Congestion under Investigation

Dr. Sven Maerivoet

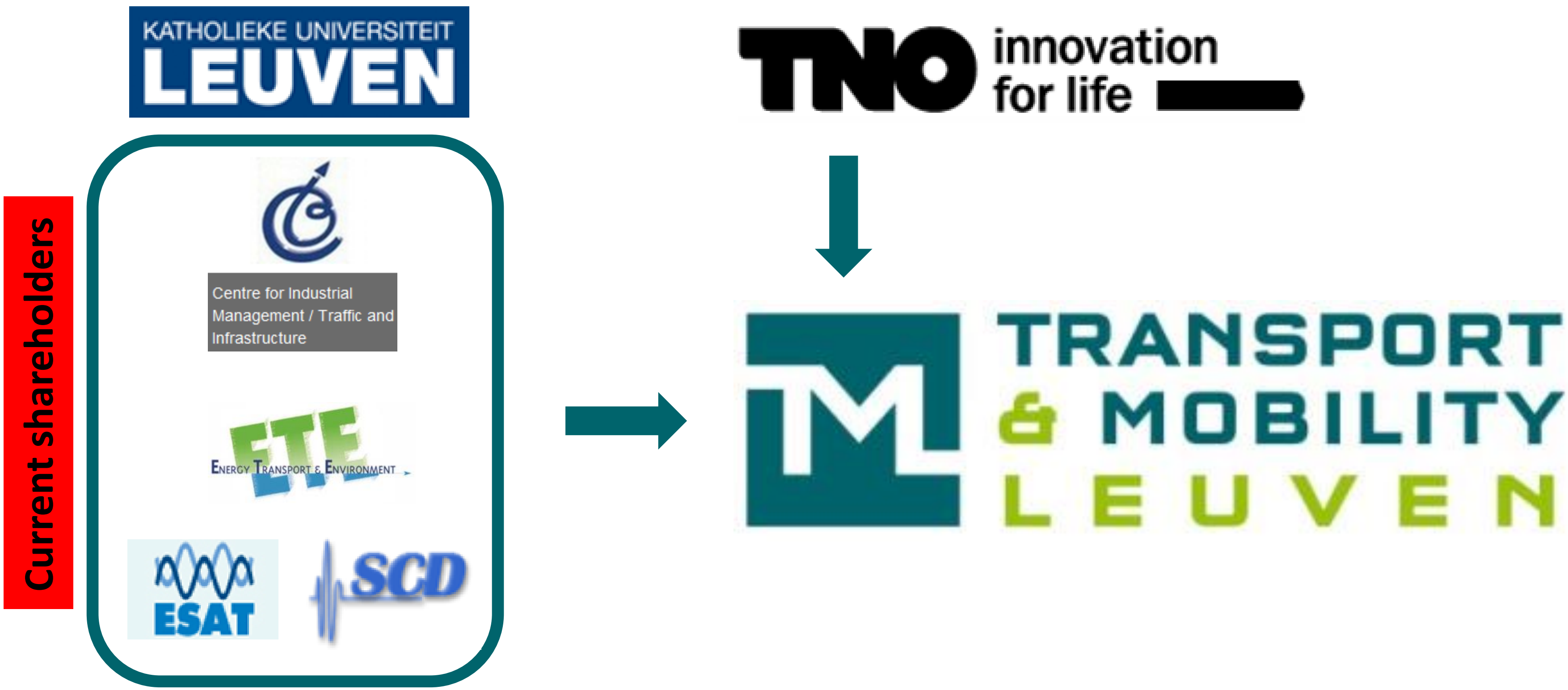
TRANSPORT & MOBILITY LEUVEN

Overview

- **Introducing Transport & Mobility Leuven (TML)**
- Traffic Flow Theory
- Traffic Management
- Traffic Data and TML Case Studies
- Extra: Traffic Cellular Automata

Background of the company

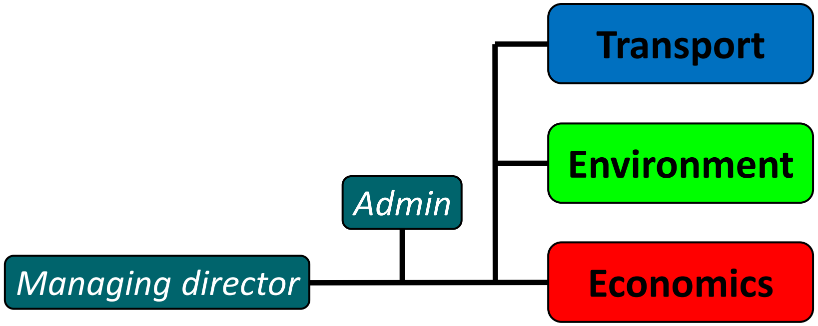
- Founded in 2002 as a spin-off company (NV):
  - Catholic University of Leuven
  - TNO research institute (The Netherlands)



Our team

The people at TML

- **Multidisciplinary** team (36 persons):
  - Transport, bio-, chemical, and environmental engineering
  - Economy
  - Computer science
  - Psychology



- **Areas of expertise:**
  - Transport economics (incl. **impact assessments**, SCBAs, …)
  - Traffic flow theory (incl. (C-)ITS measures, congestion estimates)
  - Transport analyses (private road, rail, public transport, IWW, air, …)
  - Environment, public health, …
  - Traffic safety (incl. legislation, infrastructure, veh. technology, …)
  - Spatial economics (incl. regional development)
  - Automated vehicles, Large/Big/Ubiquitous (open) data, MaaS, …

Overview of our activities

- TML conducts **research** and **studies**.
  - Strongly **quantitative** (prediction models, simulation techniques, ...)
  - Policy support (we can influence policy)
  - **Integration** of mobility, environment, and economics
  - Combining both fundamental and applied research by linking theoretical findings with practical knowledge
  - Bridge between university and society
  - Independent and **open** policy

- City and regional policies, Belgium (federal, Flanders, and Brussels), and Europe (EC, DGs, H2020, HEurope)

"Our mission is to help society
by offering scientifically sound advice"

Versatile, accurate, correct, and open

- Almost all our studies can be found online!

  https://www.tmleuven.be/

- Newsletter:

- Our relations:
  - Telematics Cluster/ITS Belgium: member + Board of Directors + Former Chair of the Belgian MaaS Alliance.
  - Former 'Vlaams Instituut voor Mobiliteit' (VIM): member + expert in advisory council
  - Active member of the Vlaamse Stichting Verkeerskunde (VSV)
  - The International Association for the History of Transport, Traffic and Mobility: member
  - Horizon 2020 / Horizon Europe / (C)INEA: external experts

TML is regularly featured in the press

- Het Nieuwsblad, De Morgen, De Standaard, Het Laatste Nieuws, Knack, Jobat, Le Soir, La Meuse, De Lloyd, Verkeersspecialist, Vacature Magazine, Ademloos, Het Belang van Limburg, Mobimix, De Zondagskrant, De Streekkrant, Verkeersnet.nl, …

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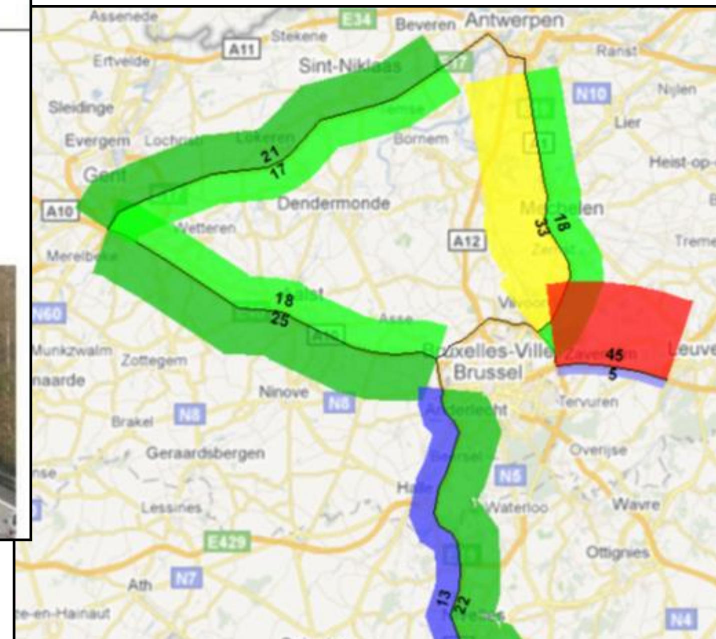
How large is the congestion problem?

