



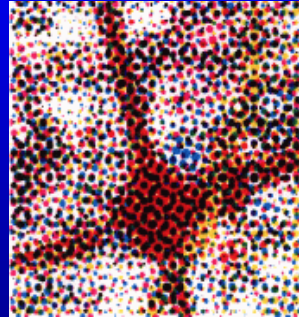
Modelling and Simulation of Road Traffic

Max Planck Institute for Physics
Munich, 08 March, 2016

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Physics of Transport and Traffic
University of Duisburg-Essen



Physics of Transport and Traffic



Since 1997 at the University of Duisburg-Essen

Physics of Transport and Traffic

Topics: Analysis, Modeling, Simulation
und Optimization of Transport Systems



Physics of Transport and Traffic

Topics:

- **Road Traffic**
- Intelligent Transport Systems
- Traffic Forecasts
- Evacuation Processes
- Inland-Shipway-Traffic
- Air Traffic
- Education



The “Problem“

“All bad luck of the human beings stems from the fact, that they are not able to stay calmly in a room“

(Blaise Pascal, Pensée, ca. 1640)



Highway Intersection



















Fire brigade









Magic Roundabout



Magic Roundabout



Magic Roundabout



Arc de Triomphe



Integration

Physical: We move physically from A to B

**Digital: We communicate via media
without movement**

Combination of both: Teleportation!?



Status quo

- **Young people do not like to own cars**
- **Extensive use of digital media**
- **Inner cities expensive**
- **Growing metropolises**
- **Online services very important**
- **Carsharing unclear**



Jam Costs

- 4 kilometers jam
- 2 lanes
- 3 hours
- caused by roadworks or an accident
- 10 instead of 80 km/h
- **between 50.000 und 100.000 \$!**



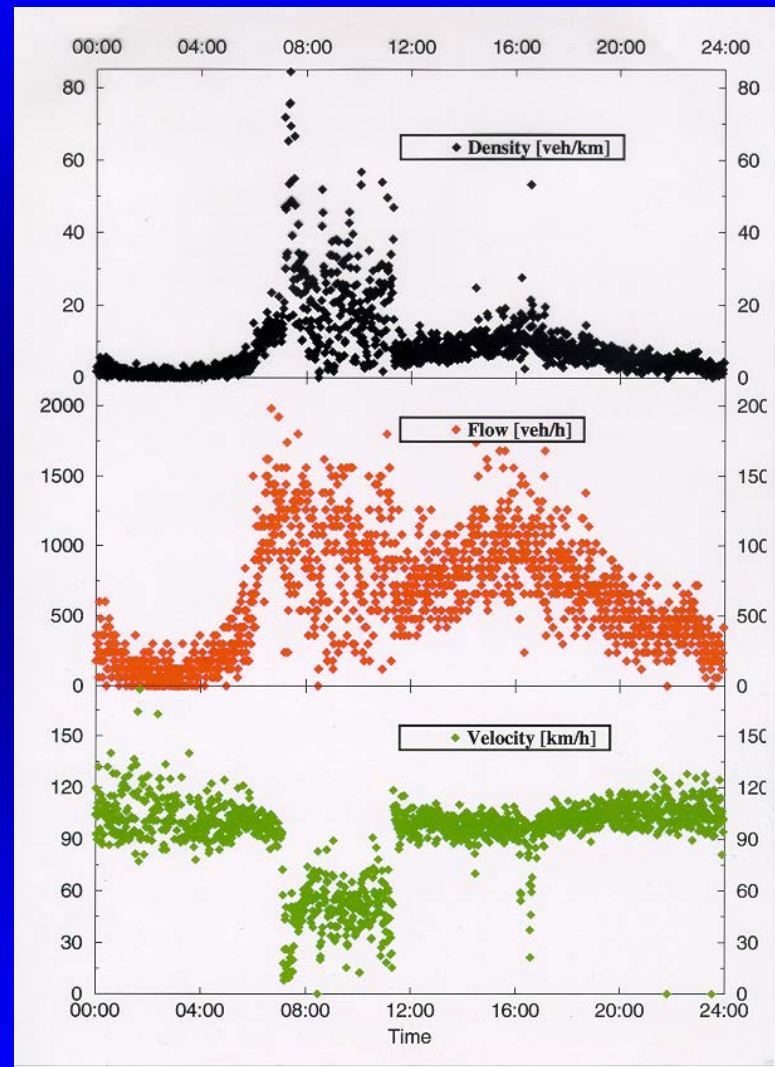
Tokai TV



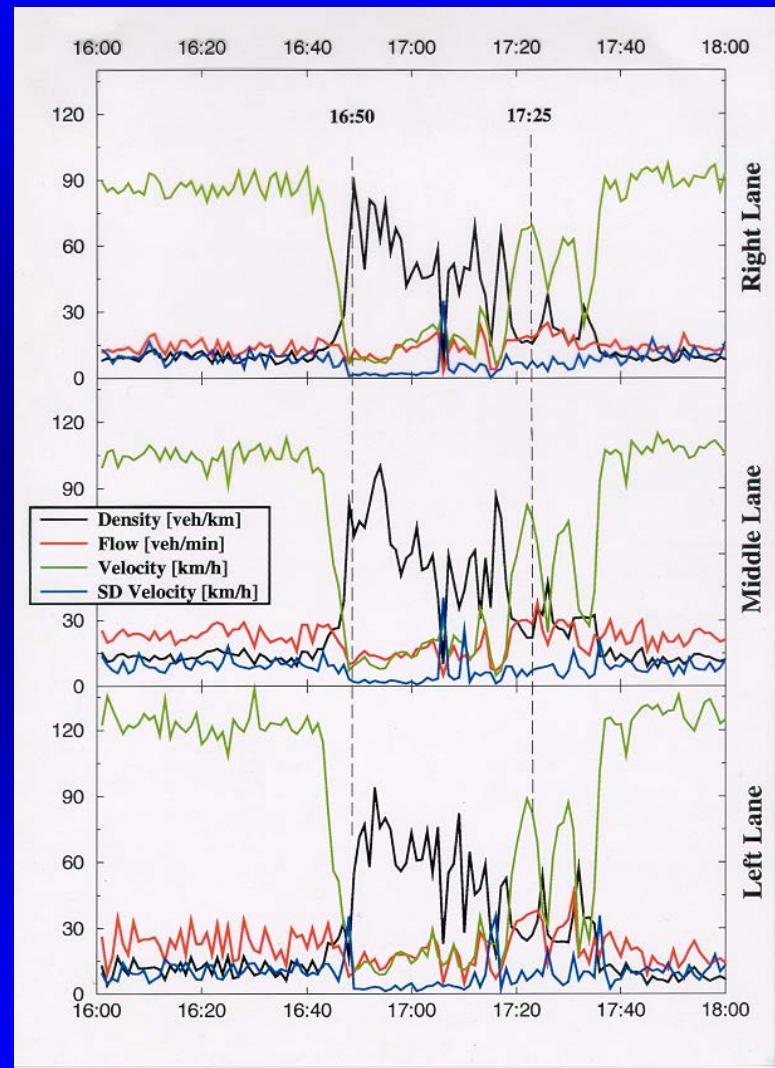
A3 north near Duisburg



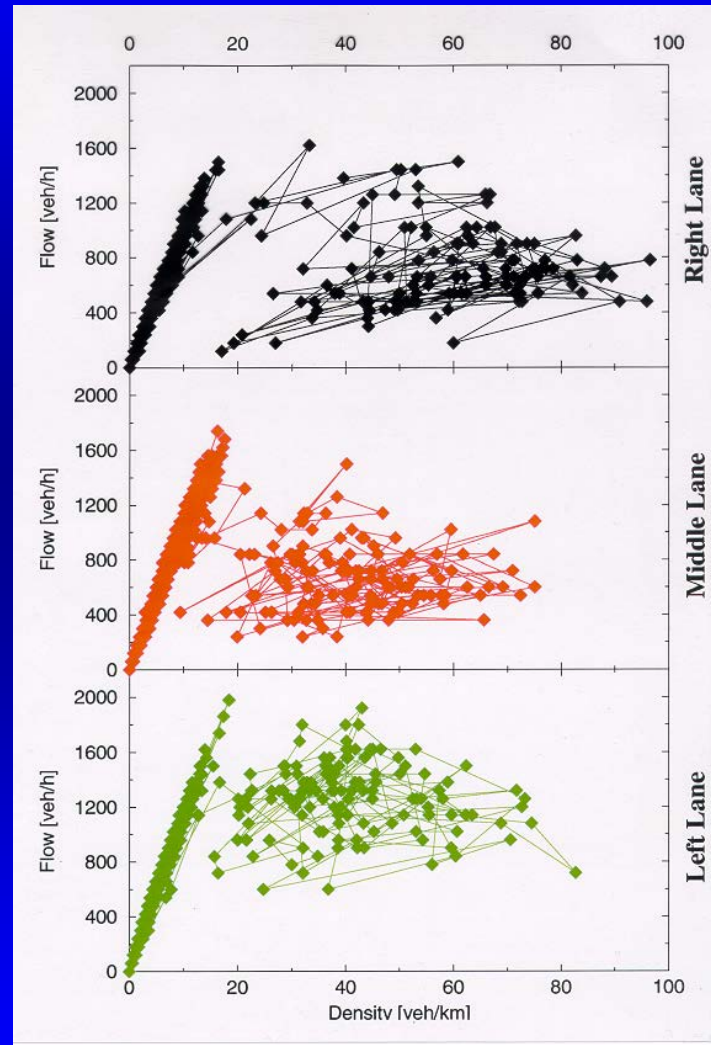
Density/Flow/Velocity



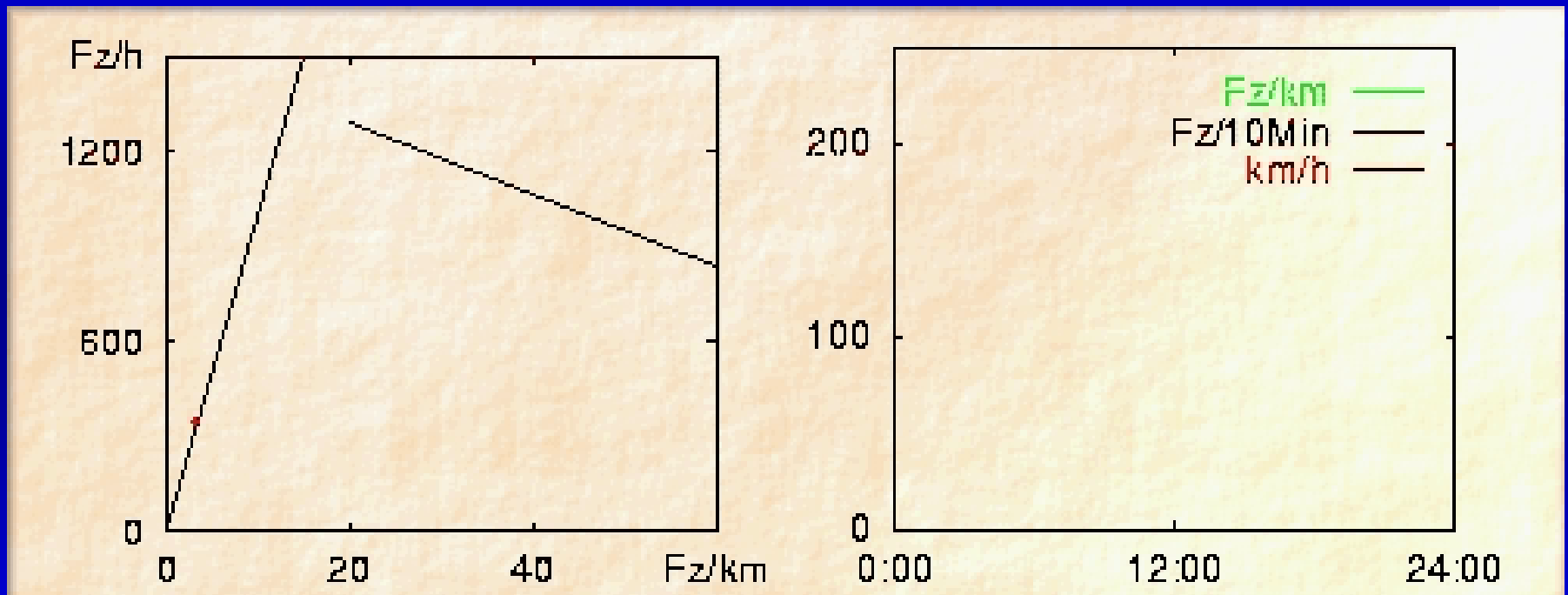
Lane Resolution and Traffic States

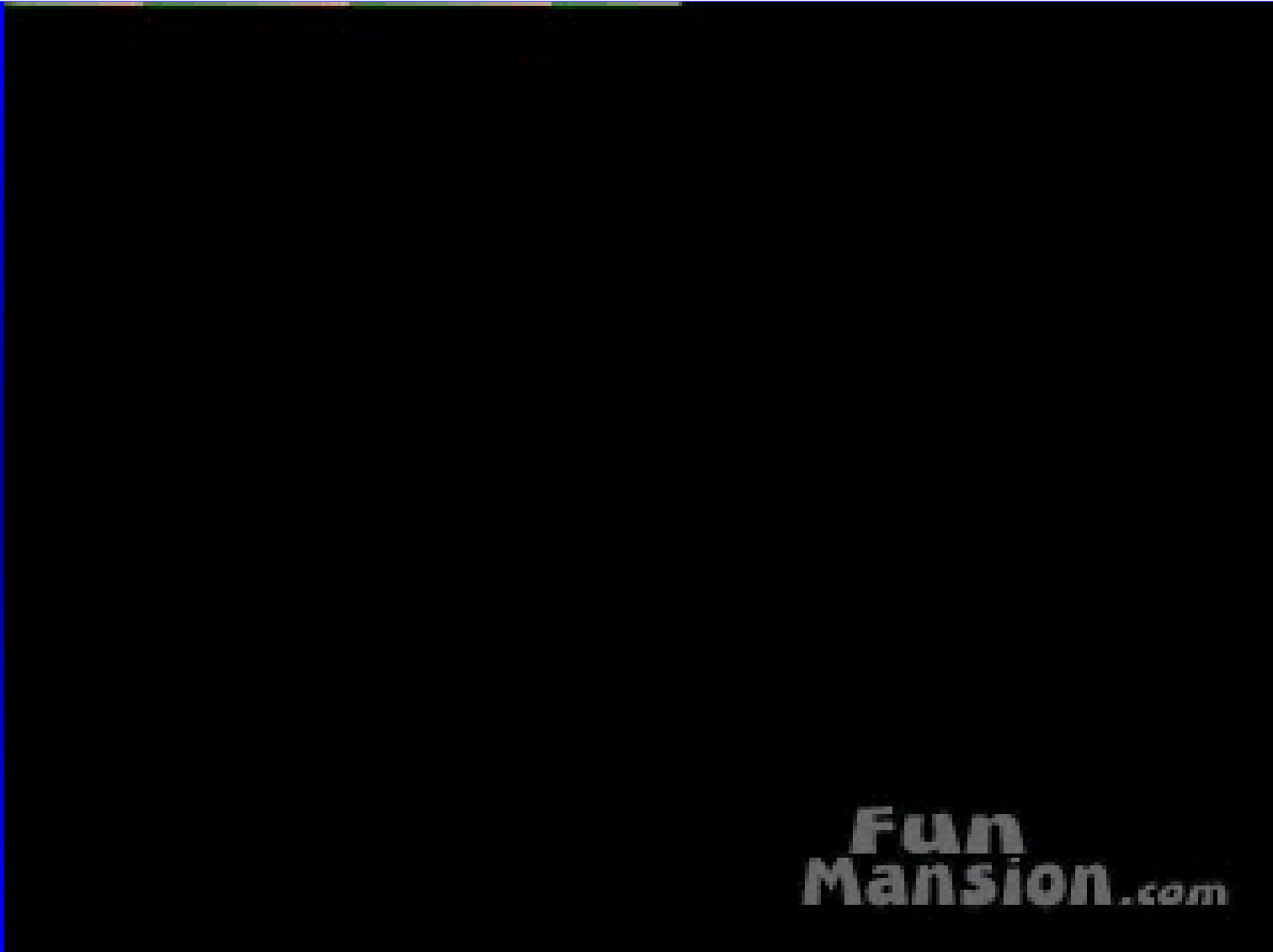


Fundamental Diagram



Dynamic Flow-Density Relation





The Energy Problem

- Oil (ltd)
- Natural gas (ltd)
- Solar car (slow)
- Electric car (losses?)
- Water-diesel mixture (not stable)
- Fuel cell (hydrogen is only energy carrier! (80% loss))
- Rape (monoculture)
- Methanol (natural gas)
- Ethanol (rape, sugar cane / beet))
- Human power



Ford Nucleon (1958)



Traffic Data Detection

- Inductive loops
- Radar sensors
- Traffic eyes (infrared)
- Video
- Floating cars / cellular phone (location)
- Air photography / video (plane, zeppelin, hot-air ballon, satellite)



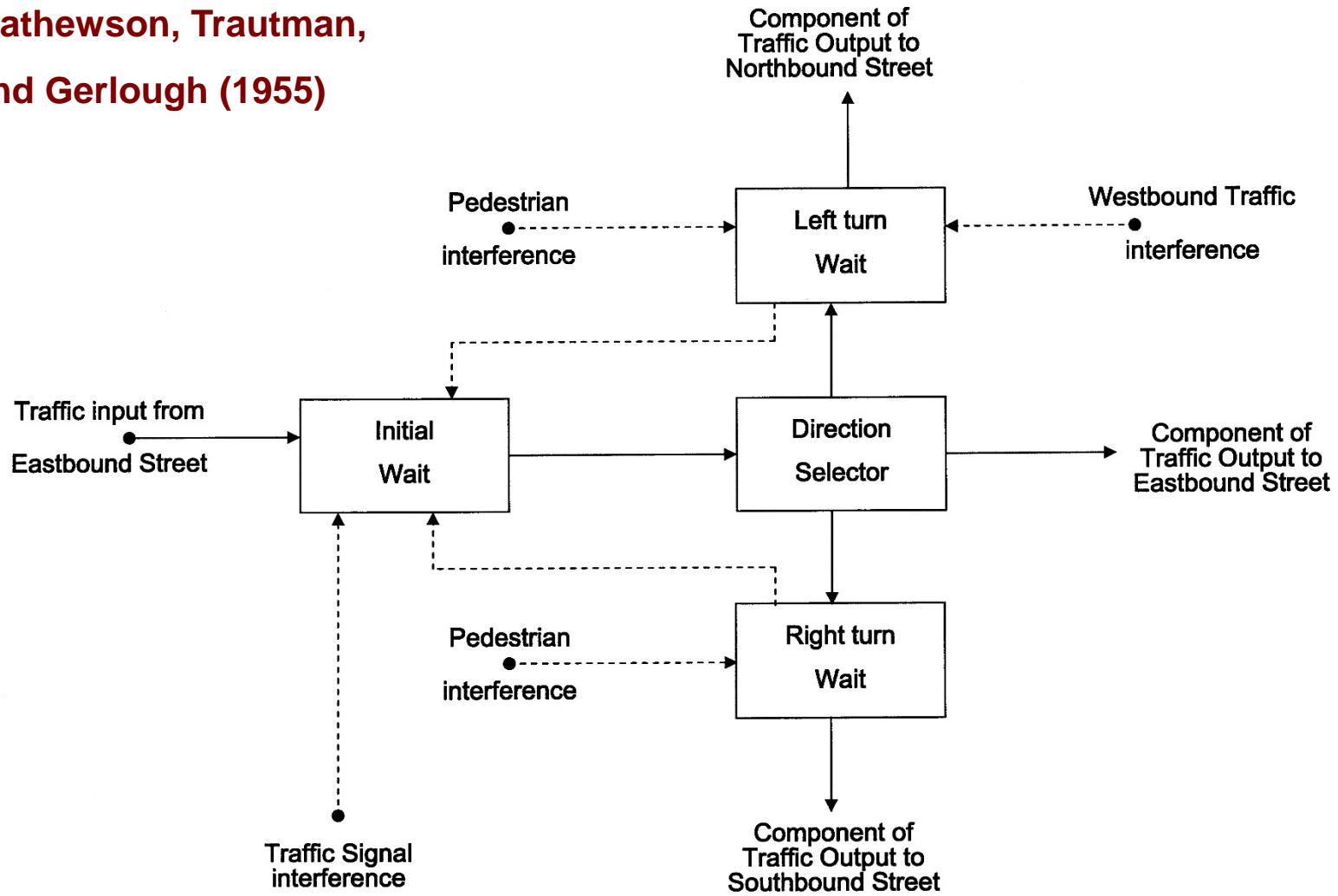
Traffic Modelling Strategies

- Continuous in space and time, vehicles „smeared out“ (hydrodynamic models, Lighthill-Whitham-Richards, LWR)
- Continuous in space and time, vehicles discrete (microscopic models, car-following models, Herman)
- Mesoscopic models, cell structure in space, time continuous or discrete
- Discrete in space and/or time, vehicles discrete (cellular automata, rule based, Mathewson, Trautmann, Gerlough)



