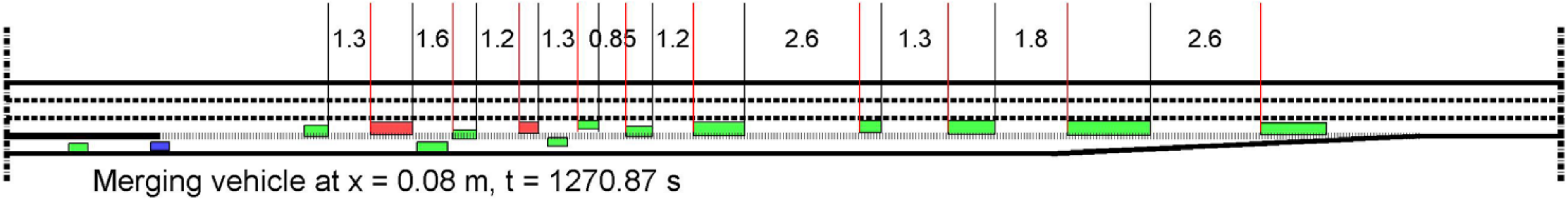
MERGING

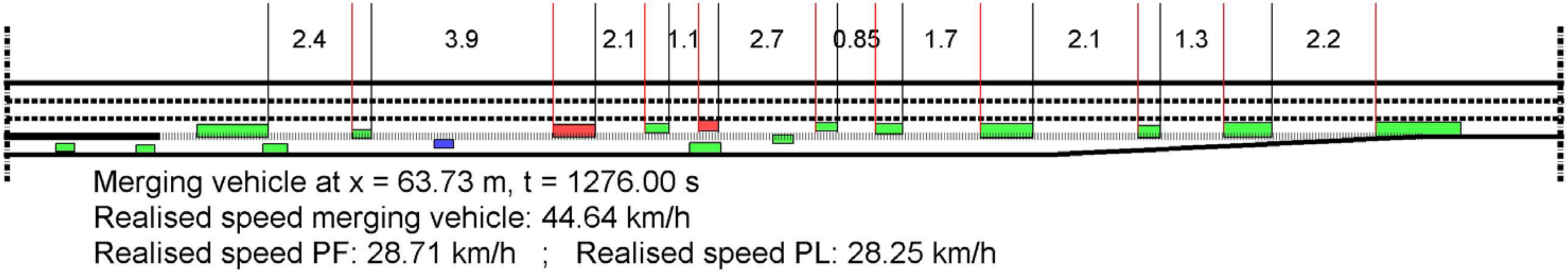
Merging

- Helicopter observations
- Gap acceptance theories are wrong
- Current research => gap selection theory?
- Relaxation present

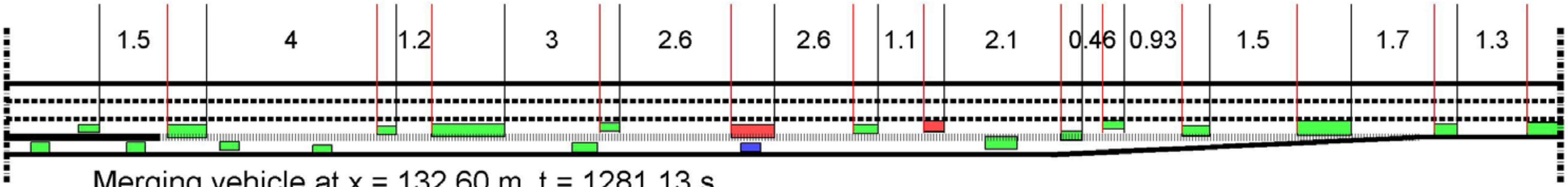


Available gaps (1)

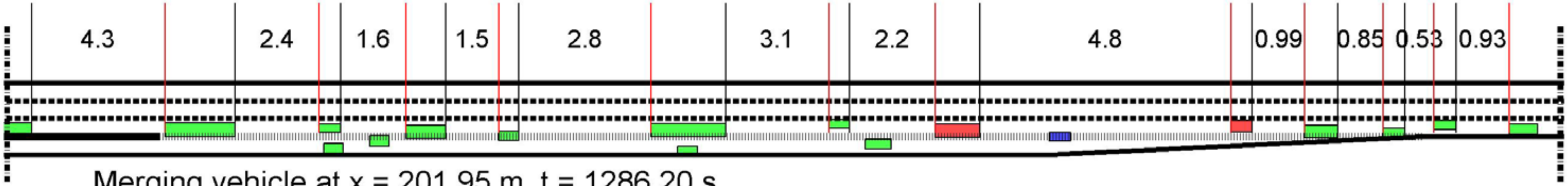




Available gaps (2)