HET NIEUWSBLAD DINSDAG 21 APRIL 2015

Files kosten ons elke dag minstens 600.000 euro

Maar hoe langer de files, hoe beter het gaat met onze economie

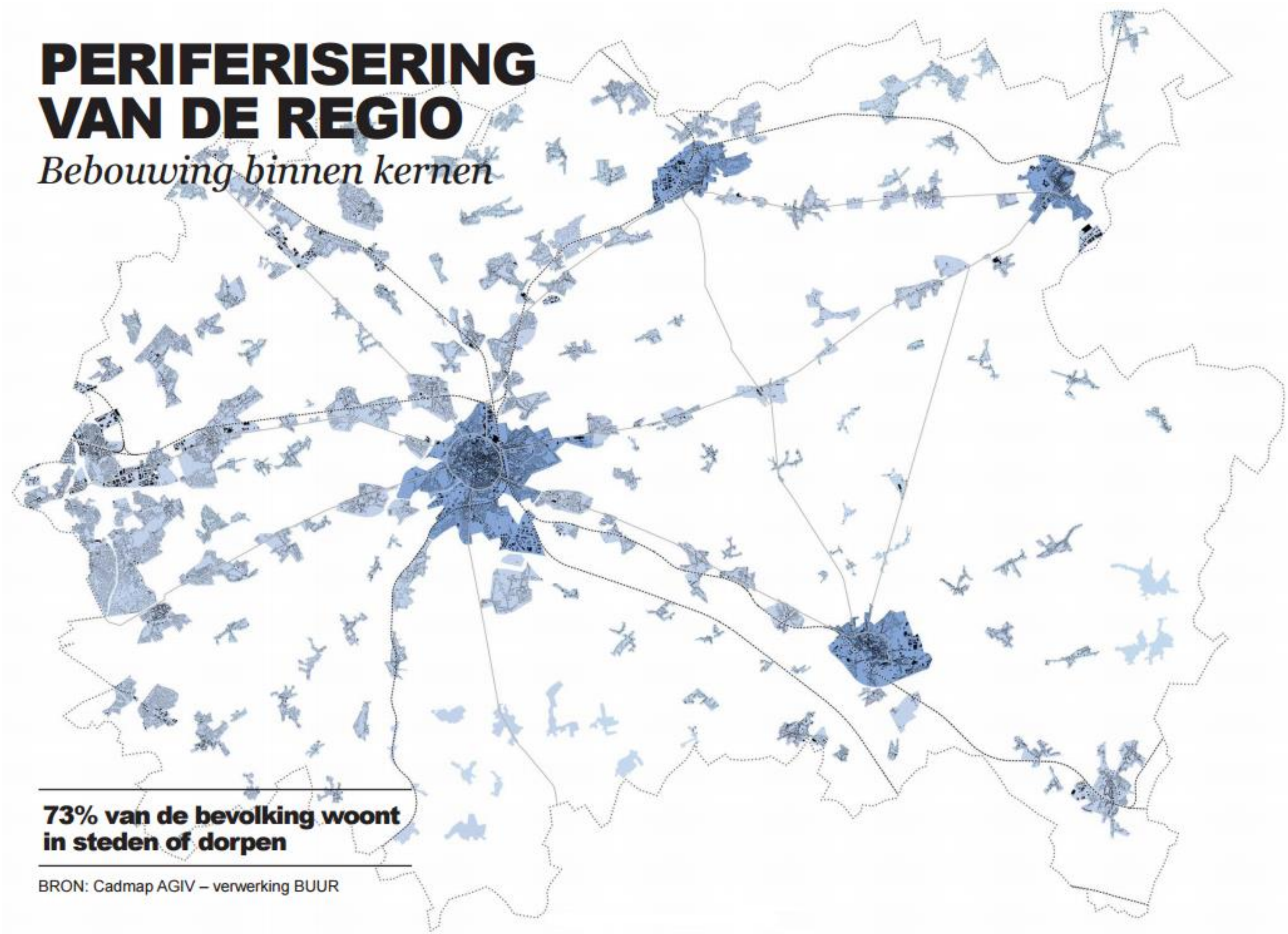
Hoe meer auto's in de file, hoe hoger het prijskaartje. Zo kosten de ochtend- en avondspits ons dagelijks zo'n 600.000 euro. En dan zijn de vertragingen op de gewestwegen daar nog niet bij gerekend. Op drukke dagen kan de totale kostprijs zelfs oplopen tot 3 miljoen euro.



- During the morning rush hour on Flemish motorways:
  - There is ~170 km congestion (losing ½ hour)
  - We all loose ~21,500 hours together
  - This costs ~300,000 euro to society
- **On the underlying road network: 4x worse!**
- 91% of the congestion is in Flanders

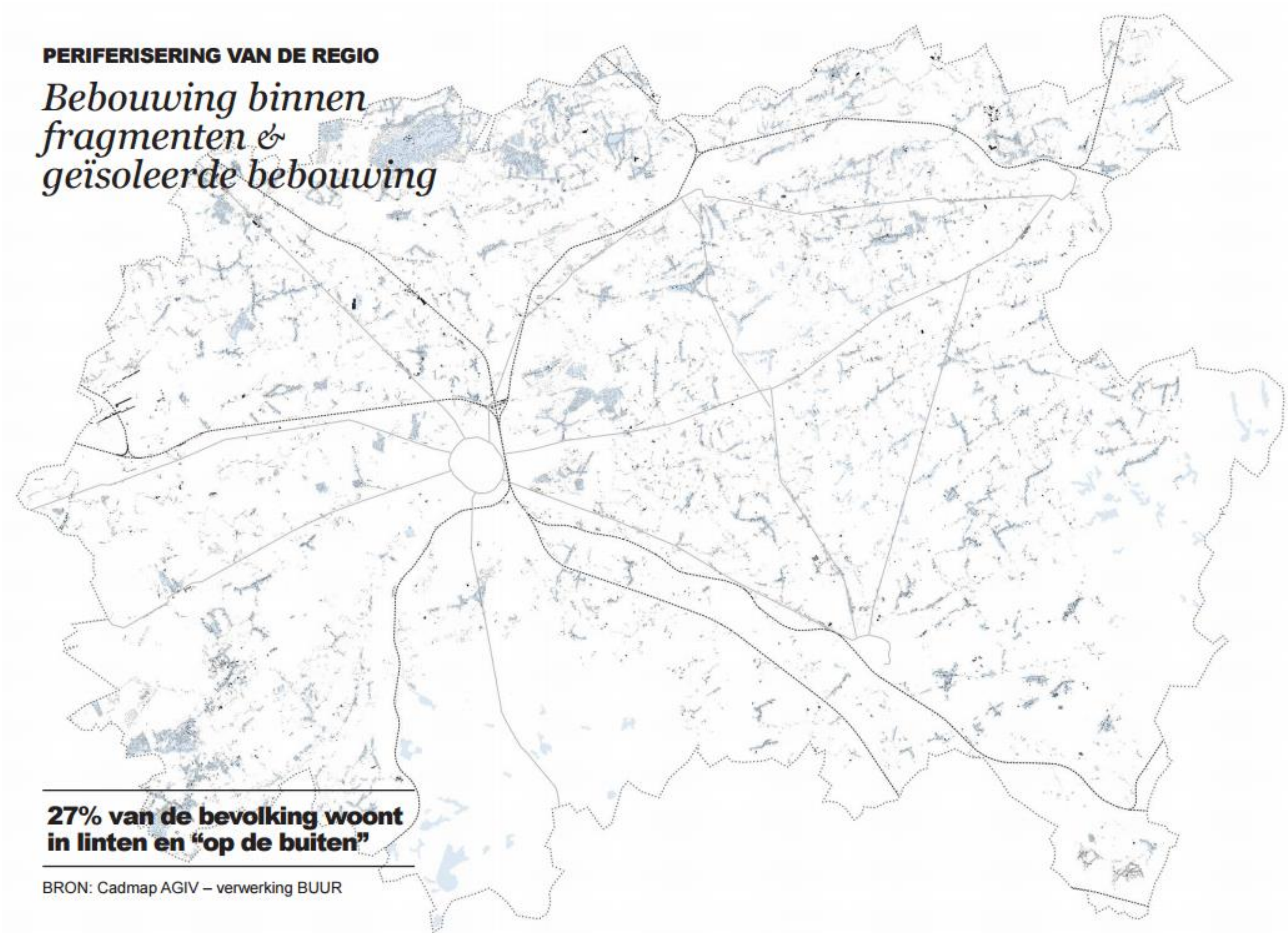
Sources: TML (2008, 2011, 2014, 2017)