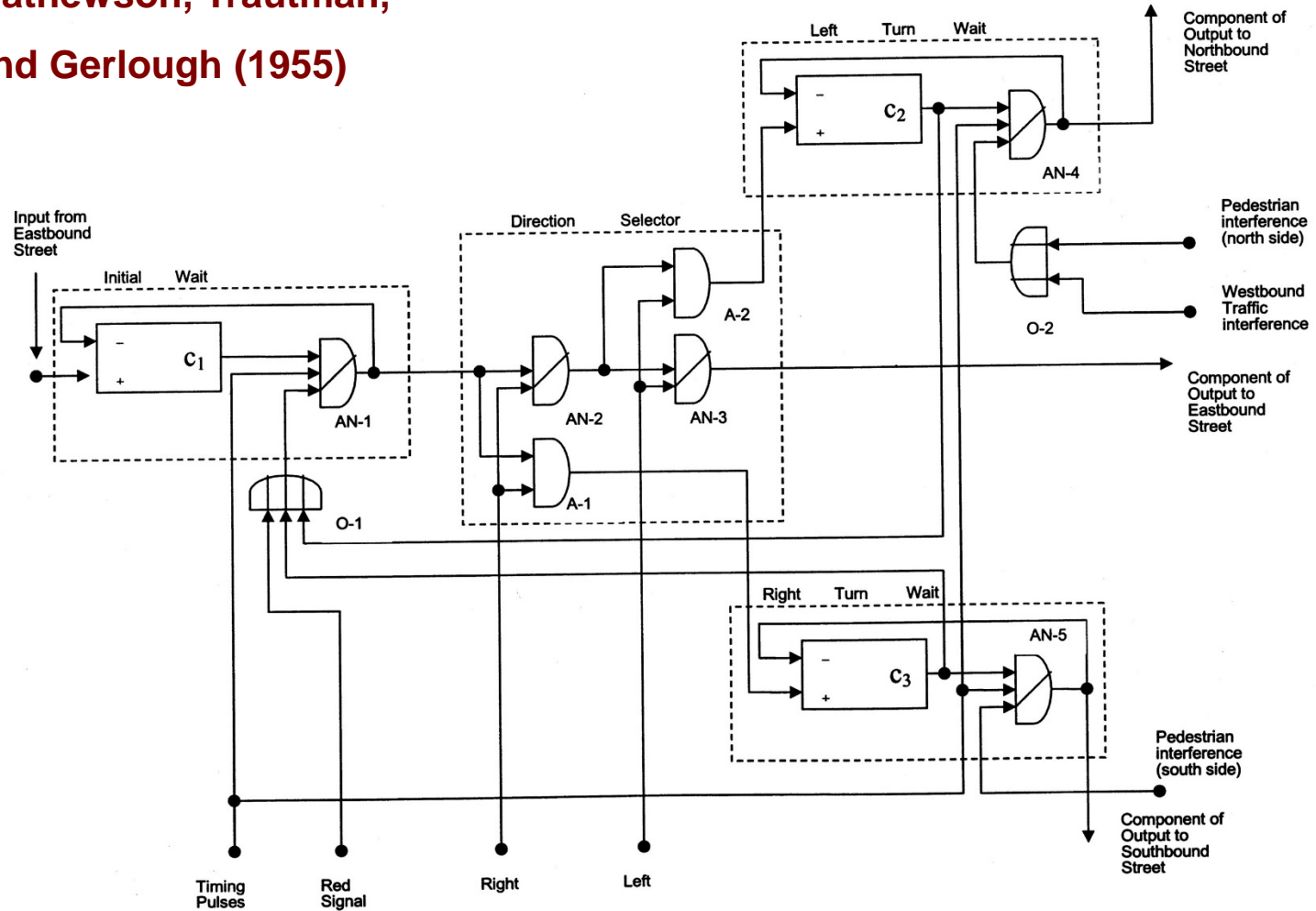
Special Purpose Computer

Mathewson, Trautman,
and Gerlough (1955)



Discrete Variables

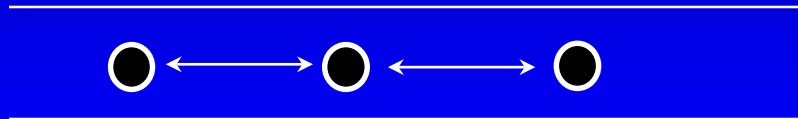
Mathewson, Trautman,
and Gerlough (1955)



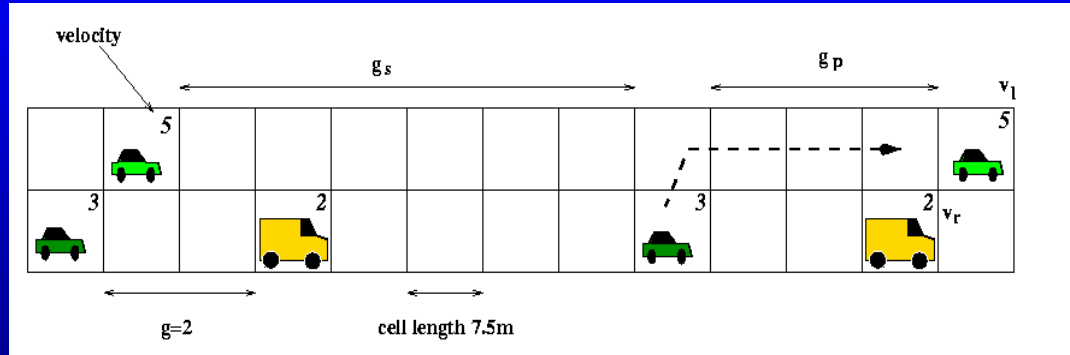
Modelling Traffic Flow

- Macroscopic models:
 - Traffic is similar to fluids
 - Continuity equation
 - Describe density waves
 - But: Assumption for function $j(\rho)$
- Microscopic models:
 - Traffic similar to granular media
 - Describe car-following (interaction)

$$\frac{\partial}{\partial t} \rho + \nabla \cdot \vec{j} = 0$$



General Strategy

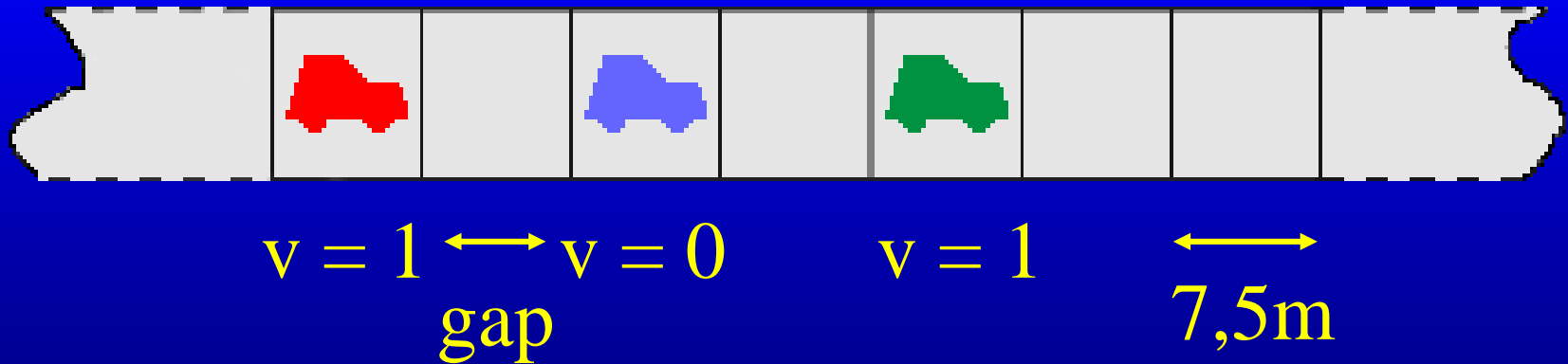


Cellular Automaton (CA) Model:

- > Discrete in time and space
- > Dynamics through update rules (in parallel)
- > Fast and efficient algorithms
- > Analysis of dynamical phases:
free, synchronized and wide moving jams



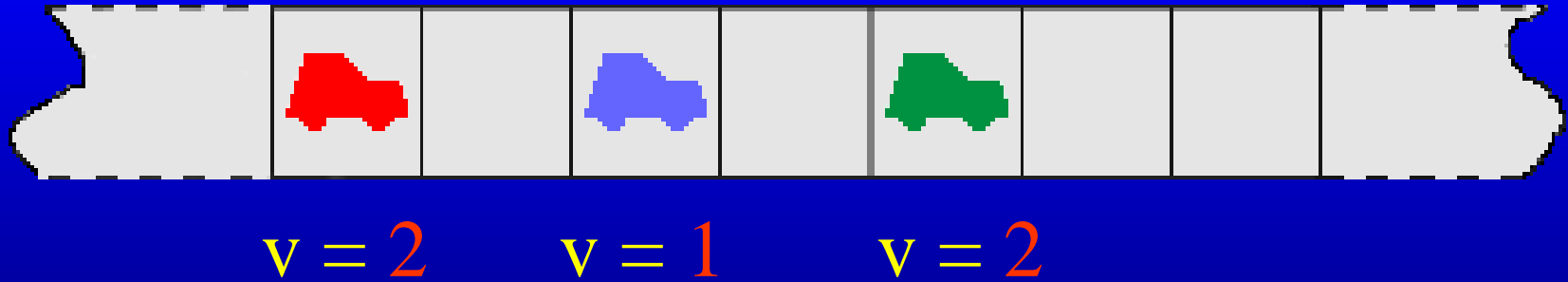
Discrete Simulation Model



- Cell length = 7,5 m
- v = speed
- gap = # of empty cells between the cars



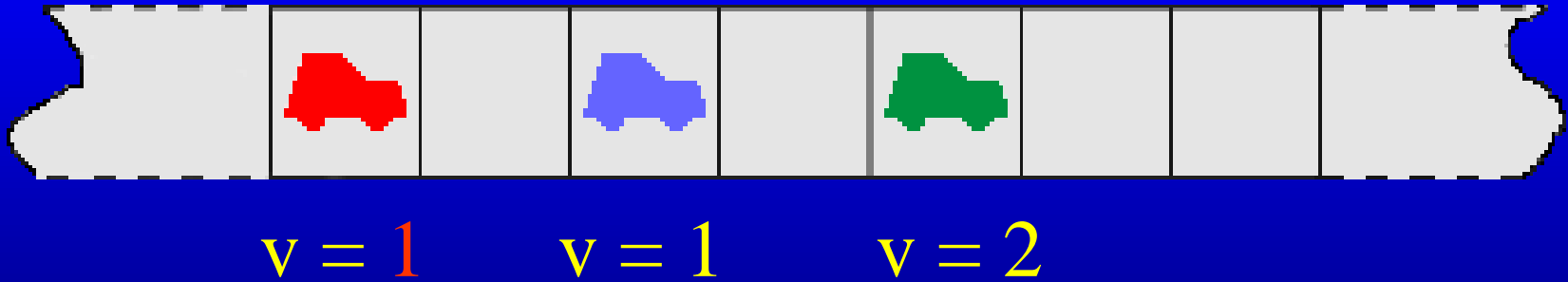
Cellular Automaton (I)



- acceleration: $v \leftarrow \min(v + 1, v_{\max})$



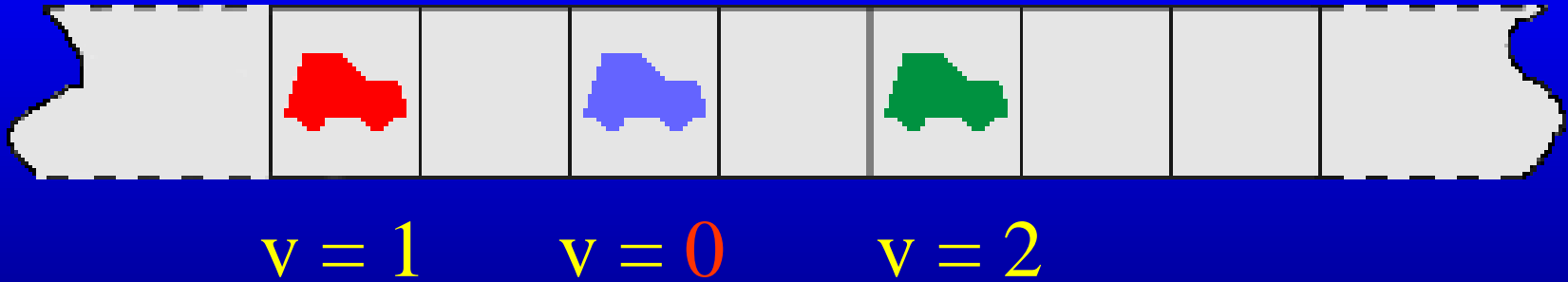
Cellular Automaton (II)



- acceleration: $v \leftarrow \min(v + 1, v_{\max})$
- braking: $v \leftarrow \min(v, \text{gap})$



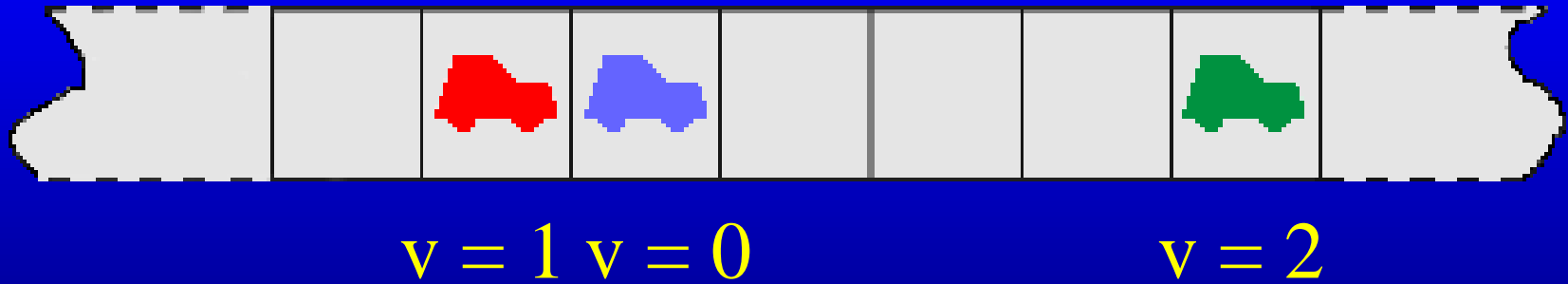
Cellular Automaton (III)



- acceleration: $v \leftarrow \min(v + 1, v_{\max})$
- braking: $v \leftarrow \min(v, \text{gap})$
- randomization with prob p_{dec} :
 $v \leftarrow \max(v - 1, 0)$



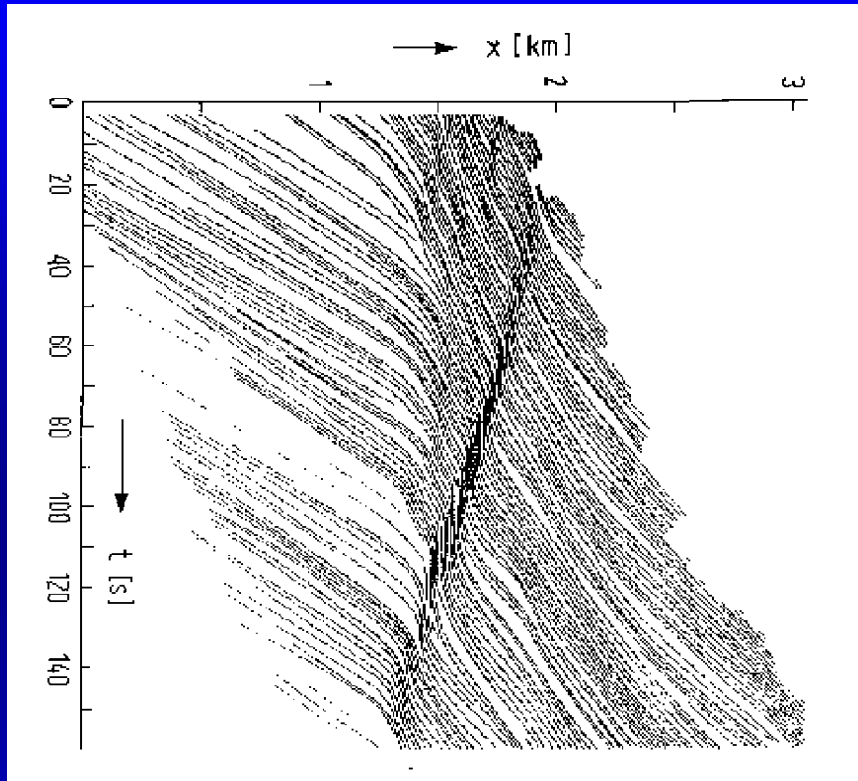
Cellular Automaton (IV)



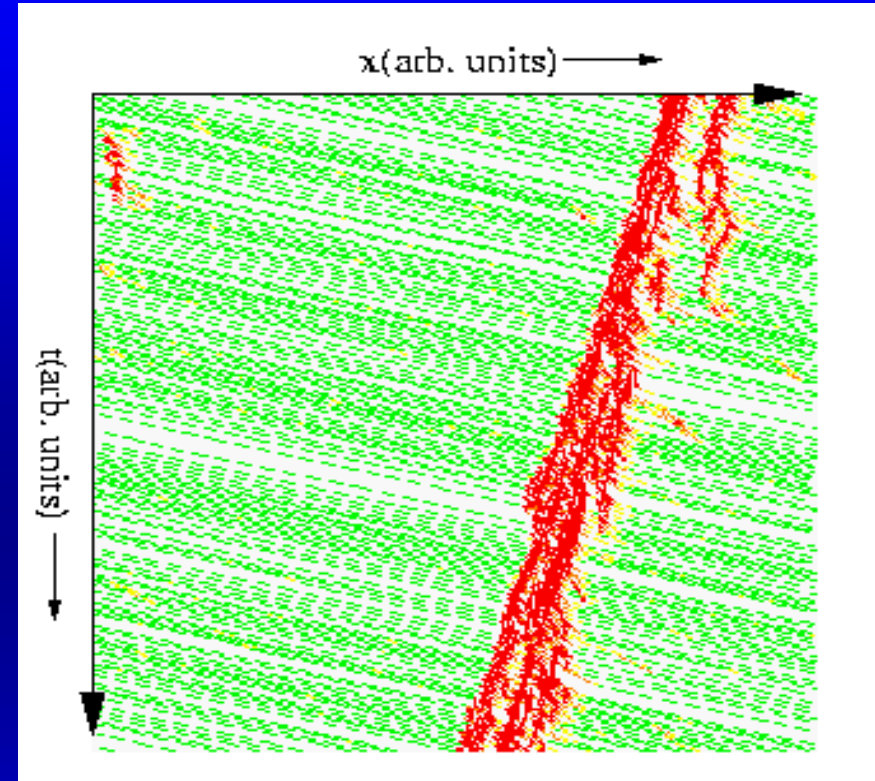
- acceleration: $v \leftarrow \min(v + 1, v_{\max})$
- braking: $v \leftarrow \min(v, \text{gap})$
- randomization with prob p_{dec} :
 $v \leftarrow \max(v - 1, 0)$
- driving: $x \leftarrow x + v$