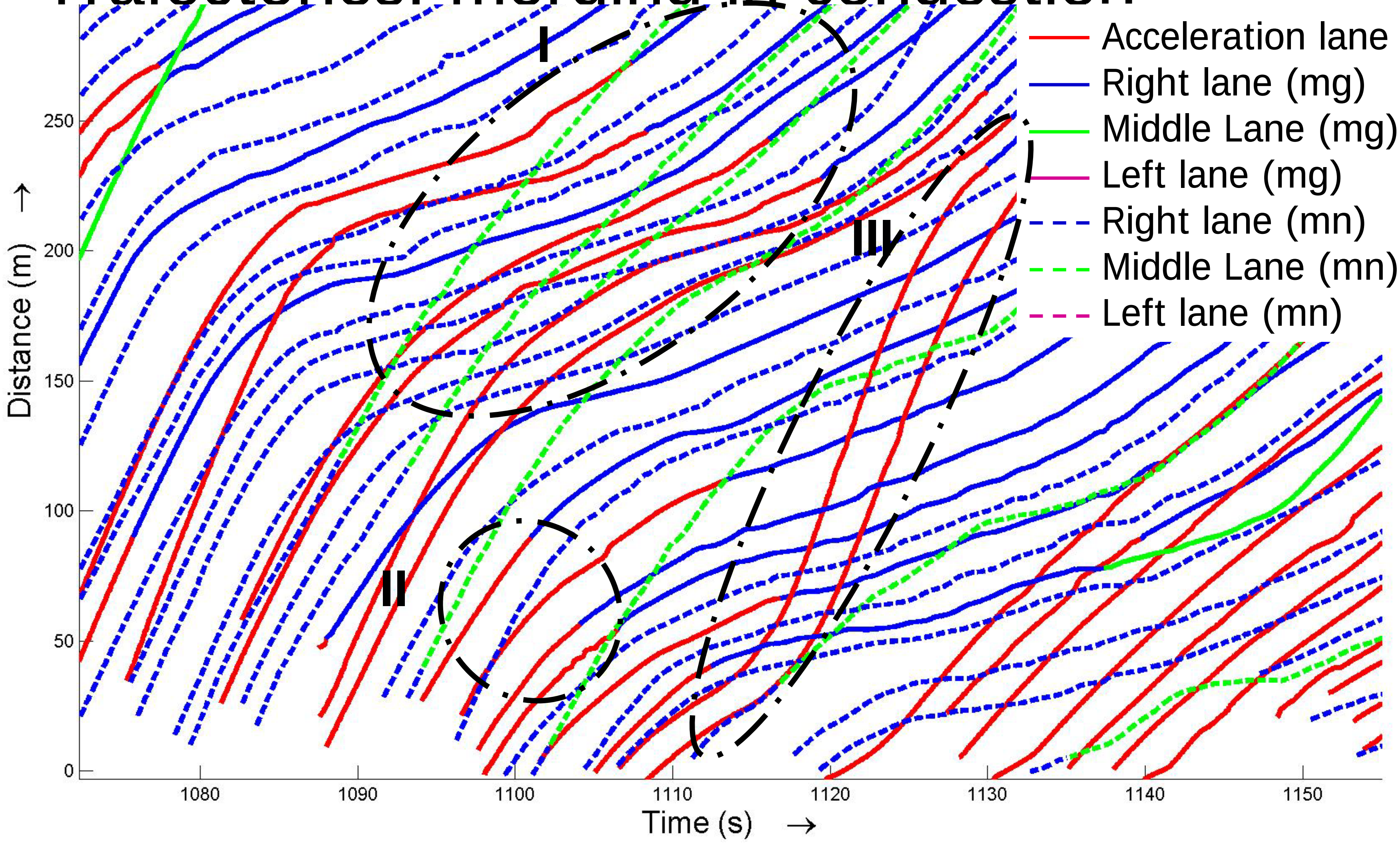


Merging vehicle at x = 132.60 m, t = 1281.13 s
Realised speed merging vehicle: 48.30 km/h
Realised speed PF: 28.17 km/h ; Realised speed PL: 35.52 km/h



Merging vehicle at x = 201.95 m, t = 1286.20 s
Realised speed merging vehicle: 49.27 km/h
Realised speed PF: 32.57 km/h ; Realised speed PL: 49.02 km/h

Trajectories, merging in congestion



After this lecture, you are able to...

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- ... explain gap acceptance theory and comment on measuring critical gaps
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- ... comment on lane selection theories
- ... comment an analyse lane distributions
- ... comment on merging
- ... describe the principle of relaxation

Mobil: safety criterion

- Always safety first:
  $a_{new\ follower} > -b_{safe}$
- b_{safe} is safe deceleration (not max!)

Photo by AutoYim