How large is the congestion problem?



Regionet Leuven, 2017

How large is the congestion problem?



Regionet Leuven, 2017

What causes congestion?

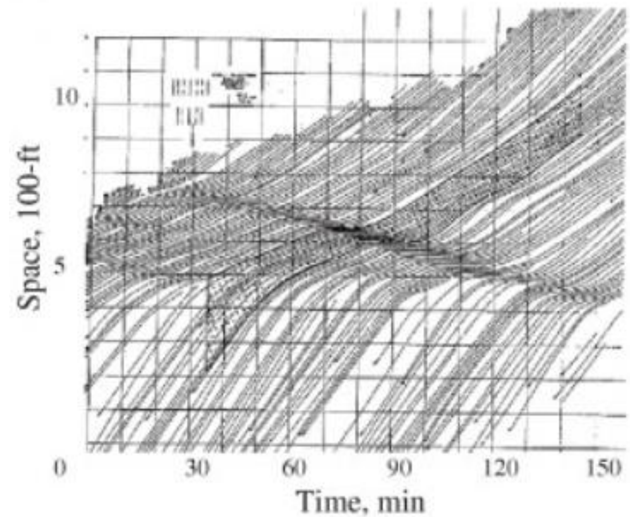
- **"Too many people want to drive on the same time at the same location"**

- Or:
  - The capacity of the road network is limited
  - They cannot process all the traffic
  - This causes jams leading to delays

- On top of that:
  - Accidents can cause congestion (and vice versa)
  - In cities congestion arises due to intersections and traffic lights

On the origin of congestion: 2 different theories

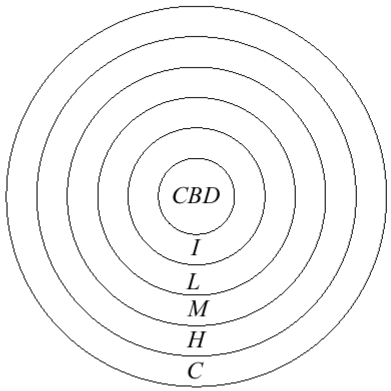
- The European (**German**) school:
  - Ghostjams out of nothing (Treiterer en Myers, 1974)
  - Kerner, Konhäuser en Rehborn (1994)
  - Helbing (1999)

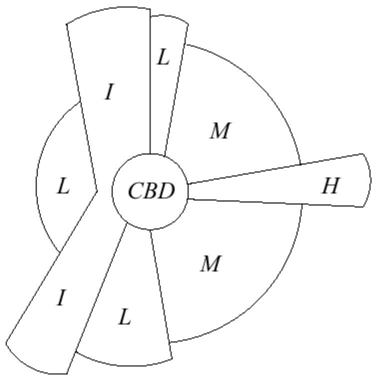


- The **Berkeley** school (University of California):
  - All congestions arises due to 'bottlenecks'
  - There is always a geometric explanation for a jam
  - Newell, Daganzo, Bertini, Cassidy, Muñoz, …

Land use & socio-economic behaviour

- The demand for transport originates out of the wish to **participate** at **spatially separated** social/cultural/economic/… **activities**





CBD = central business district
I = industriezone
L/M/H = lage/midden/hoge inkomensklasse
C = commuter zone

- Trend towards **geosimulation**

Source: Benenson and Torrens (2004)

Trip-based transport model

- Travellers take decisions that lead to a trip-based model

trip generation	*(how many trips?)* → **Aggregation!**
trip distribution	*(where are they going?)*
modal split	*(by which means of transport?)*
traffic assignment	*(which routes do they take?)*

"The four-step model"

Trip-based transport model

- Travellers take decisions that lead to a trip-based model

trip generation

trip distribution

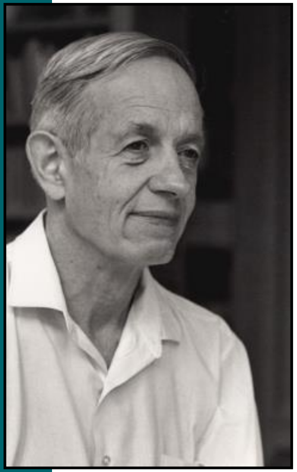
modal split

traffic assignment

Route choice is governed by Wardrop/Nash criteria:
(1952)

User equilibrium
(W1)

System optimum
(W2)



Traffic assignment: calculation of equilibria

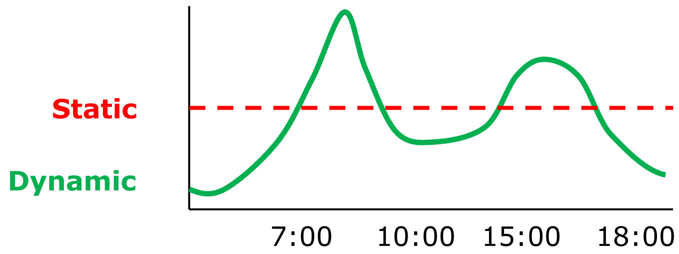
- Formalised by Beckmann, McGuire, and Winsten:
  - The “BMW-trio”
  - “*Studies in the Economics of Transportation*” (1956)

- Calculations:
  - Convex optimisation theory (quadratic programming)
  - Non-linear congestion functions (e.g., BPR functions)
  - Shortest path algorithms

- Additions:
  - Stochasticity
  - Risk
  - Non-rational, nor all-informed travellers
  - …

Dynamic traffic assignment: the holy grail

- Static:
  - Use a simplification of road capacity
  - Typically calculates a complete morning rush hour in 1x ("*all traffic is simultaneously put on the network*")