Jam Formation



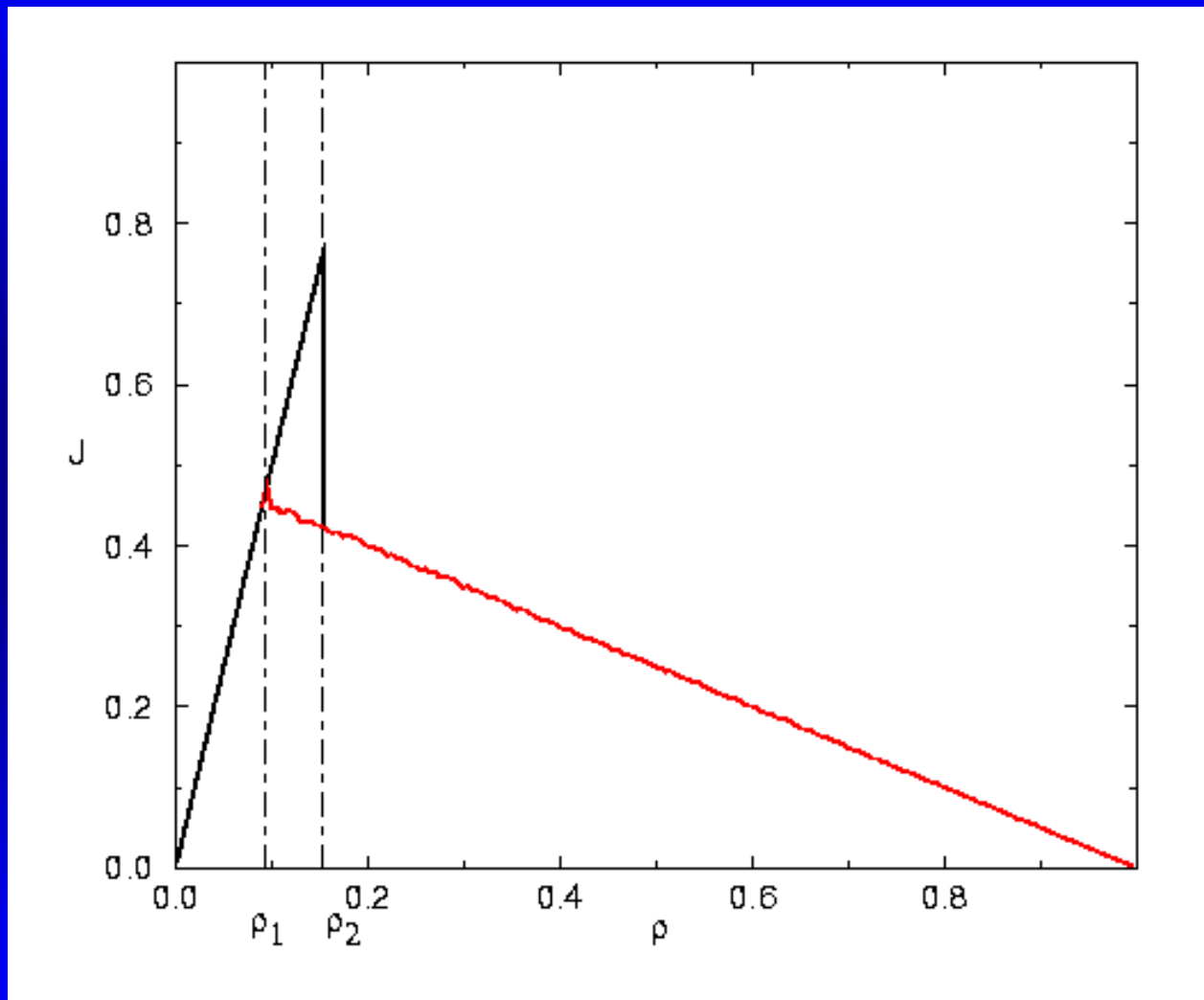
Air video analysis
(Treiterer 1965)

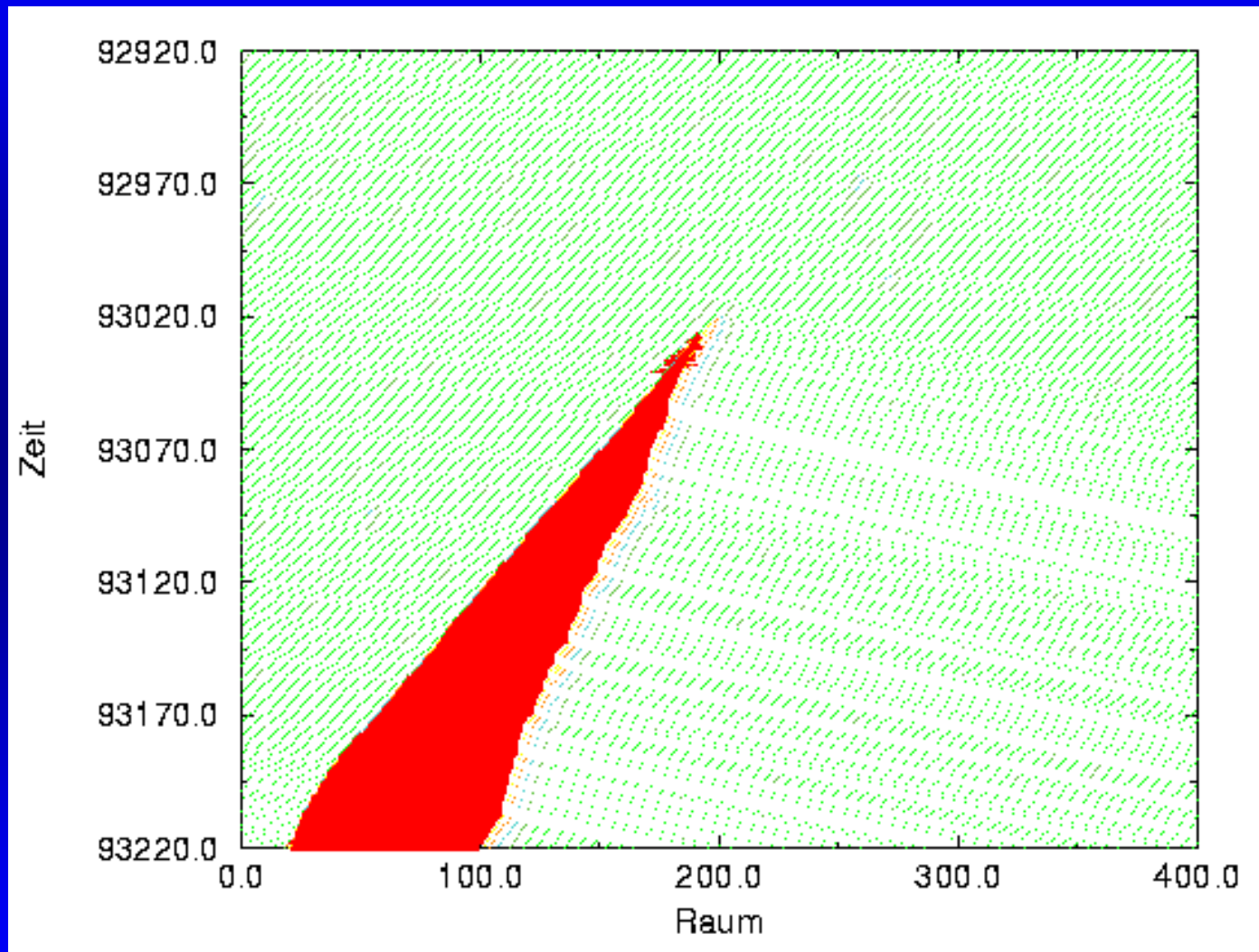


Simulation



Metastability





Model Extensions

Requirements:

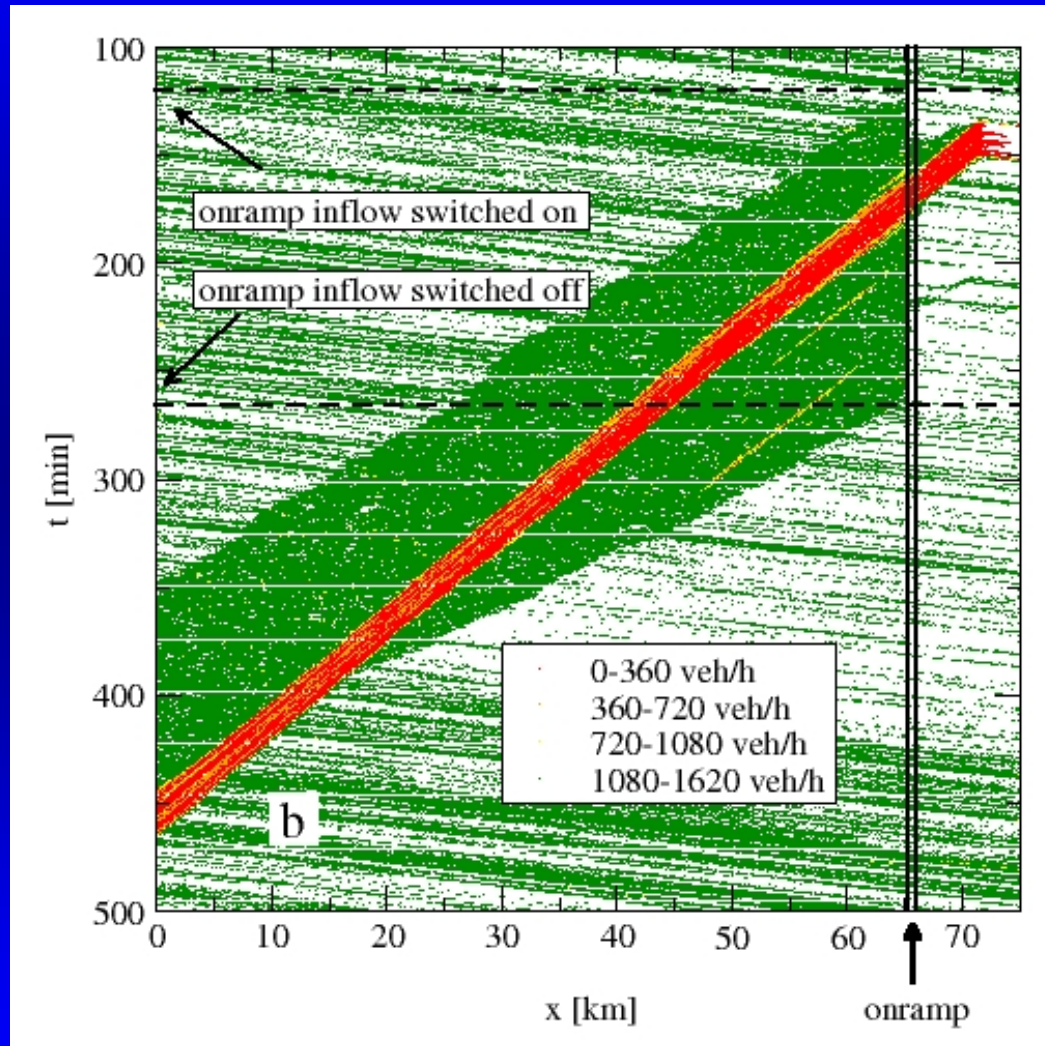
- Unaffected driving in free traffic
- Reaction on acceleration or braking
- Delayed acceleration out of jams (capacity drop)

Ansatz:

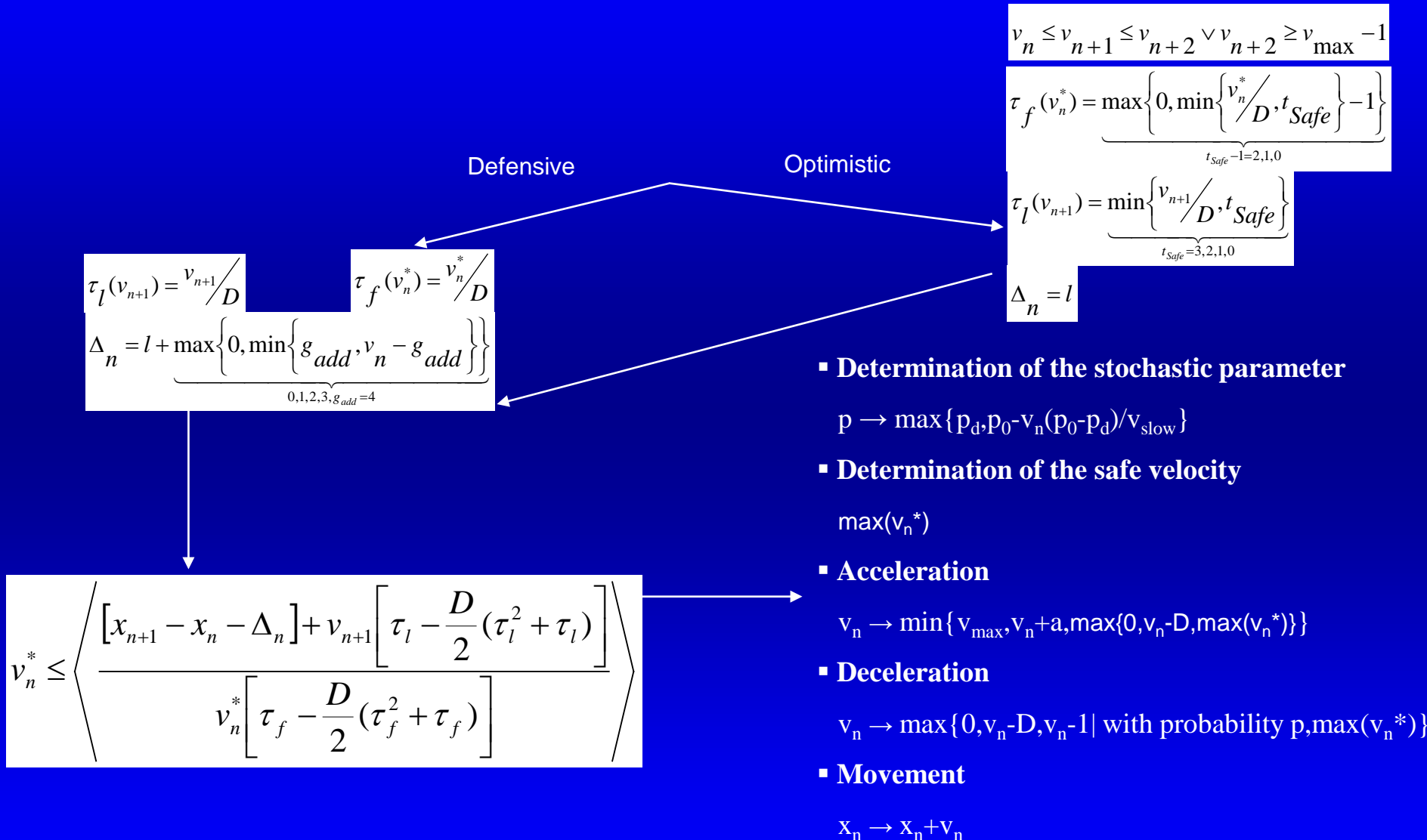
- Velocity dependent reaction (VDR)
- Anticipation of driver's behavior
- Adjustment of the cell length



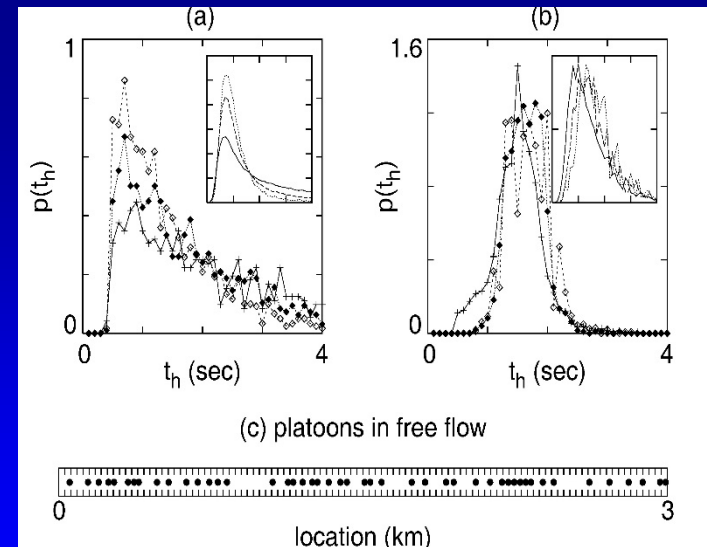
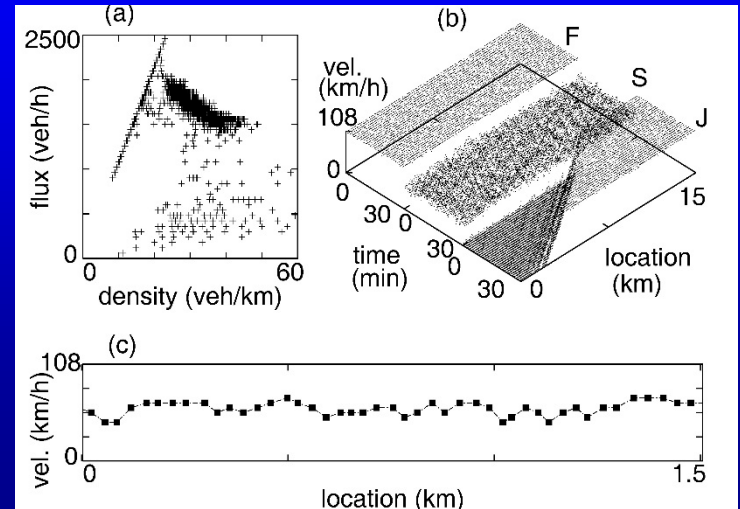
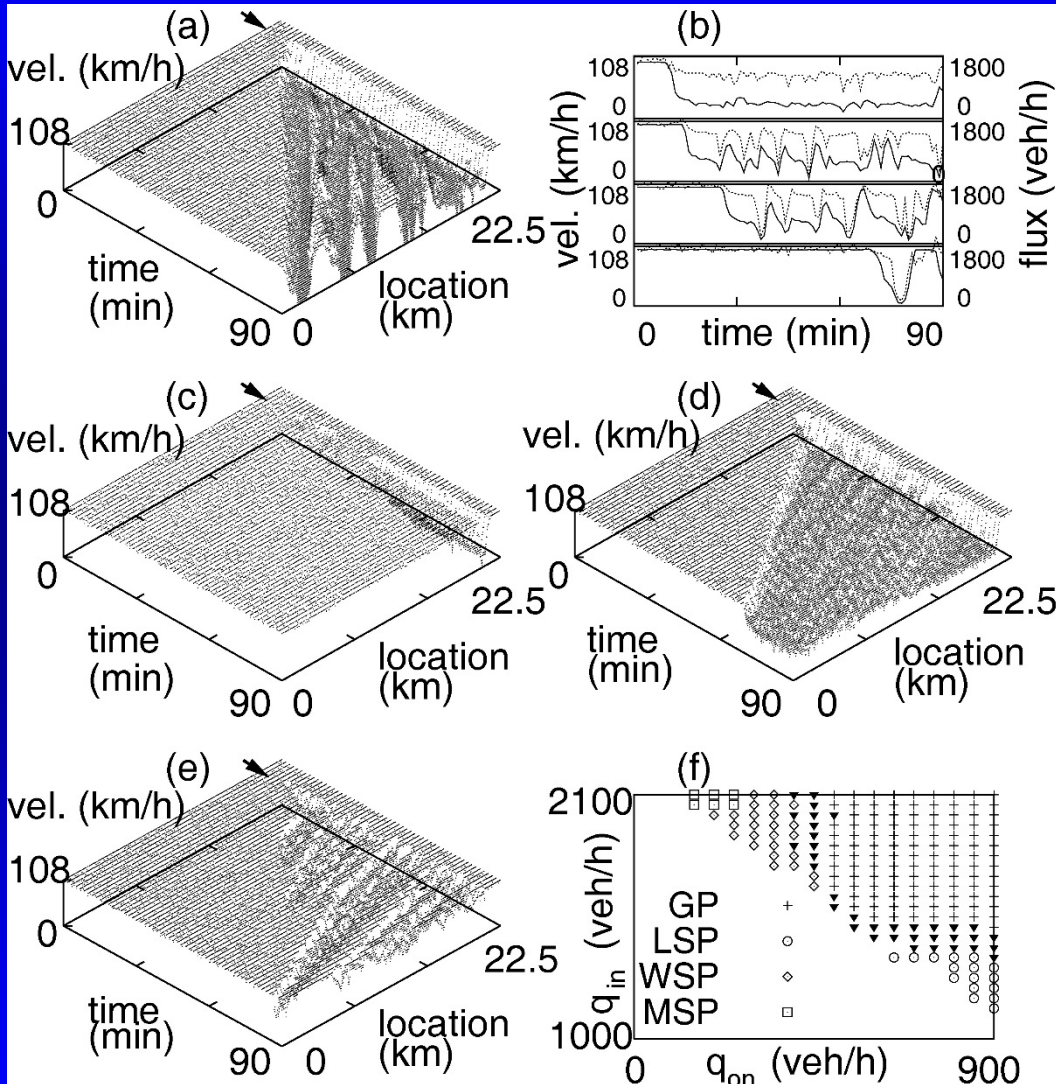
Synchronized Traffic and a Jam: Flow

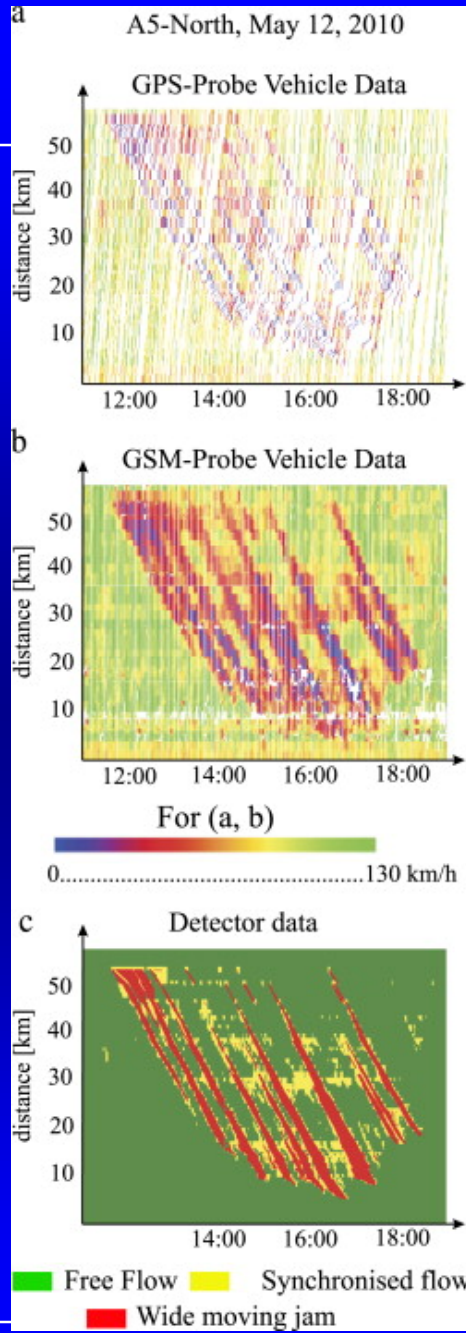


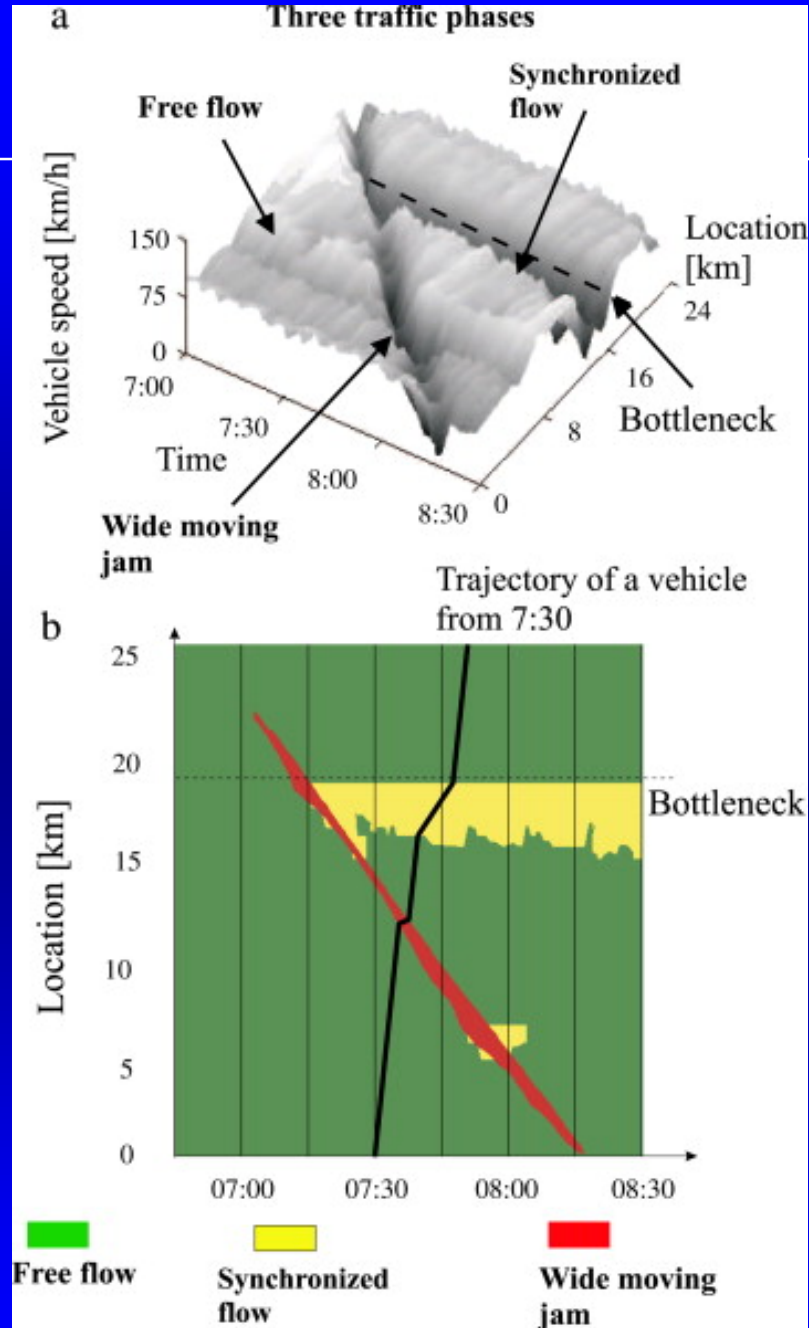
Driver-Behaviour-Modell (Lee et al)



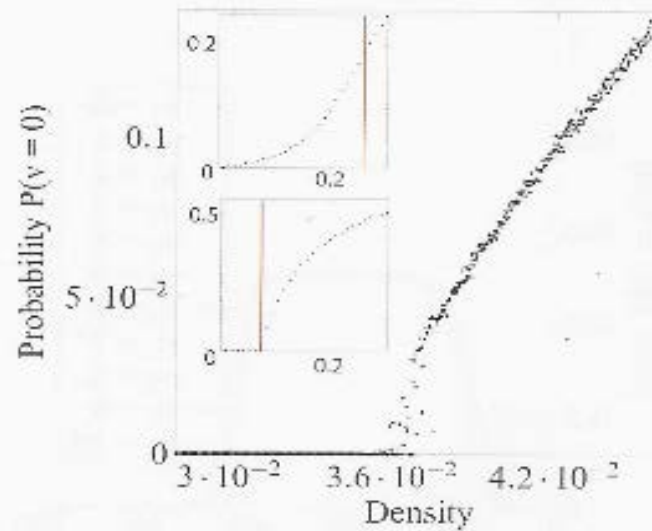
Traffic Phases







VELOCITY STATISTICS OF THE NAGEL-...

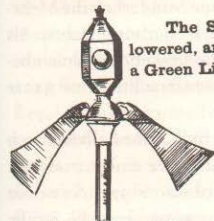


First Traffic Light

POLICE NOTICE.

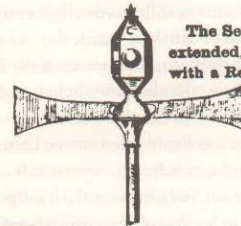
STREET CROSSING SIGNALS. BRIDGE STREET, NEW PALACE YARD.

CAUTION.



The Semaphore Arms
lowered, and by Night with
a Green Light.

STOP.



The Semaphore Arms
extended, and by Night
with a Red Light.

By the Signal "CAUTION," all persons in charge of Vehicles and Horses are warned to pass over the Crossing with care, and due regard to the safety of Foot Passengers.

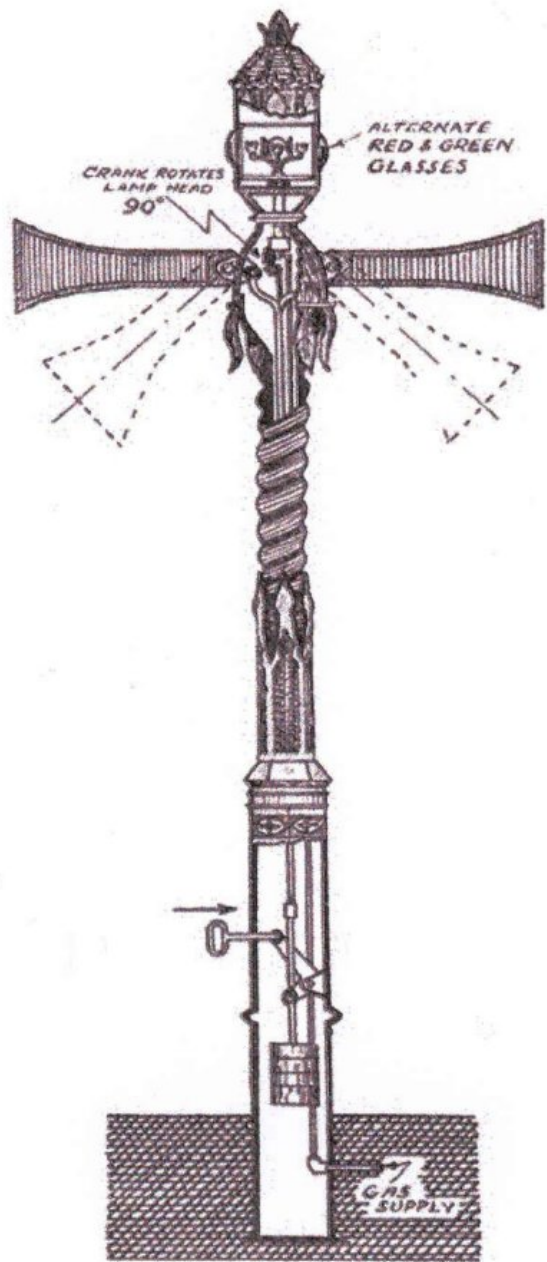
The Signal "STOP," will only be displayed when it is necessary that Vehicles and Horses shall be actually stopped on each side of the Crossing, to allow the passage of Persons on Foot; notice being thus given to all persons in charge of Vehicles and Horses to stop clear of the Crossing.

RICHARD MAYNE,

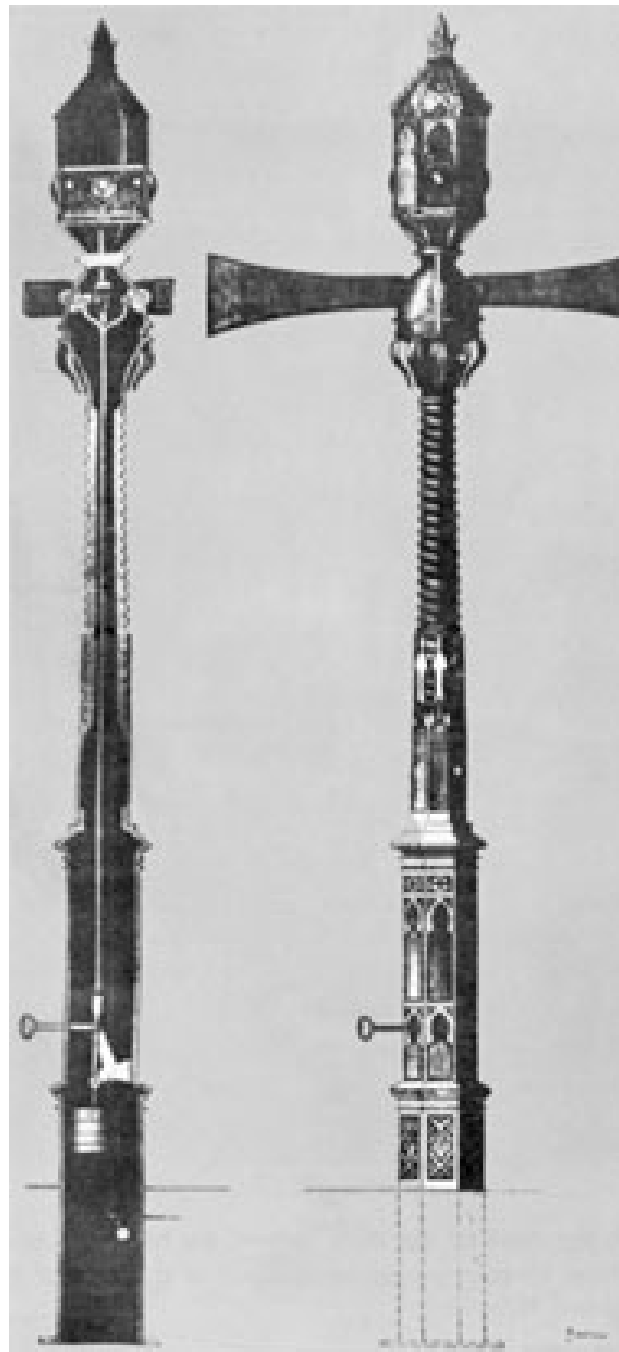
Commissioner of Police of the Metropolis.

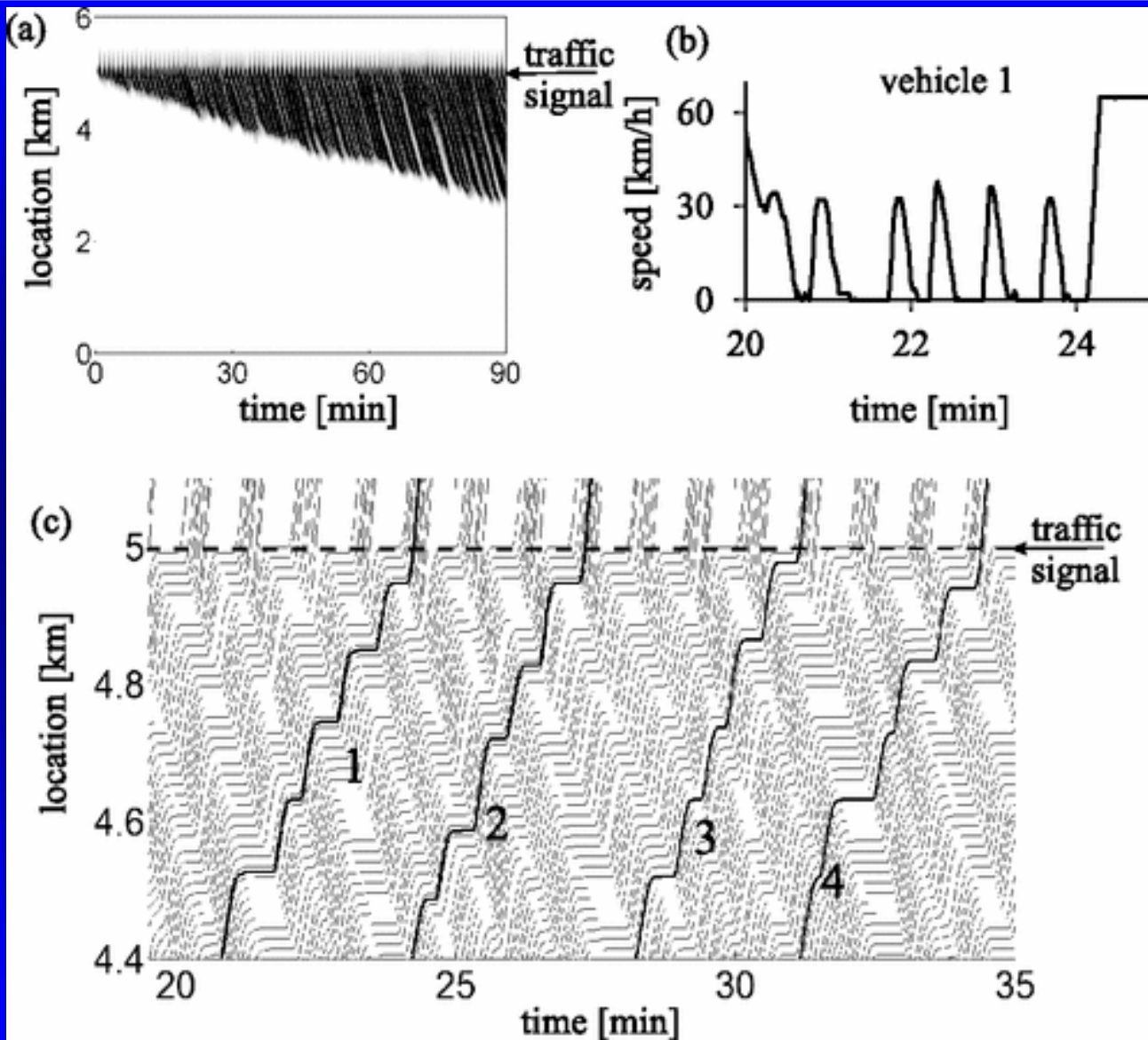
Abb. 34 Polizeilicher Hinweis zur Bedeutung der ersten Verkehrsampeln. Abdruck mit Genehmigung des Science Museum London.