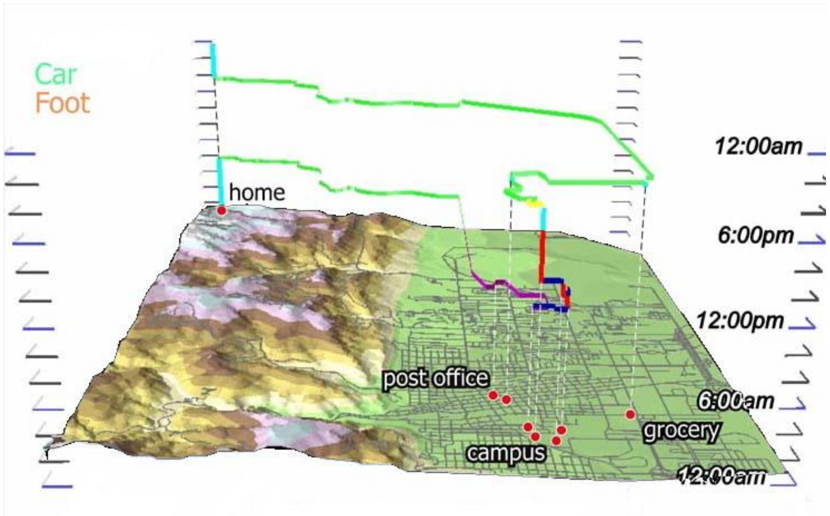
- Dynamic:
  - DTA = '*dynamic traffic assignment*'
  - Congestion is a dynamic phenomon in time and space
  - Allows to model blocking back of queues
  - Choice of route and departure time
  - Dynamic network loading (DNL):
    - Analytic
    - Based on simulations (convergence via iterative relaxation)

Activity-based transport model

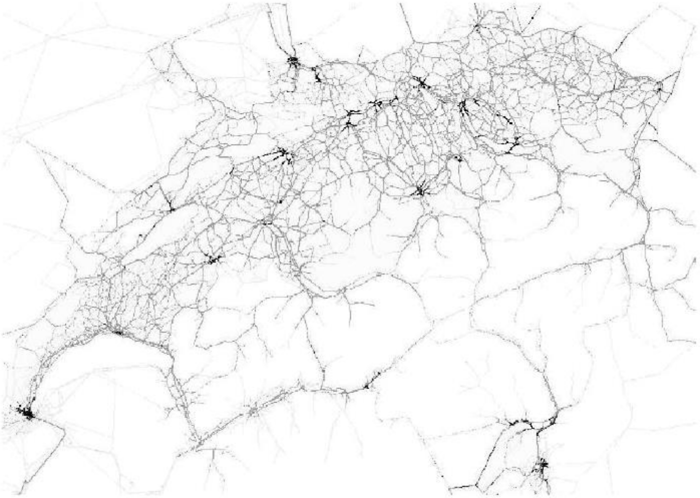
- Generation of a **synthetic population**
- Generation of plans of **activities**
- Executing these activities

  = physical movement of the **agents**

activity pattern → *multi-agent systems*



Source: Detlov (2001)



Source: Voellmy (2001)

Macro-/mesoscopic flow models

- Describe how traffic **physically** propagates on a road
- Based on **partial differential equations** (i.e., conservation laws)
- *High aggregation, low level of detail*

➡ Macroscopic: **fluid-dynamic models** that consider traffic as a <u>compressible</u> fluid (Navier-Stokes)

➡ Mesoscopic: **gas-kinetic models** that consider traffic as a many-particles system: derivation of macroscopic equations from microscopic driver behaviour (e.g., speed distributions)

The LWR macroscopic model

- Lighthill-Whitham-Richards **1st order** model
- Traffic = non-viscous compressible fluid
- Based on a scalar conservation law of density (*k*) and intensity (*q*):

$$\frac{\partial k(t,x)}{\partial t} + \frac{\partial q(t,x)}{\partial x} = 0$$

- **Assumption:** intensity is a function of the density!

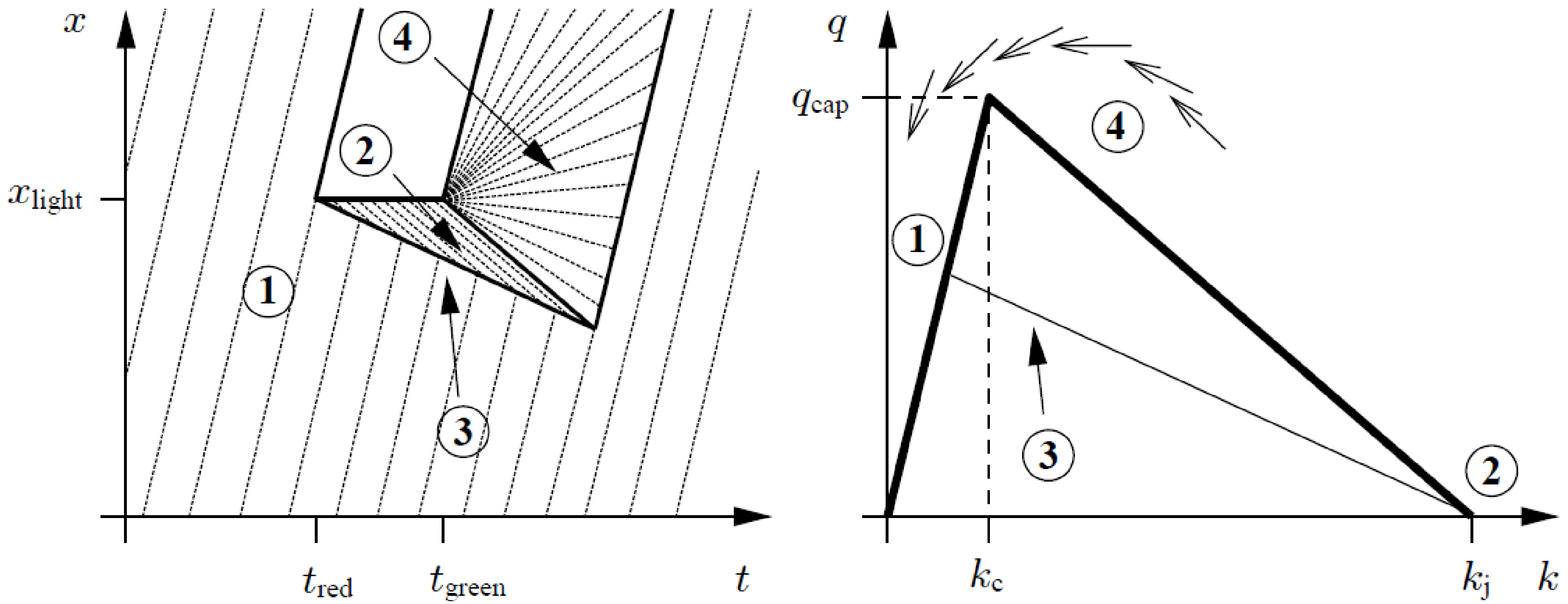
$$k_{\mathrm{t}} + q_{\mathrm{e}}(k)_{\mathrm{x}} = 0$$

Fundamental diagram

- Relation: $q = k\,\overline{v}_{\mathrm{s}}$

LWR: solutions and variations

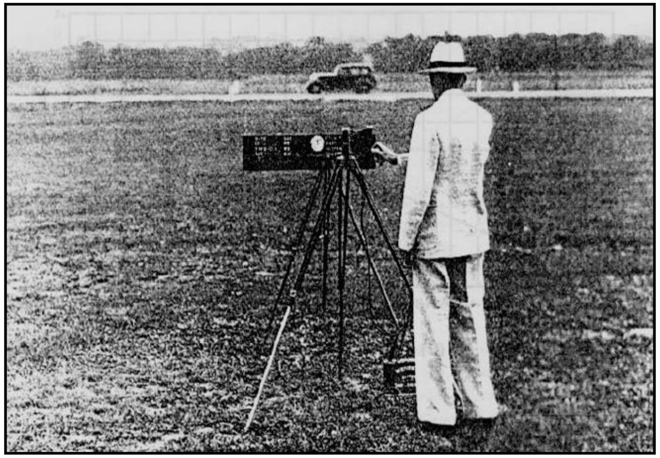
- Didactically rich: can be solved ‘graphically’