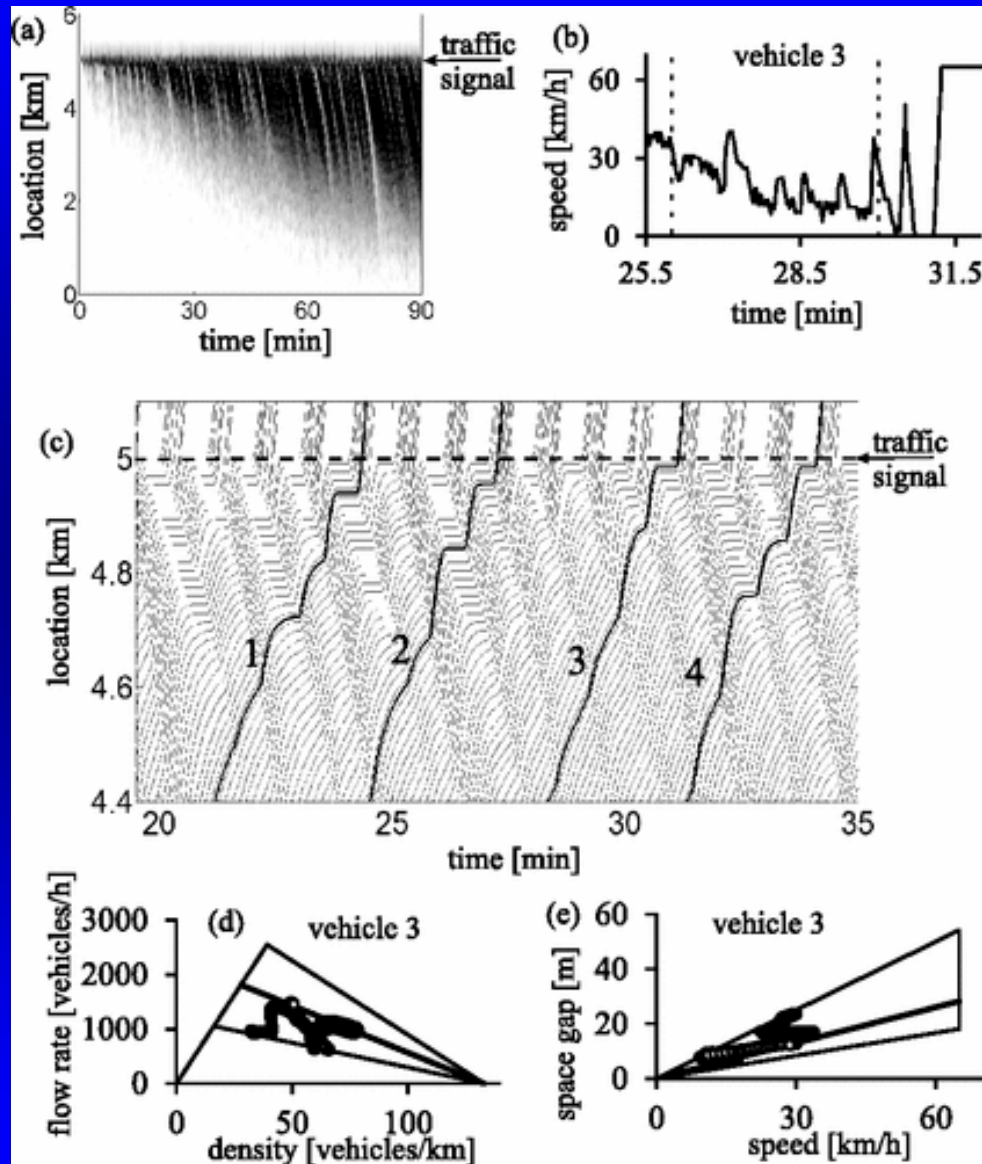


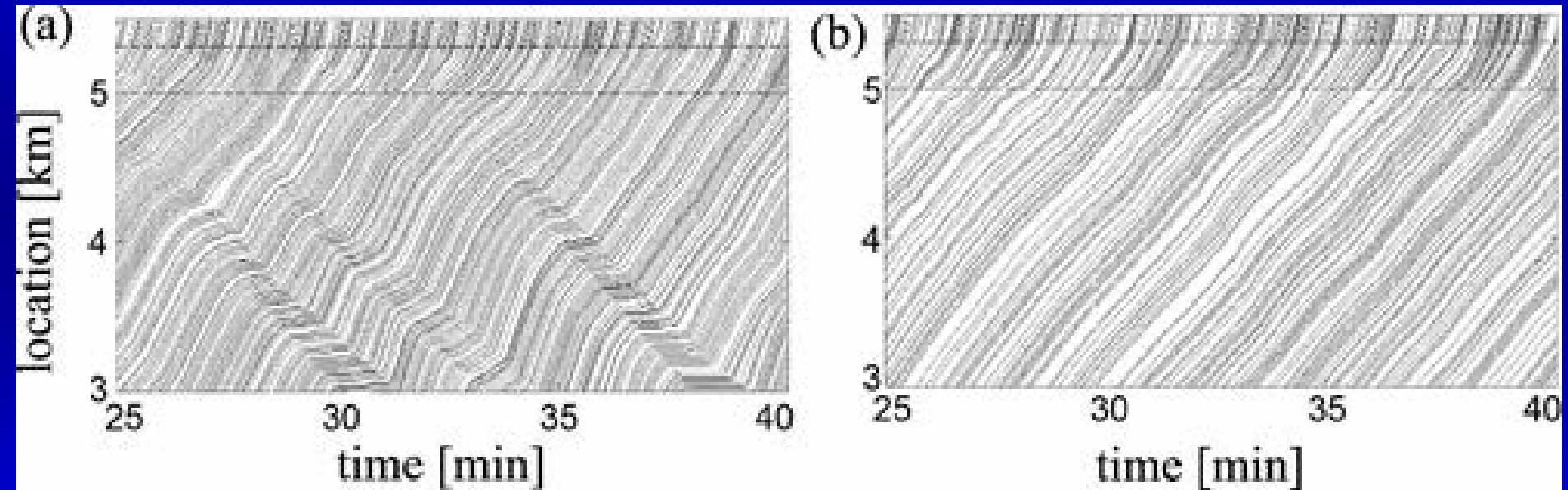


1868 london

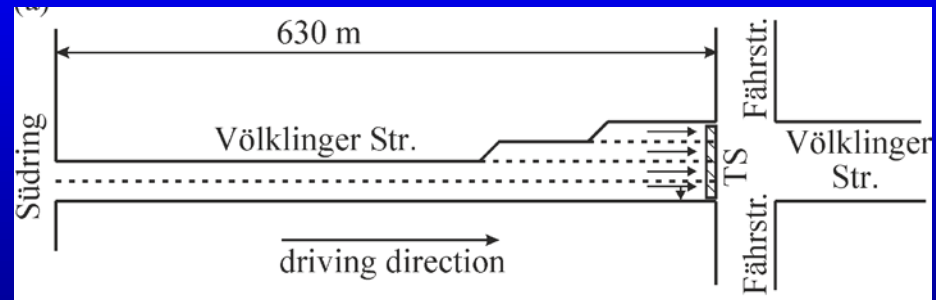
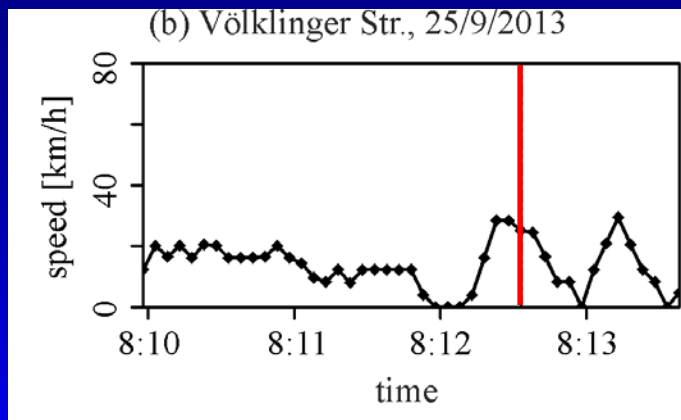
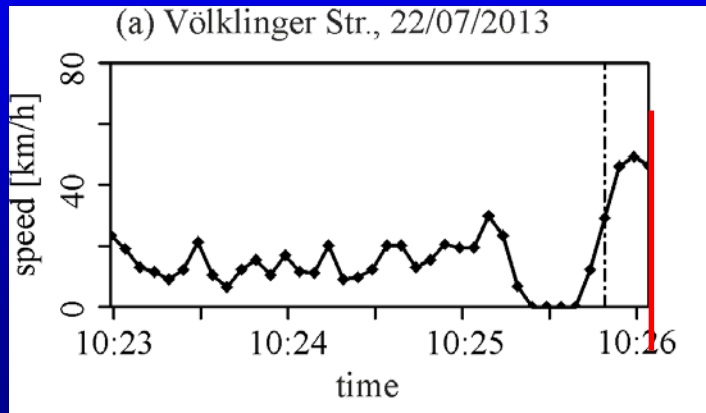








Empirical Synchronized Flow at Traffic Signal



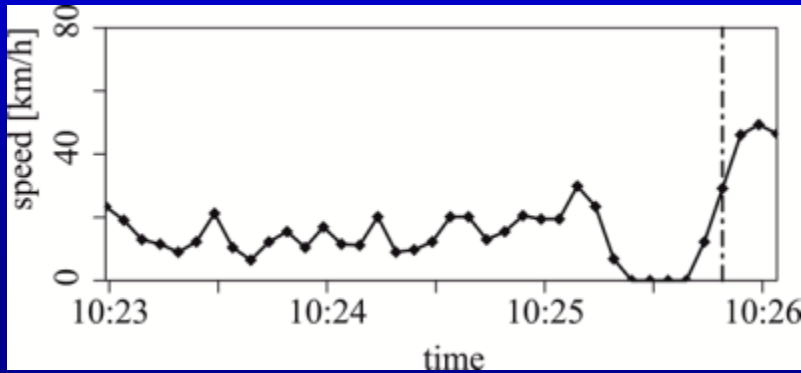
- Empirical examples:
 - TomTom single vehicle probe GPS data (anonymized)
 - 5-second data intervals
- Recently predicted by Kerner et al. [1]
- Speed is lower than in Free Flow
- Vehicles don't stop more than once in front of traffic signal

[1] B. S. Kerner, S. L. Klenov, G. Hermanns, P. Hemmerle, H. Rehborn, M. Schreckenberg: "Synchronized Flow in Oversaturated City Traffic", *Phys. Rev. E*, 88 (5), (2013).

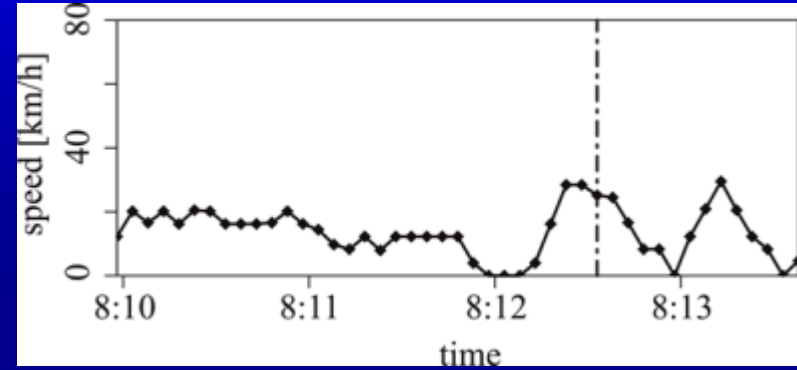
Moving Queues and Synchronized Flow

Synchronized Flow

S1 (Vöklinger Straße)

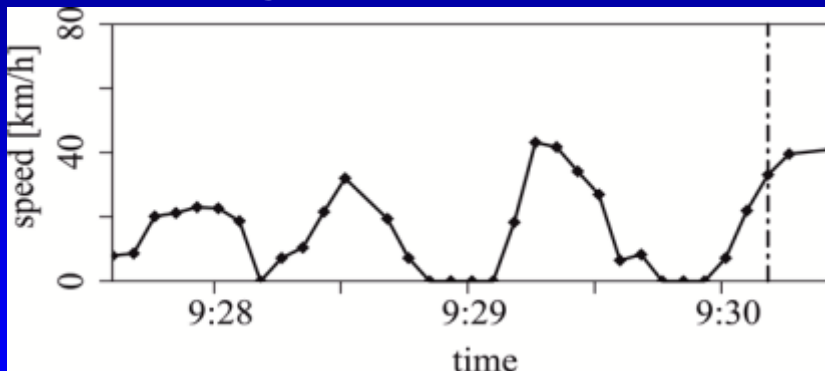


S2 (Vöklinger Straße)

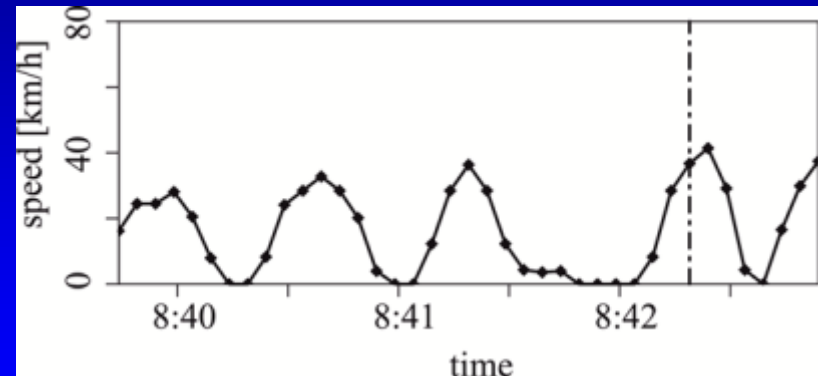


Moving queues

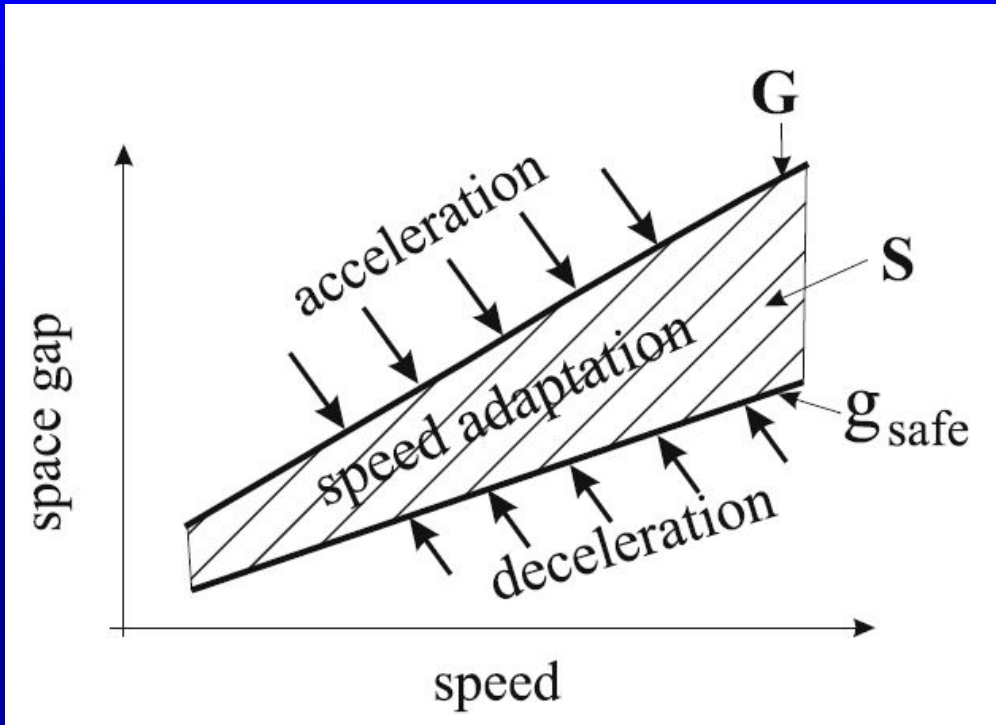
Q1 (Vöklinger Straße)



Q2 (Vöklinger Straße)



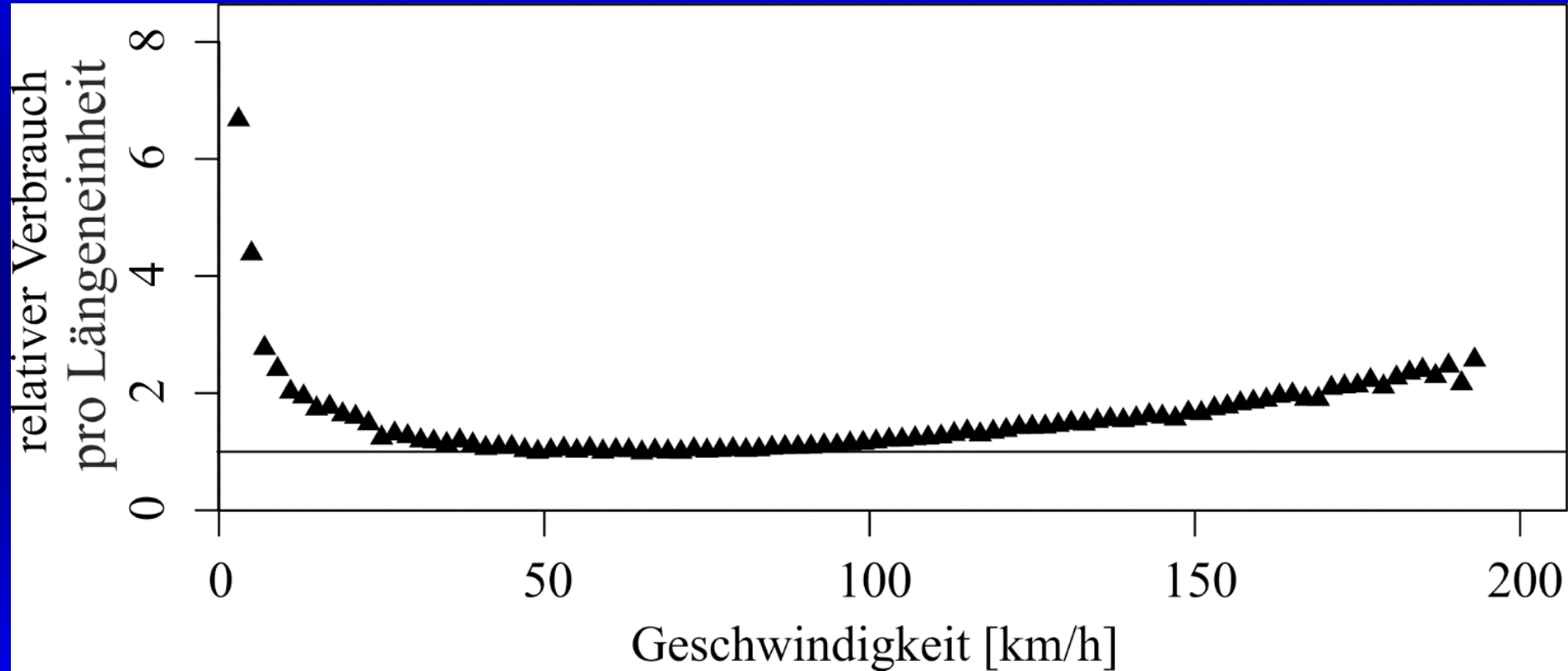
Synchronization Gap

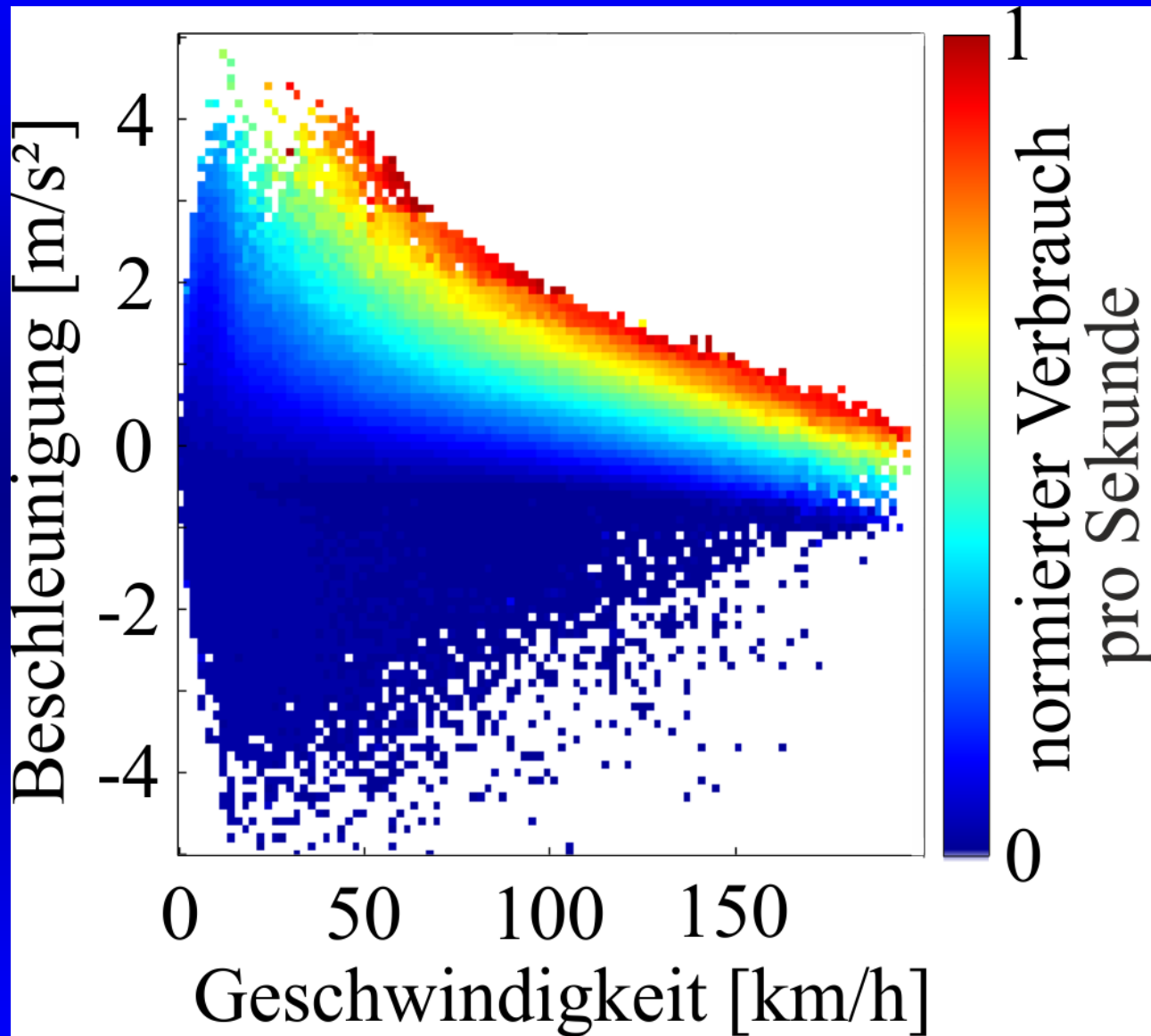


g_{safe} = safety gap
 S = states of synchronized flow
 G = synchronization gap

Synchronization Gap:

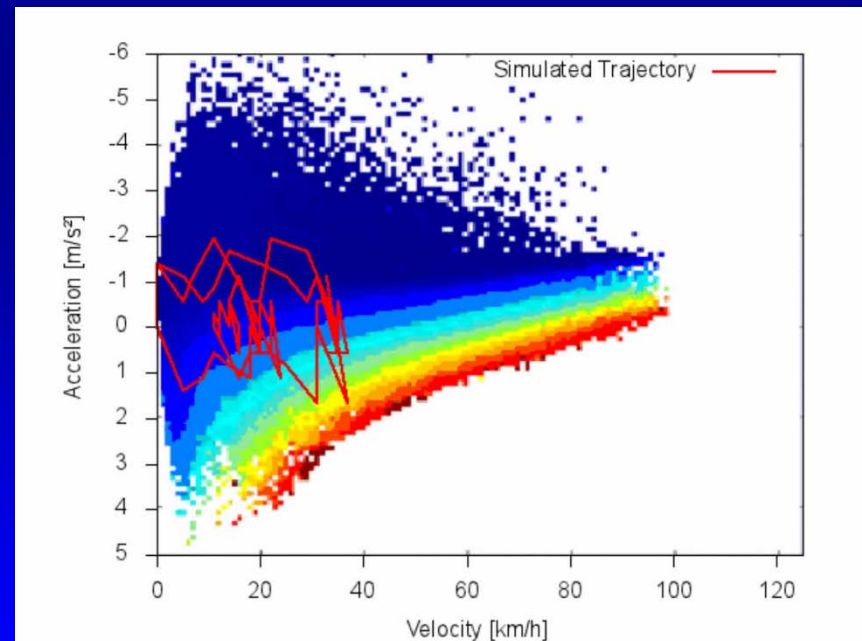
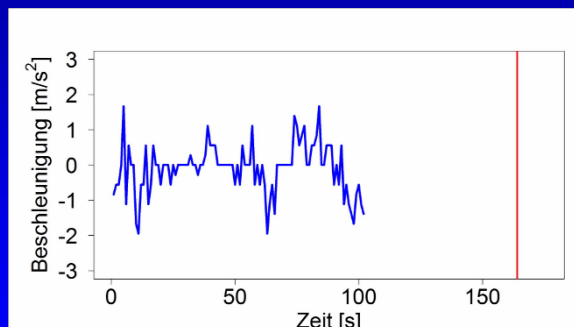
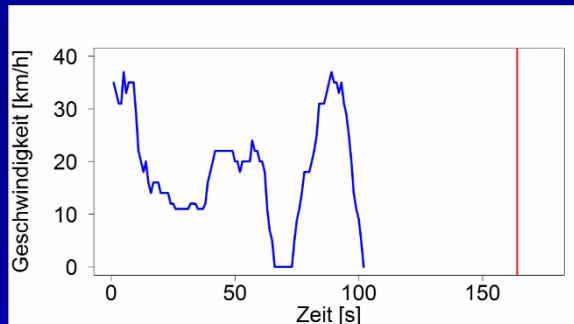
- Vehicle adapts to speed of leading vehicle
- But it can do so in an arbitrary distance within certain distance margin (“synchronization gap”)
- Competition between two effects:
 - Over-acceleration (OA)
 - Speed adaptation (SA)
- OA leads to jam dissolution
- SA leads to traffic breakdown





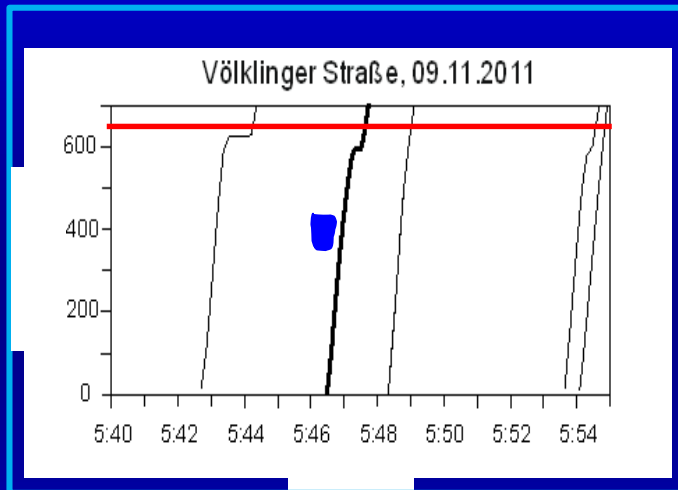
UR:BAN – Fuel Consumption Calculation

- Speed and acceleration profiles are taken from simulations.
- These profiles are simulated for characteristic traffic situations for each road section separately.
- Together with an empirical fuel consumption matrix the additional consumption factors can be calculated.
- The additional consumption factors per road section are input for energy efficient routing strategies.