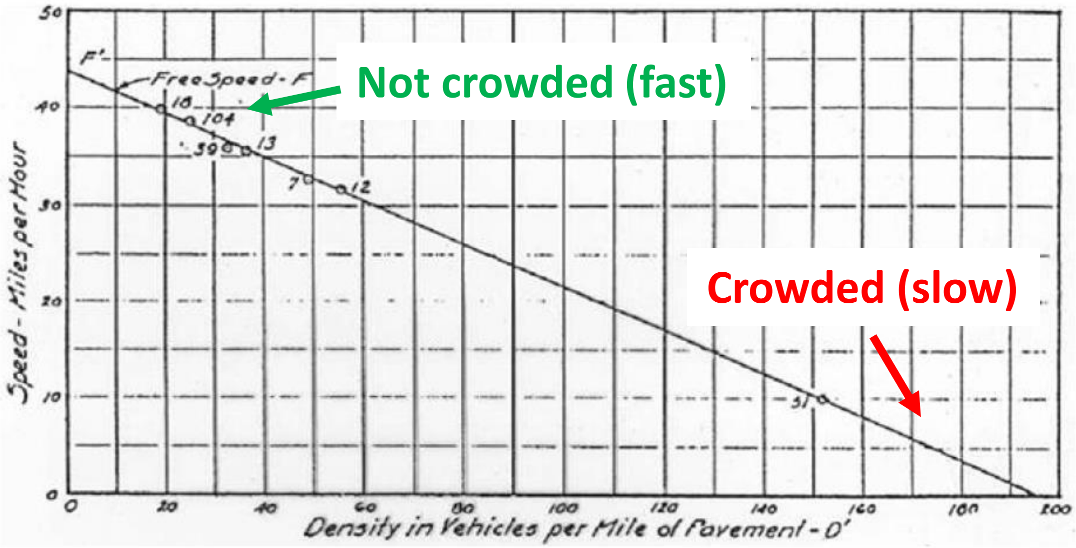
- Also accurate numerical approximations possible
- Variations: multi-class, rabbits and slugs, …

The fundamental diagram

- Dates back to Greenshields (1935):

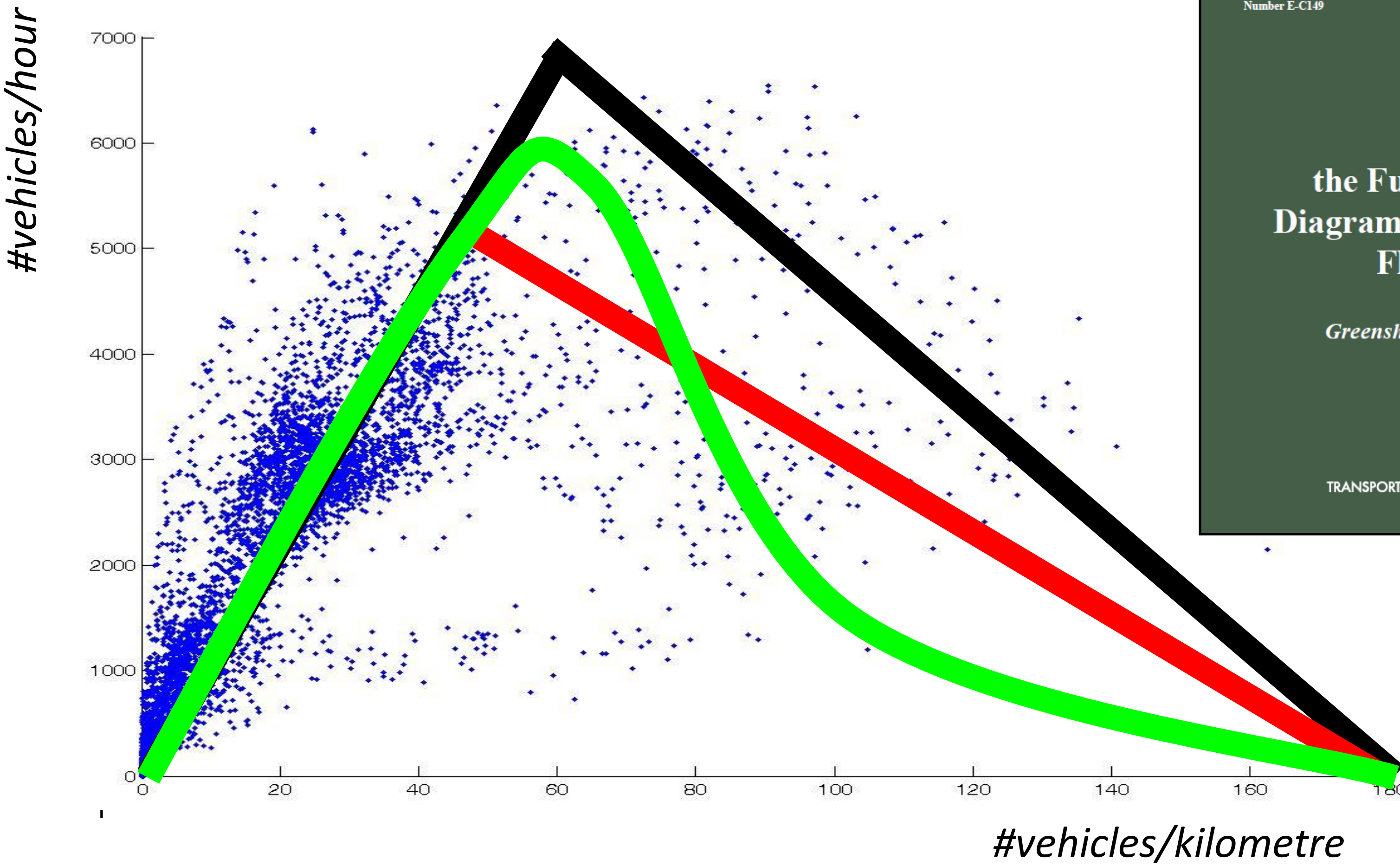


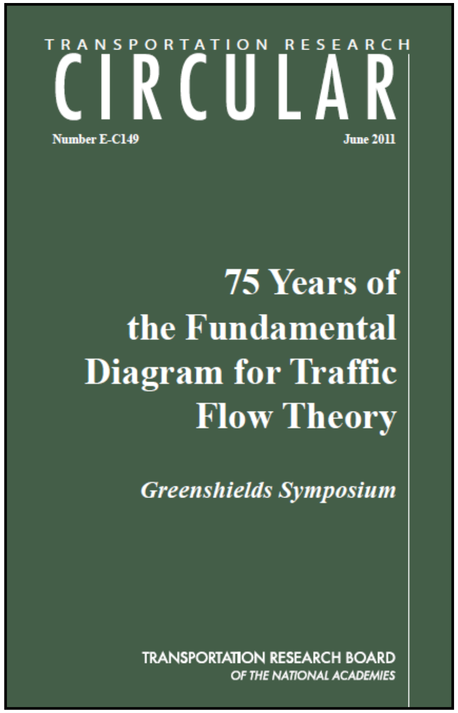
Source: Greenshields (1935)



The fundamental diagram

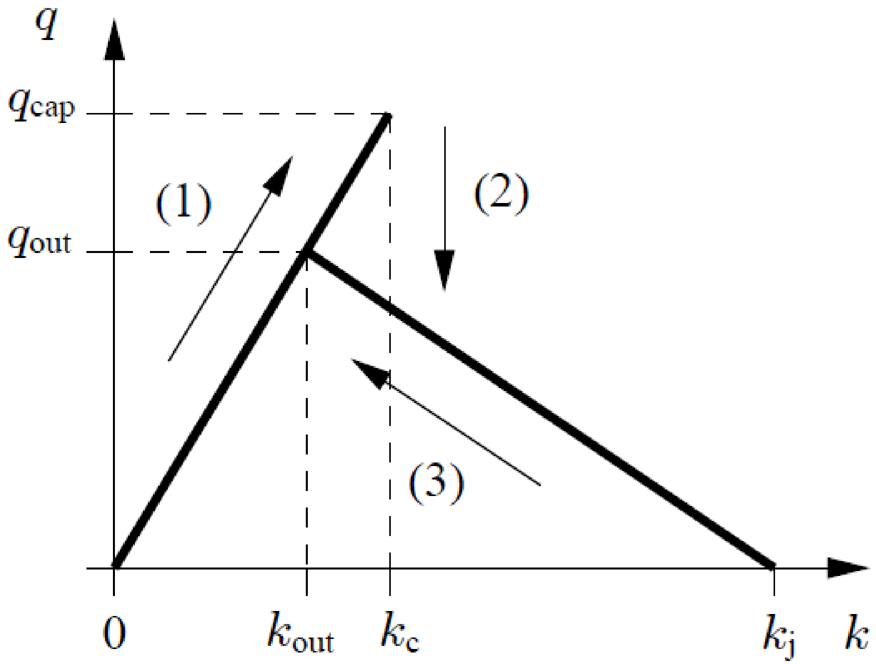
- Theory versus practice:

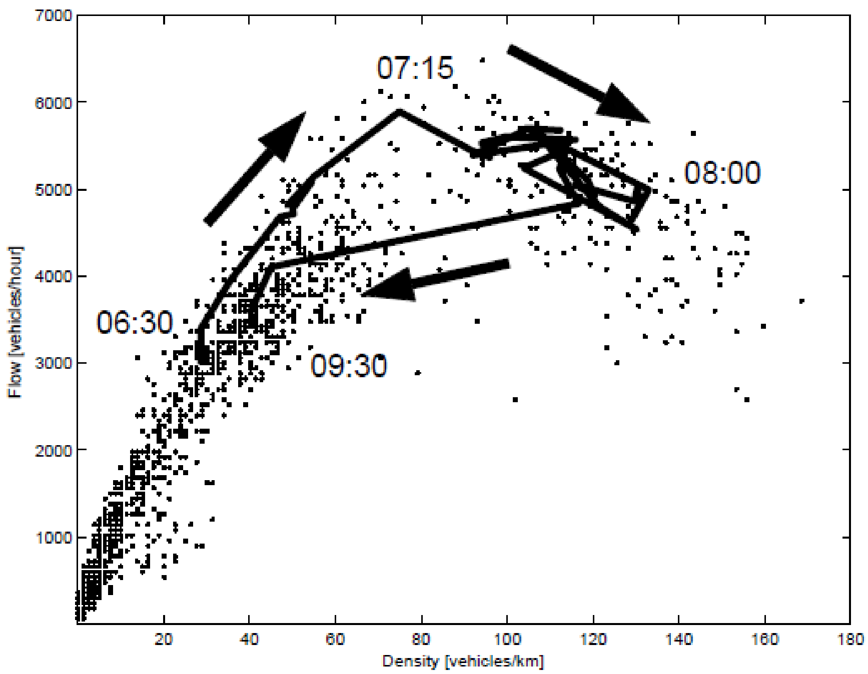




Capacity drop and hysteresis

- Different theories, …



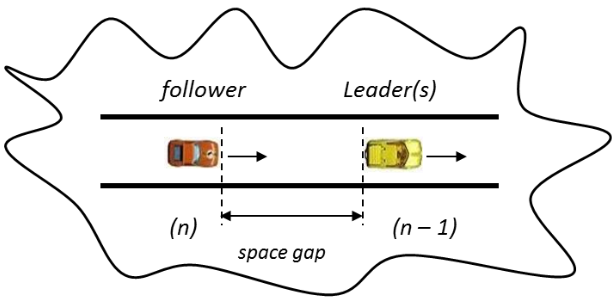


Microscopic flow models

- Describe **explicitly** the interactions of vehicles in a traffic stream (seems more realistic)
- *Low aggregation, high level of detail*

Car-following model

- Stimulus-response
- Optimal velocity
- Psycho-physical distance
- Cellular automata
- Queueing theory



Lane-choice model

- Gap-acceptance
- Mandatory versus discretionary lane change

- **Submicroscopic flow models** encompass physical characteristics such as engine performance, gear shifting, ... and human decisions (non-strategic)

Eye for detail

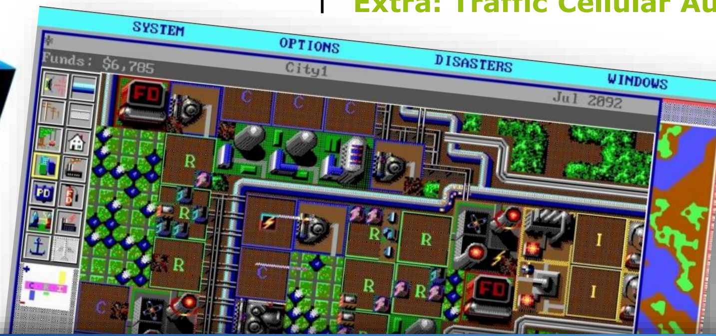
Source: AIMSUN (2006)

Convincing visualisations

Source: VISSIM (2005)

Digitising the city: digital twins

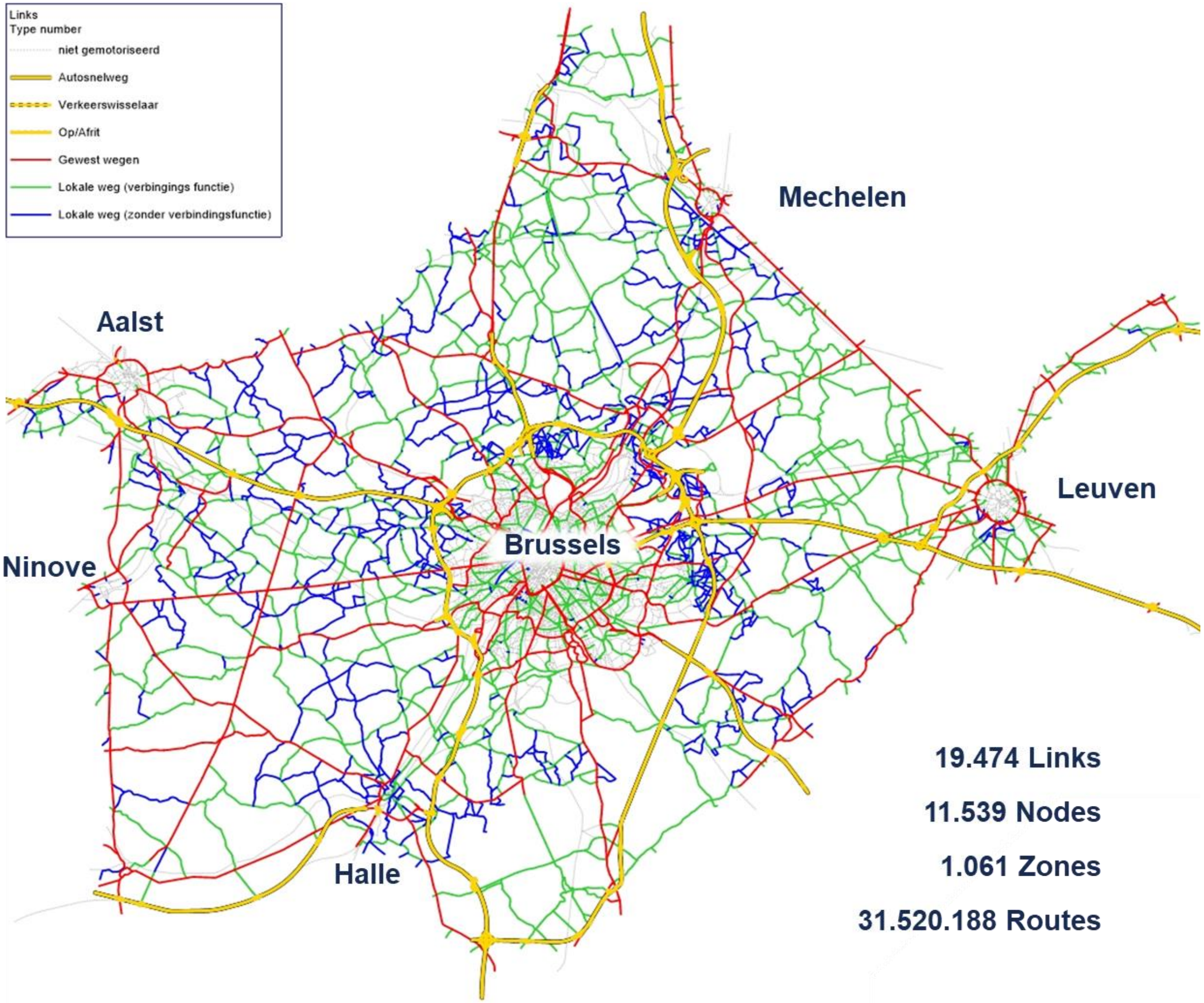
SIMCITY
CITIES OF TOMORROW



When SimCity is made by traffic engineers

Source: Pixabay (Cities: Skylines, 2019)