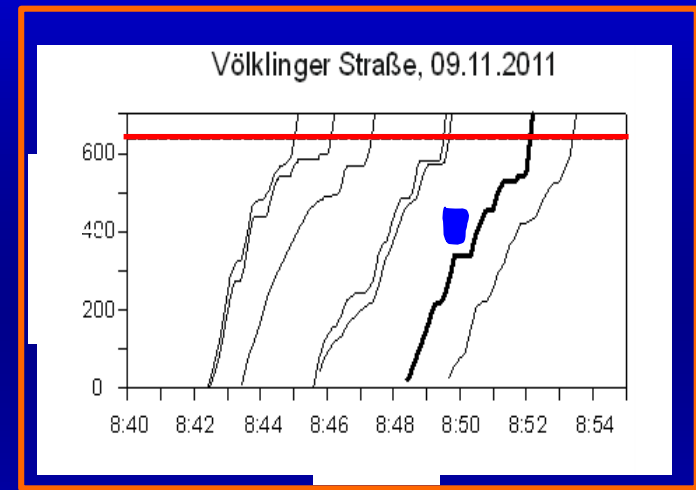


Patterns of City Traffic

Undersaturated



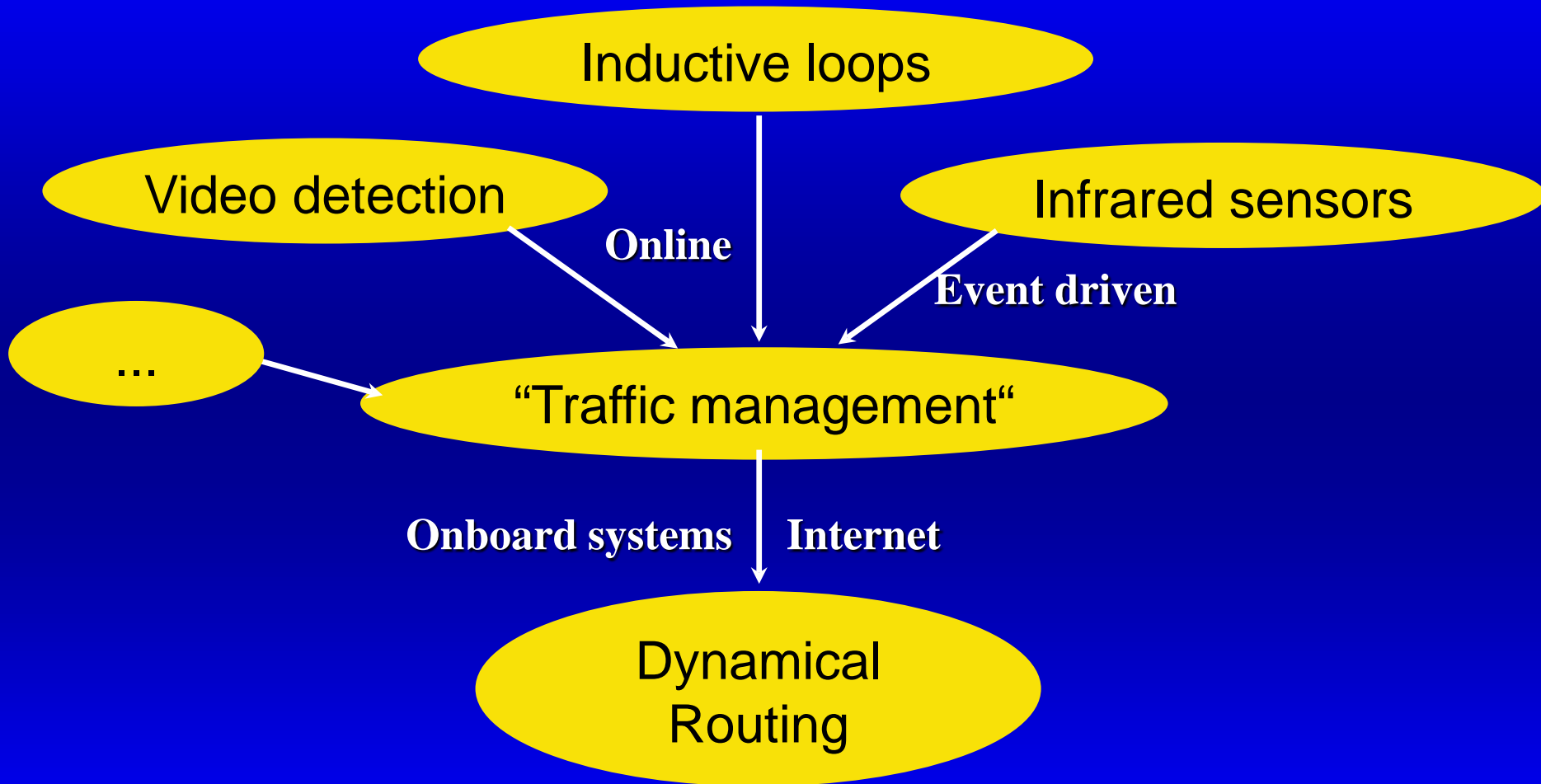
Oversaturated



■ Oversaturated city traffic:

- Not all vehicles of the queue can pass during the next green phase
- Vehicles stop more than once

Informations in Transport Systems

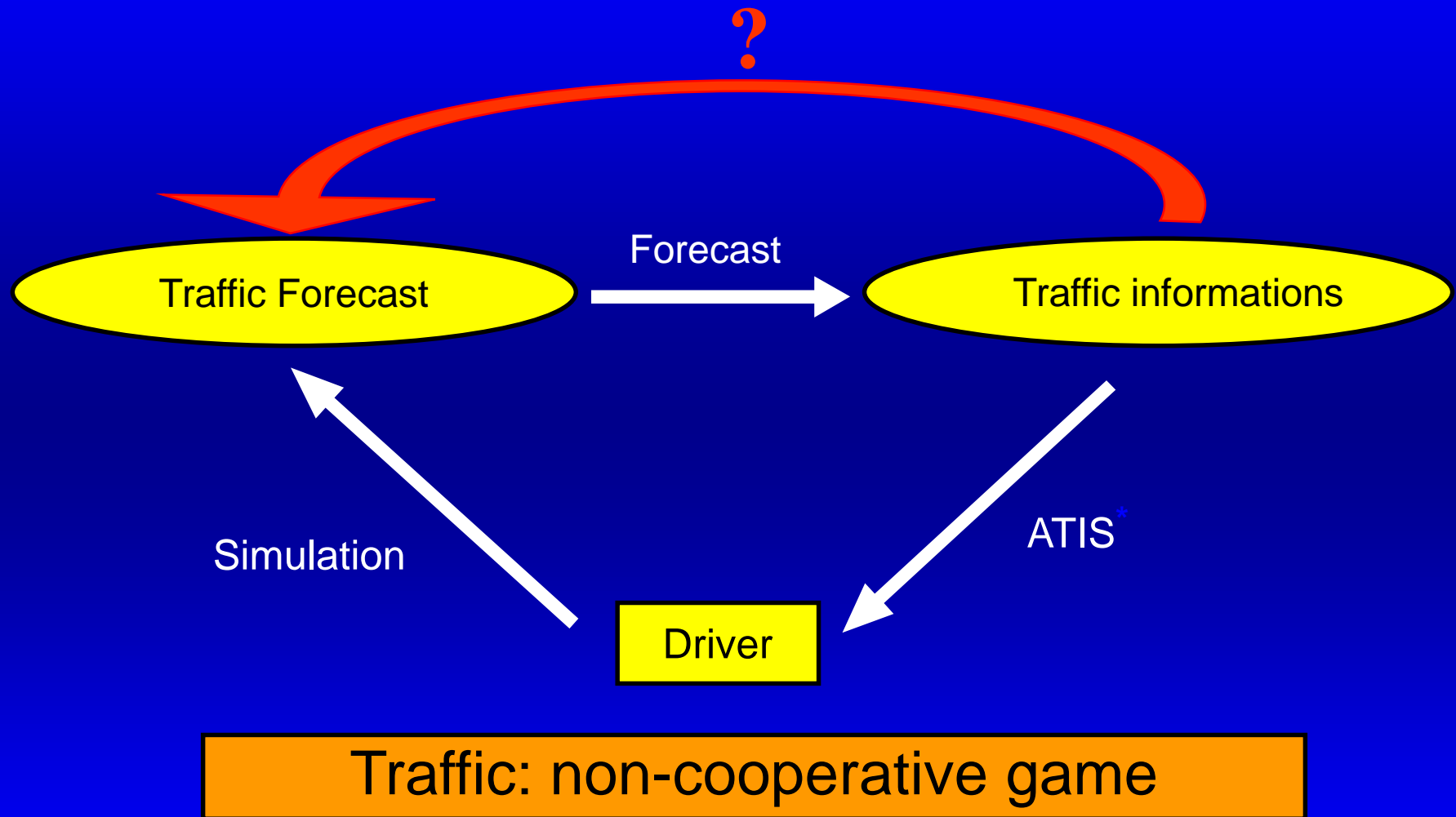


Traffic Informations / Navigation

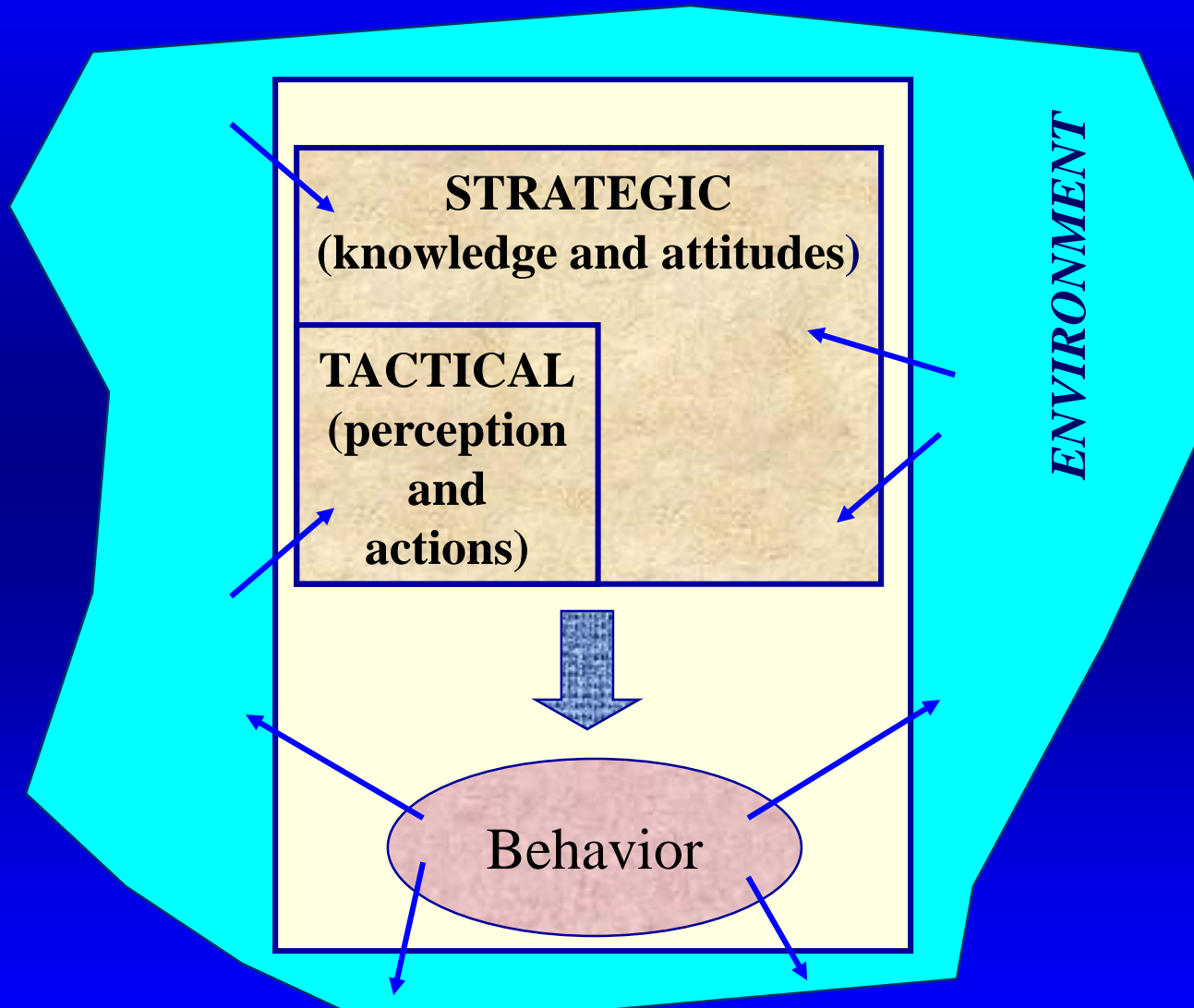
- ❑ Static navigation / maps
- ❑ Dynamic navigation (RDS-TMC/Private)
- ❑ Pre-trip: Internet / TV
- ❑ On-trip: radio / mobile phone / Internet / digital TV / information panels
- ❑ Post-trip: Internet



Anticipatory Traffic Forecast



Multi-Agent Model

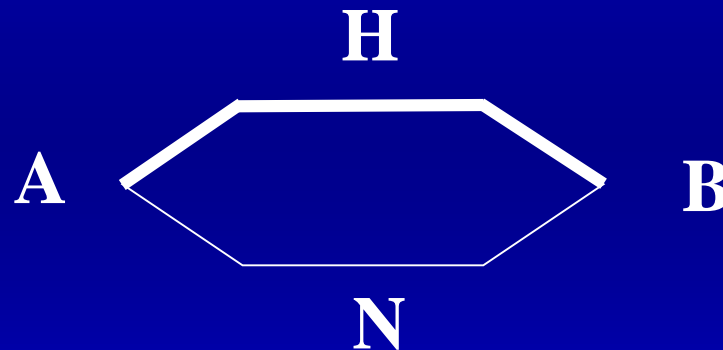


Day-to-Day Route Choice-Behaviour

Experimental design

Trip from **A** to **B**

Two routs **H** and **N** (**H** main, **N** side route)



Each of the 18 participants chooses in every round the main route **H** or the side route **N**.

Play it for 200 rounds.



Experiments



Quelle: <http://www.elfe.wiwi.uni-due.de/>

**Mutual influence
of driver decision**



Teilnehmer auf der Mautstrecke:	0
Teilnehmer auf der Strecke ohne Maut:	4

Sie haben die Strecke ohne Maut gewählt.

Wollen Sie diese Wahl beibehalten?

Ergebnisse der letzten Runden	
Kosten	Teilnehmer auf Strecke ohne Maut
20	2



Day-to-Day Route Choice-Behaviour

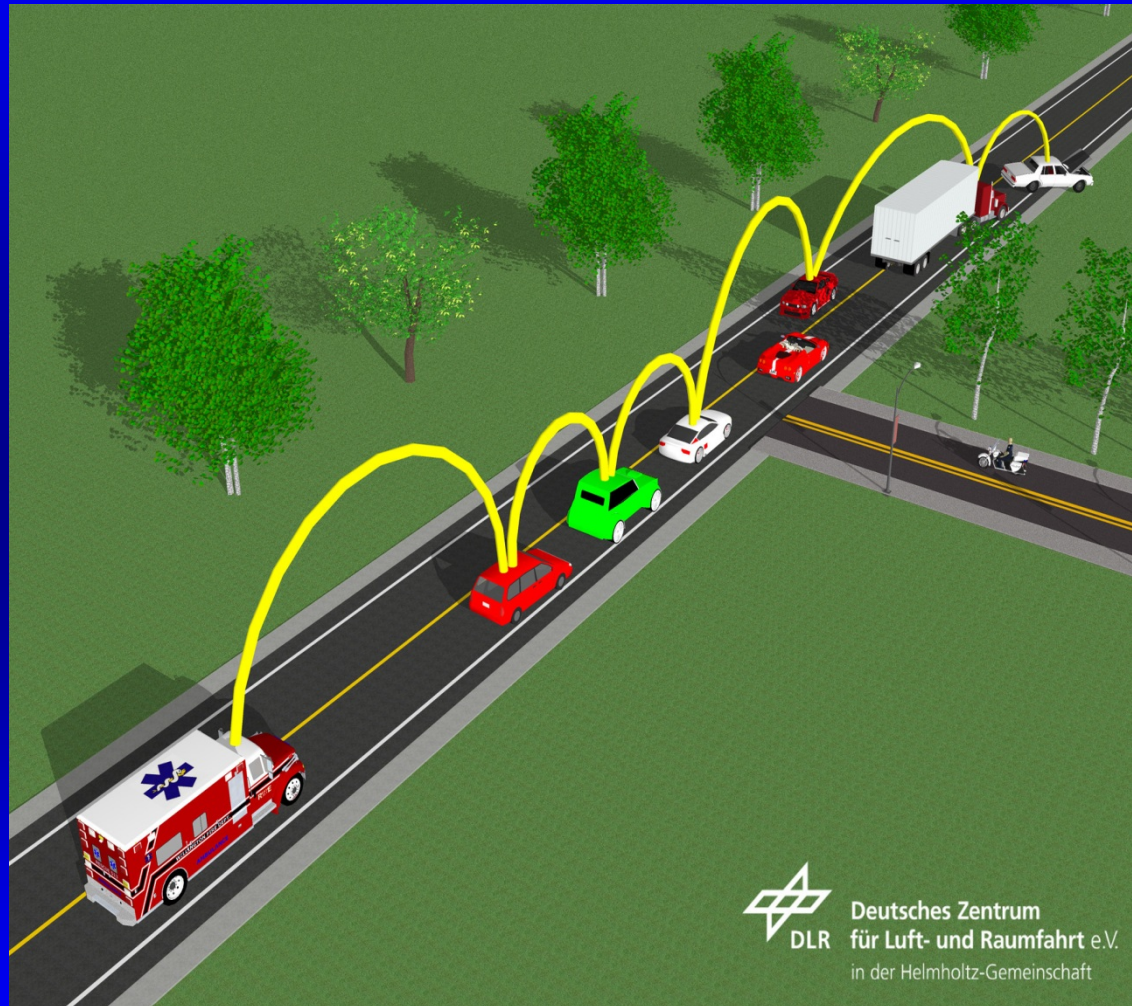
Results

- 1. Mean number of players on main and side route is near to the equilibrium.*
- 2. Fluctuations remain in both experiments up to the end.*
- 3. Fluktuations are significantly lower in experiment II .*
- 4. The total number of route changes ist significantly larger in experiment I.*
- 5. Three typs can be classified: direct ("sensible“, 44%), contrarian ("tactical“, 14%) und conservative ("not sensible“, 40,5% und "stoical“, 1,5%).*
- 6. The number of route changes and the payments are in all in all experiments negatively correleted.*