Macroscopic dynamic traffic model Brussels

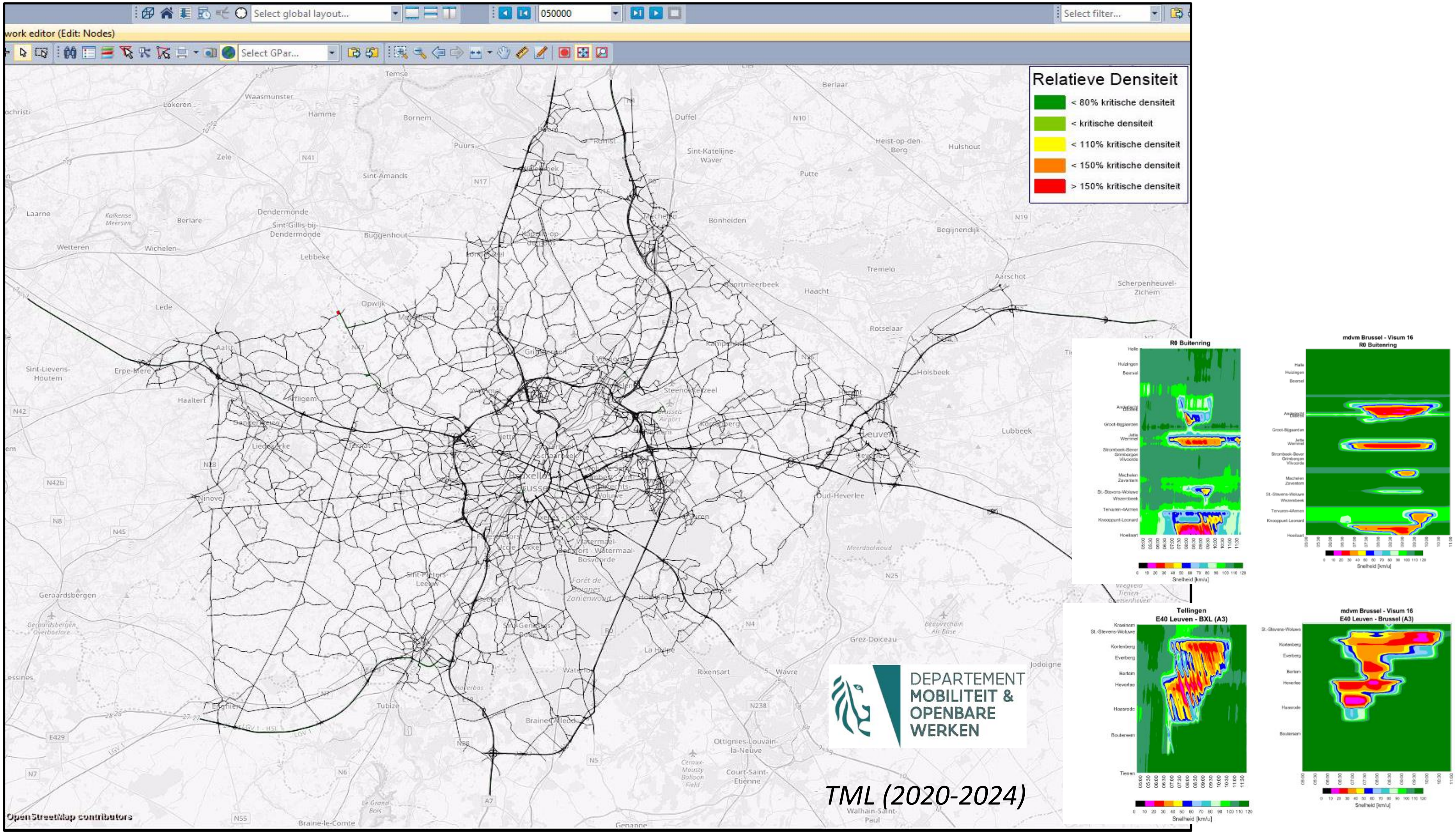


19.474 Links
11.539 Nodes
1.061 Zones
31.520.188 Routes

DEPARTEMENT MOBILITEIT & OPENBARE WERKEN

TML (2020-2024)

Macroscopic dynamic traffic model Brussels



Computersimulations of traffic

- You can say what you want, but...

  ... there just models of reality

  - ***"Reality is just another model"***
  - They have their limitations and reproduces what we feed them
  - Be mindful when policy makers interprete your results
  - "Garbage in / Garbage out" → **do not mess with the internals!**
- The available commercial packages are *transport planning models*, mainly based on the four-step model
- Scale: local, network, regional, national, transnational

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Possibilities for traffic management

- Travellers change their **departure time** (depart earlier, arrive later, not making the journey, …)
  - ➔ Flexible hours, work at home: if possible, JIT, shifts, ...
- **Road user charging** (smart mobility, tollcordons, …)
- Management of **parkings**, dynamic car sharing such as **car pooling** and even real-time **ride sharing**, …
- Peak lanes, public transport uses dedicated lanes (if ample capacity remains for the remaining traffic)
- **Detection** of fog, snow, heavy rain, …

Incorporating ICT

- Advanced Traffic Management Systems (**ATMS**):
  - **Cooperative Intelligent Transportation Systems (C-ITS)**
  - Automatic incident detection
  - Intelligent traffic lights (incl. GLOSA)
  - Dynamic route information panels (DRIPs)
    aka. Variable message signs (VMSs)
  - Variable speed limits (VSLs, ISA)
  - Ramp metering

- Advanced Traffic Information Systems (**ATIS**):
  - Radio broadcasts, navigation devices, parking information, …
  - Travel time predictions
  - Public transport routing

Classic traffic management

- Scope (for road traffic):
  - The focus lies heavily on urban traffic management (i.e., traffic lights)

- Techniques:
  - Classic algorithmic solutions, simple heuristics, expert systems, …
  - Ramp metering, speed harmonisation, route guidance, incident detection, …
  - Some fancier stuff: congestion prediction (MPC), fuzzy logic, …

- Tools:
  - Traffic Network Study Tool (TRANSYT)
  - Split Cycle Offset Optimisation Technique (SCOOT)
  - Urban Traffic Optimisation by Integrated Automation (UTOPIA)
  - OPAC / Rhodes / OMNIA / MOTION / SCATS / Optimax / Green Logic / MOVA / LHOVRA / COCON / LISA+ / VERA+ / ANNA+ / INES+ / SYLVIA+

Intelligent traffic lights

- Goal: tune intersections with each other, keep traffic on main axes flowing, less emissions of pollutants in "*canyons*" (e.g., Wetstraat)

- Leading to high returns:
  - Green waves for throughput on priority routes
  - Indication of remaining red-/green cycle times