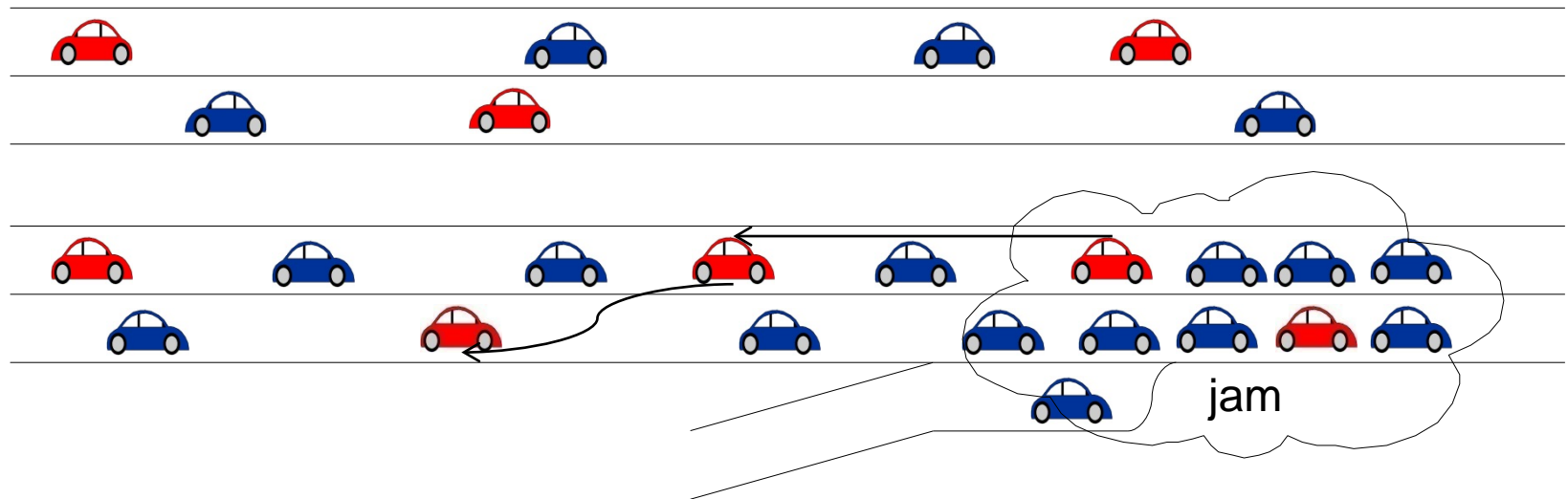


Communication car2car

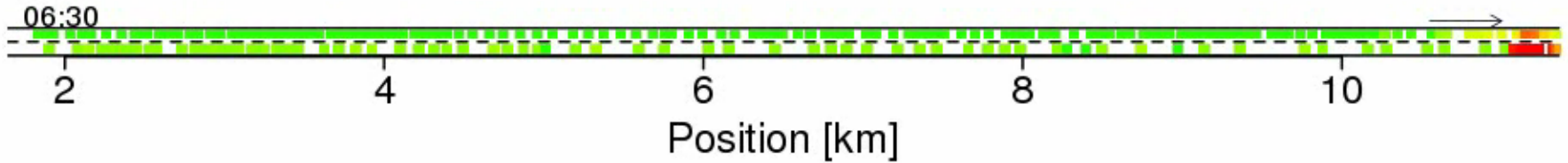


Communication avoids congestion

Idea: cloud of communicating vehicles



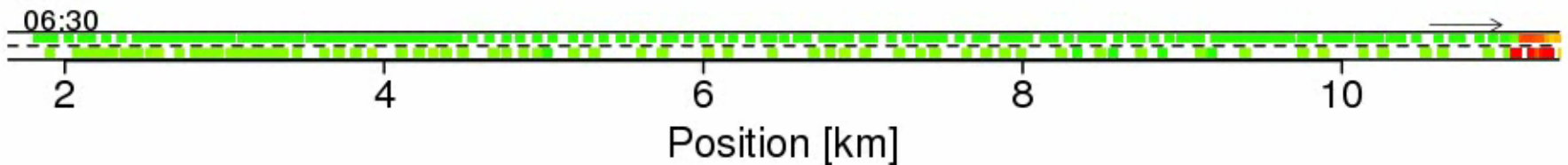
Congestion near on-ramps



0 %



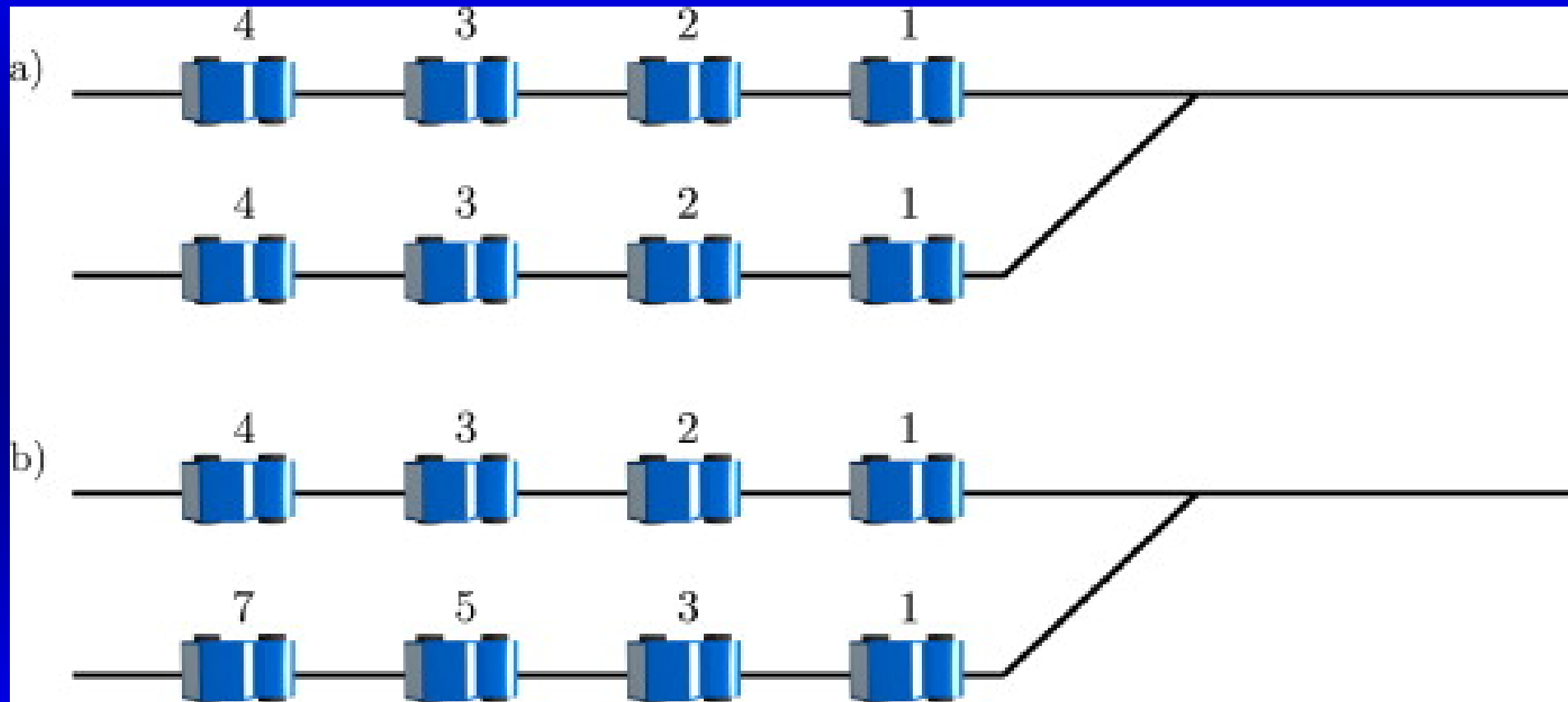
15 %



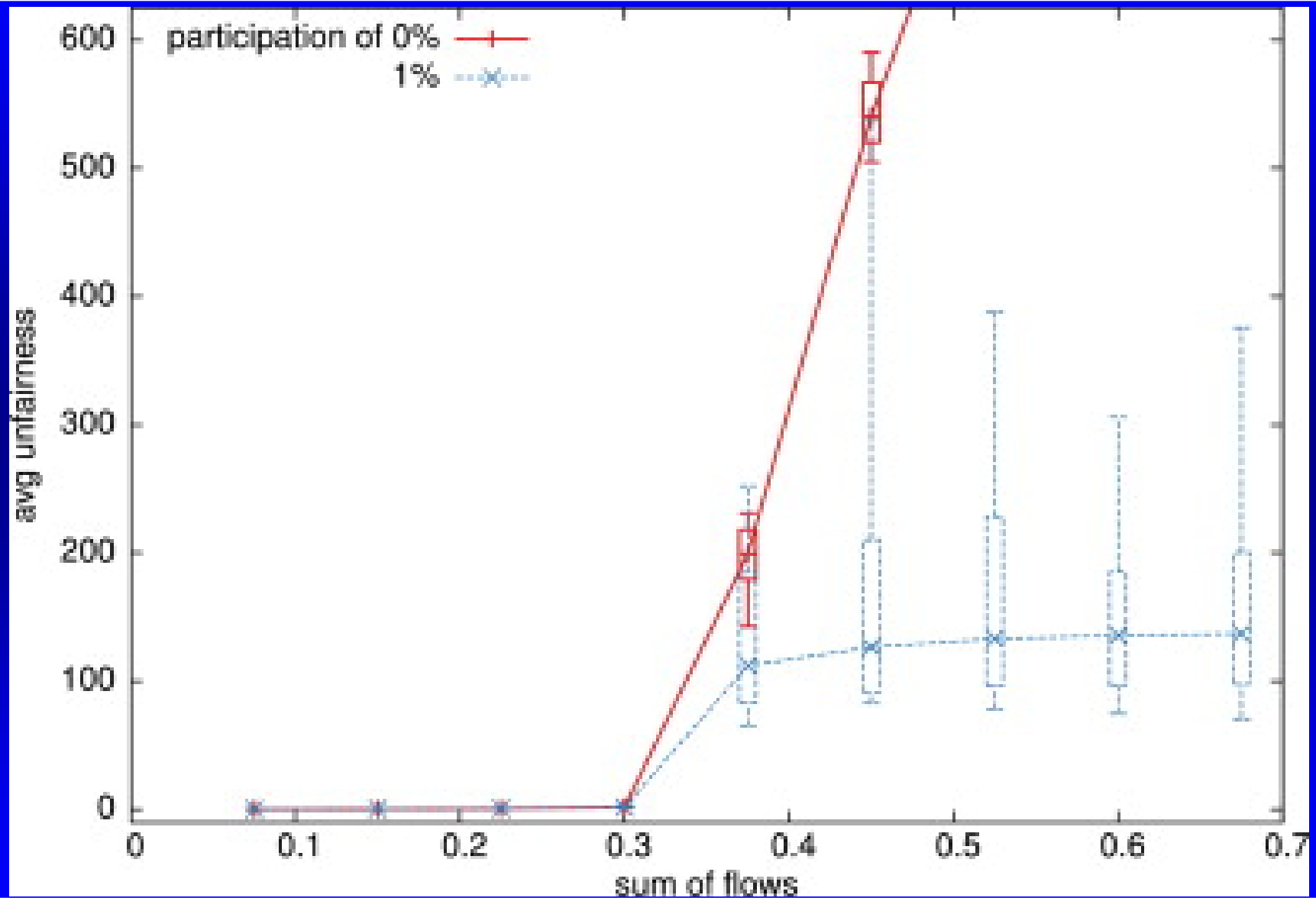
40 %



Zip process



Zip process



Parking

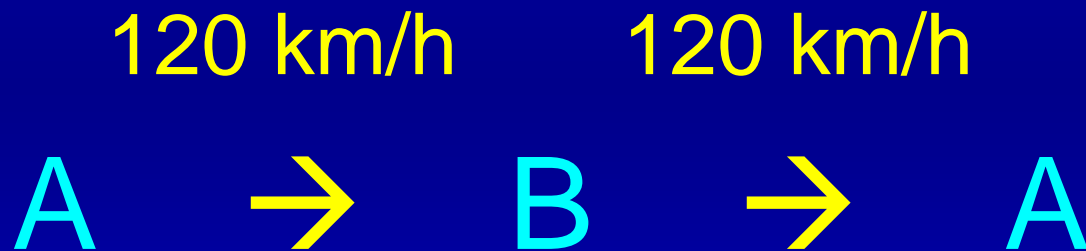
- 30% of the traffic in larger cities due to park space search traffic
- Automatic detection of free space.
- Only 5-10% of the cars have to be equipped
- Efficient analysis of unclear data
- Statistical analysis of parking behavior
- Common format necessary



Risk: time

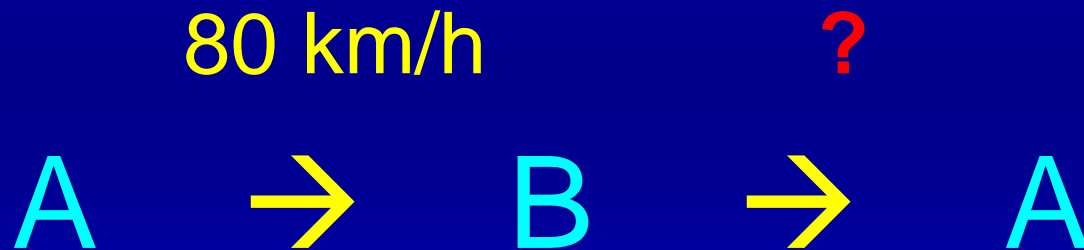
Example:

From A to B and back. Plan: 120 km/h



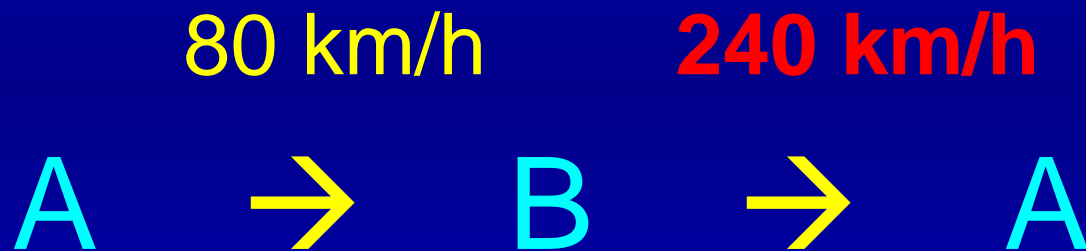
Risk: time

But: due to high load only



Risk: time

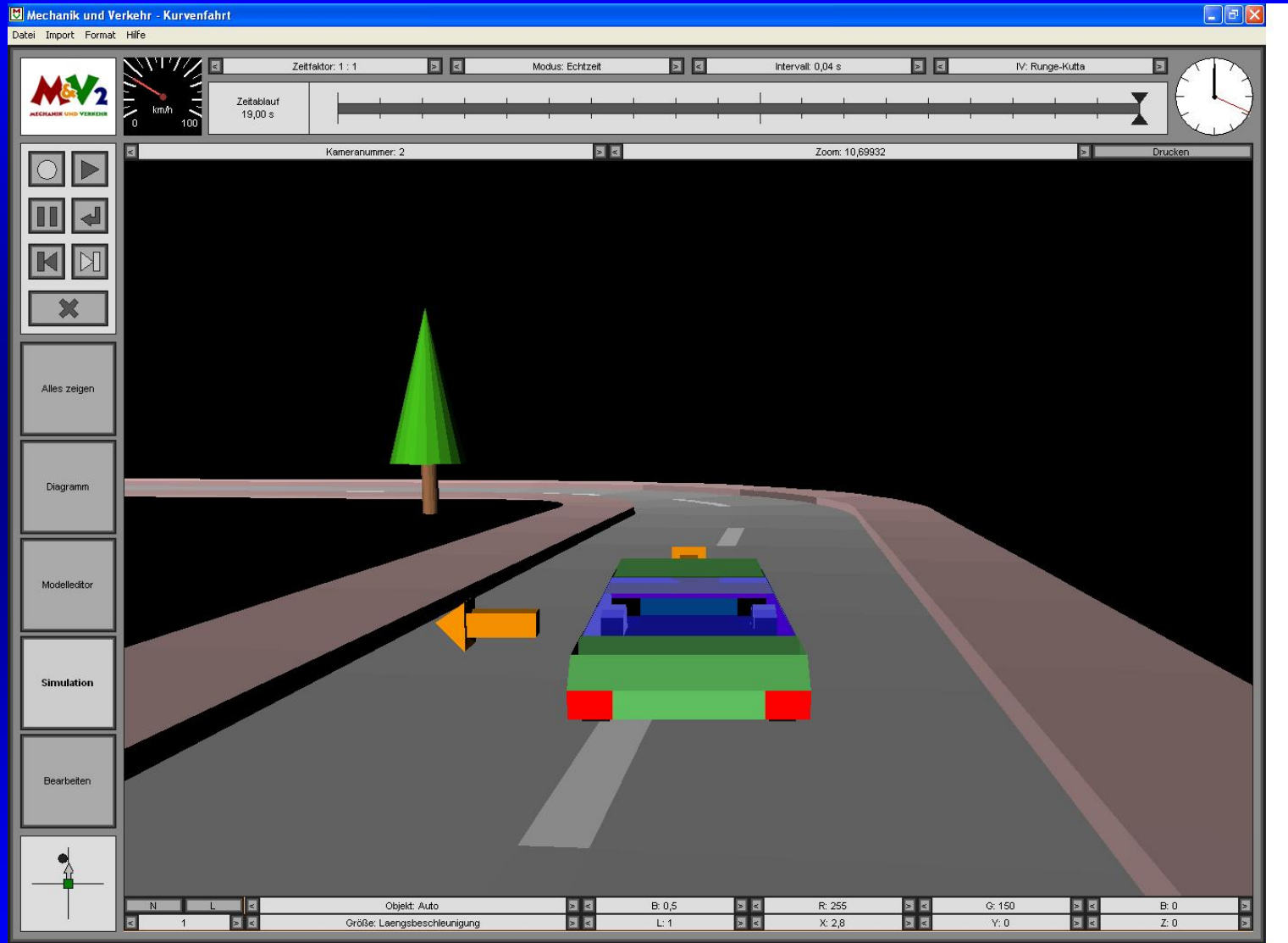
For the same total time:



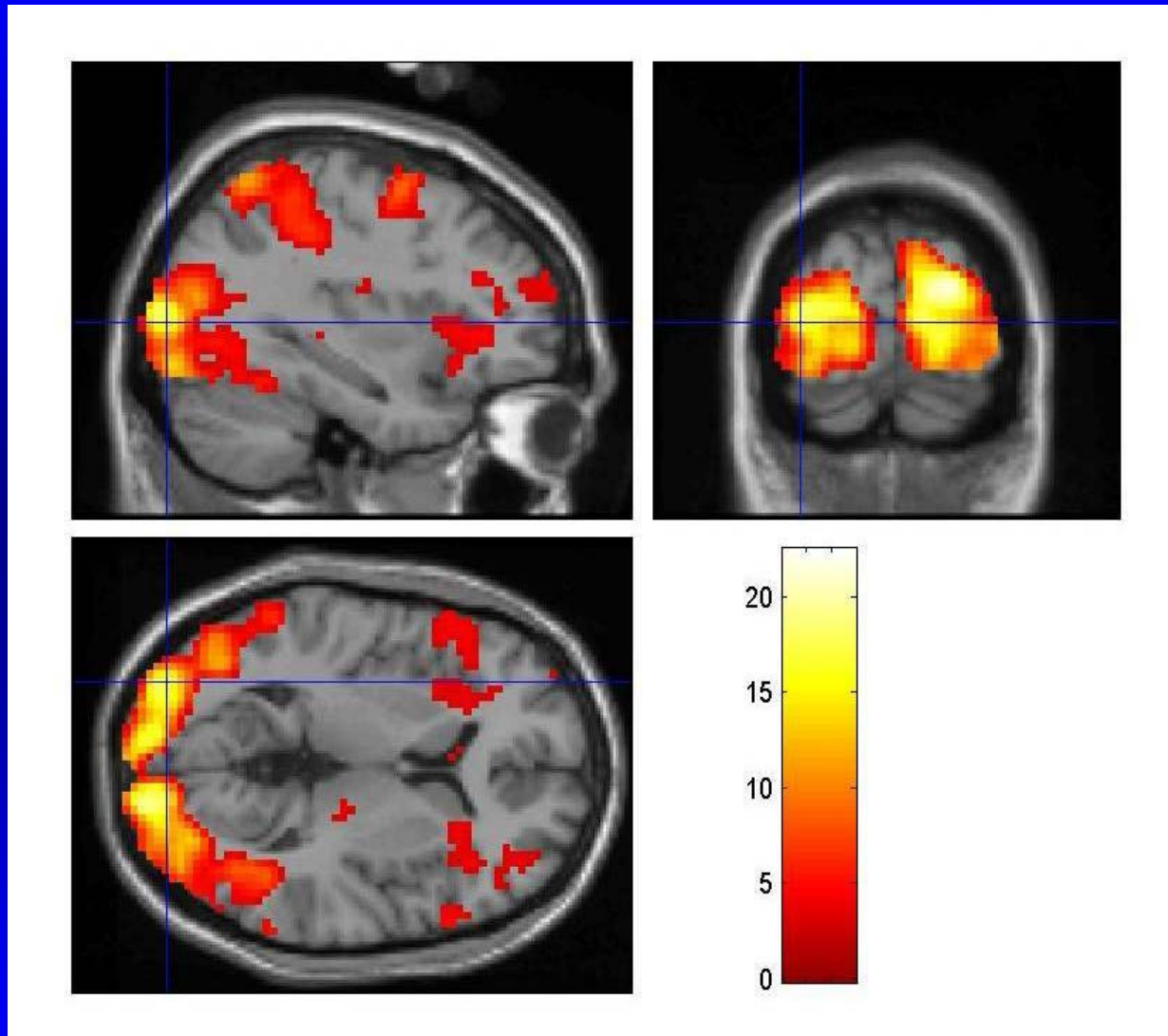
fMRI



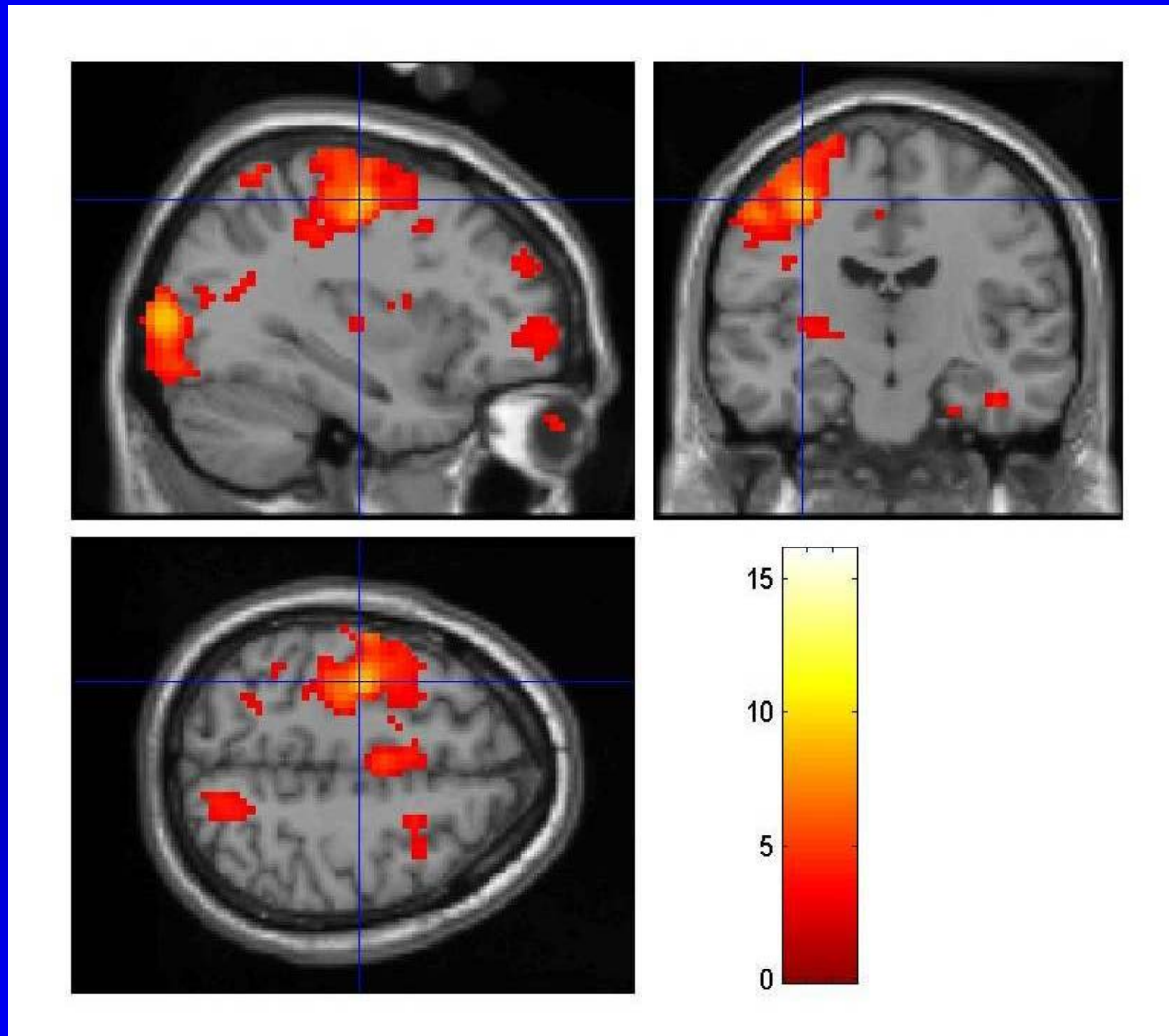
Simulation



Looking



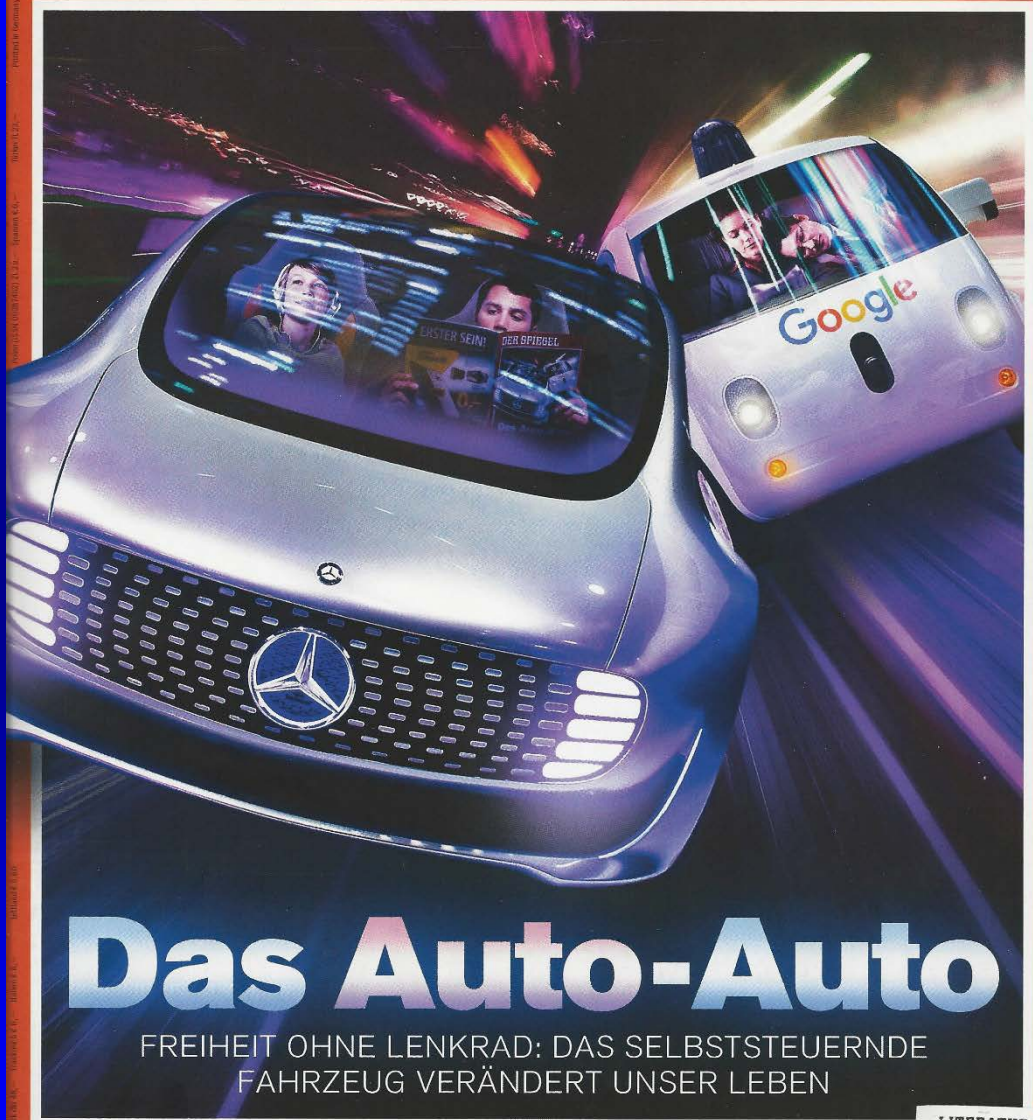
Driving











Das Auto-Auto

FREIHEIT OHNE LENKRAD: DAS SELBSTSTEUERENDE
FAHRZEUG VERÄNDERT UNSER LEBEN

Horst Seehofer
„Es geht um politische
Lebenswerke“

Handwerker
Deutschland: Paradies
für Schwarzarbeiter

LITERATUR SPIEGEL
Volker Weidemann über
die Bücher des Frühlings

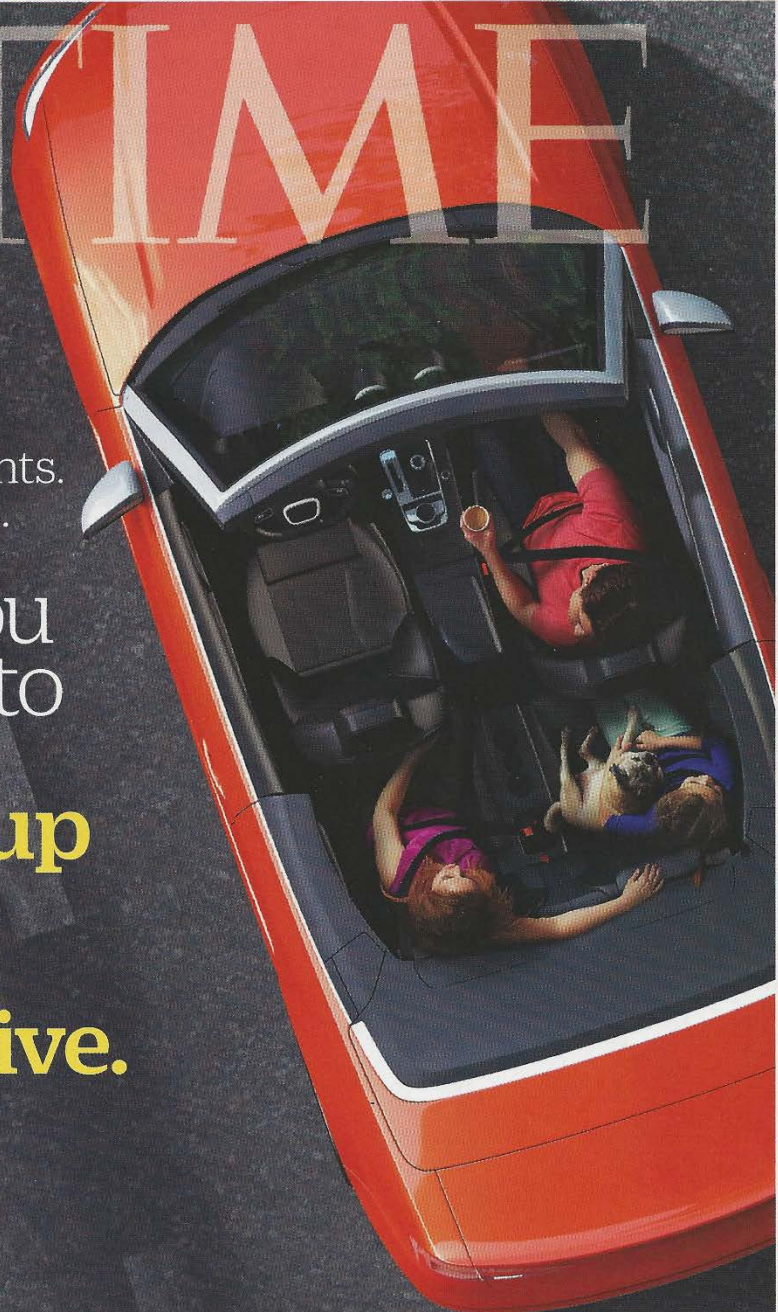


TIME

No traffic.
No accidents.
No deaths.

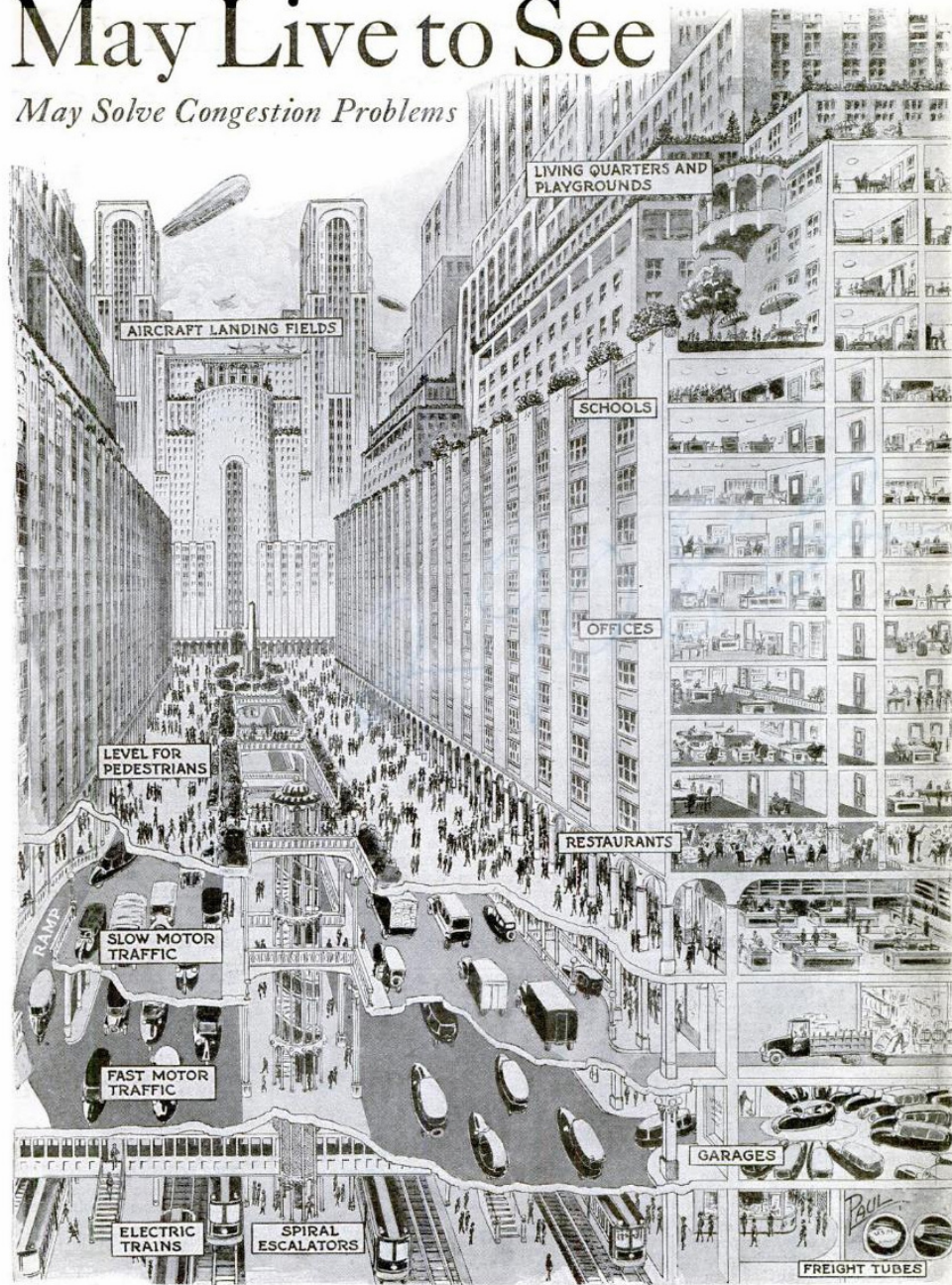
All you
have to
do is
**give up
your
right
to drive.**

By Matt Vella



May Live to See

May Solve Congestion Problems



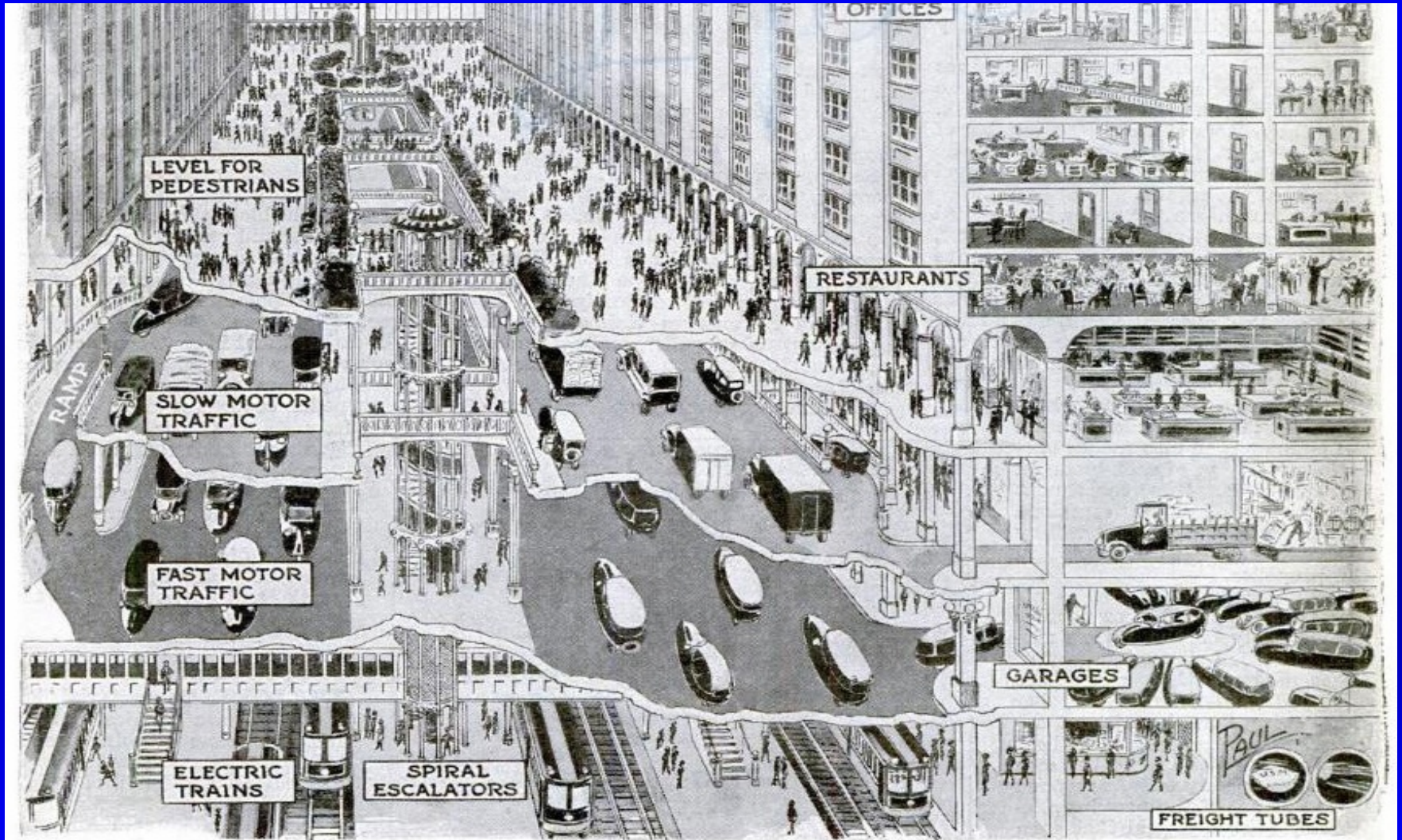
How You May Live and Travel in the City of 1950

Future city streets, says Mr. Corbett, will be in four levels: The top level for pedestrians; the next lower level for slow motor traffic; the next for fast motor traffic, and the lowest for electric trains. Great

blocks of terraced skyscrapers half a mile high will house offices, schools, homes, and playgrounds in successive levels, while the roofs will be aircraft landing-fields, according to the architect's plan



History of the future of mobility



How You May Live and Travel in the City of 1950



Aeromobil



Terrafugia TF-X



PAL-V



Internet

<http://www.ptt.uni-due.de>



Crisis in Switzerland