- The city of Antwerp:
  - Supercomputer with city-wide control
  - TML defines all phase timings
  - 02/22: TML defined the 100th intersection
  - Conflict-free optimisations: safe & flowing

Enter AI!
(well… ‘machine learning’)

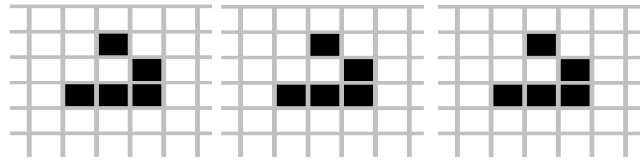
- Artificial narrow intelligence (‘weak AI’)
  - Very narrow, specific purpose
  - Big Data and complex algorithms (chess players, Facebook wall, …)
  - Will not pass Turing test

- Artificial general intelligence (‘strong/true AI’)
  - AI thinks as humans do (incl. intentionality)
  - Machines that are good at doing what comes easily for humans
  - Eventually learns and upgrades itself, on its own (~ 2035)

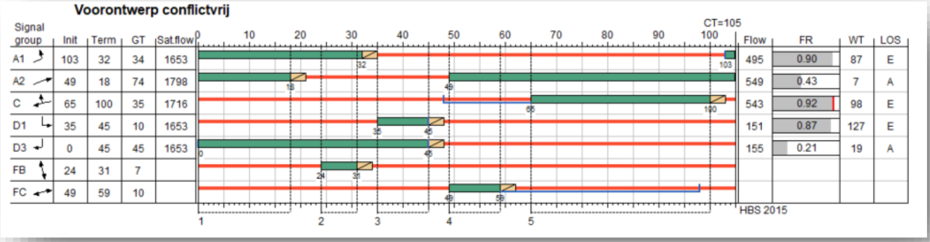
- Artificial superintelligence
  - Behold, the technological singularity! (~ 2040)
  - Cannot be easily ‘turned off’

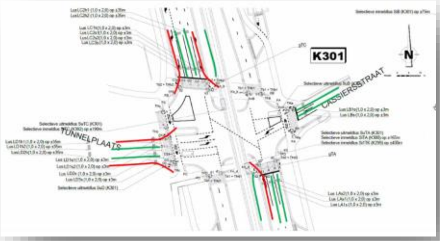
AI and traffic lights

- Intersection control has non-linearities and NP-**hard**

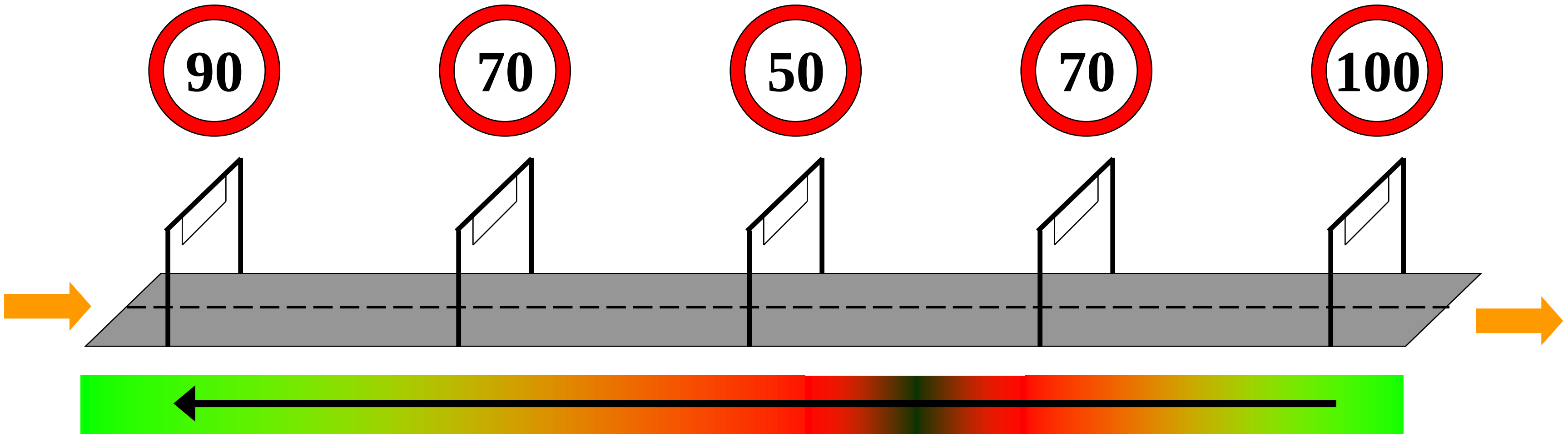


- Techniques:
  - Vehicles and intersections as intelligent agents
  - Self-organisation through ant-based optimisation
    - Information exchange (pheromones and evaporation)
    - 'Antiquette' (moving aside)
  - Examples of decentralised control:
    - Pittsburgh: I2I(V) (+ unknown AI algorithms)
    - Toronto/Burlington (MARLIN): game theory + learning
    - Dresden: multimodal + model-based predictions





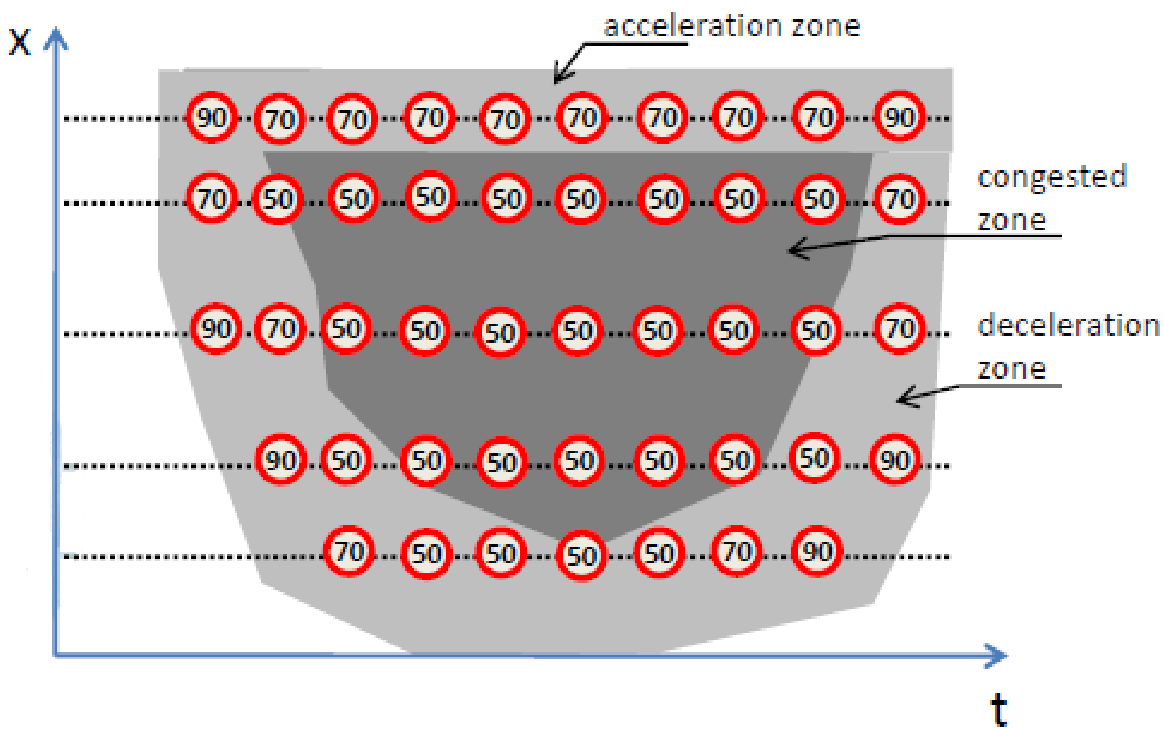
Variable speed limits on DRIPs



upstream moving shockwave

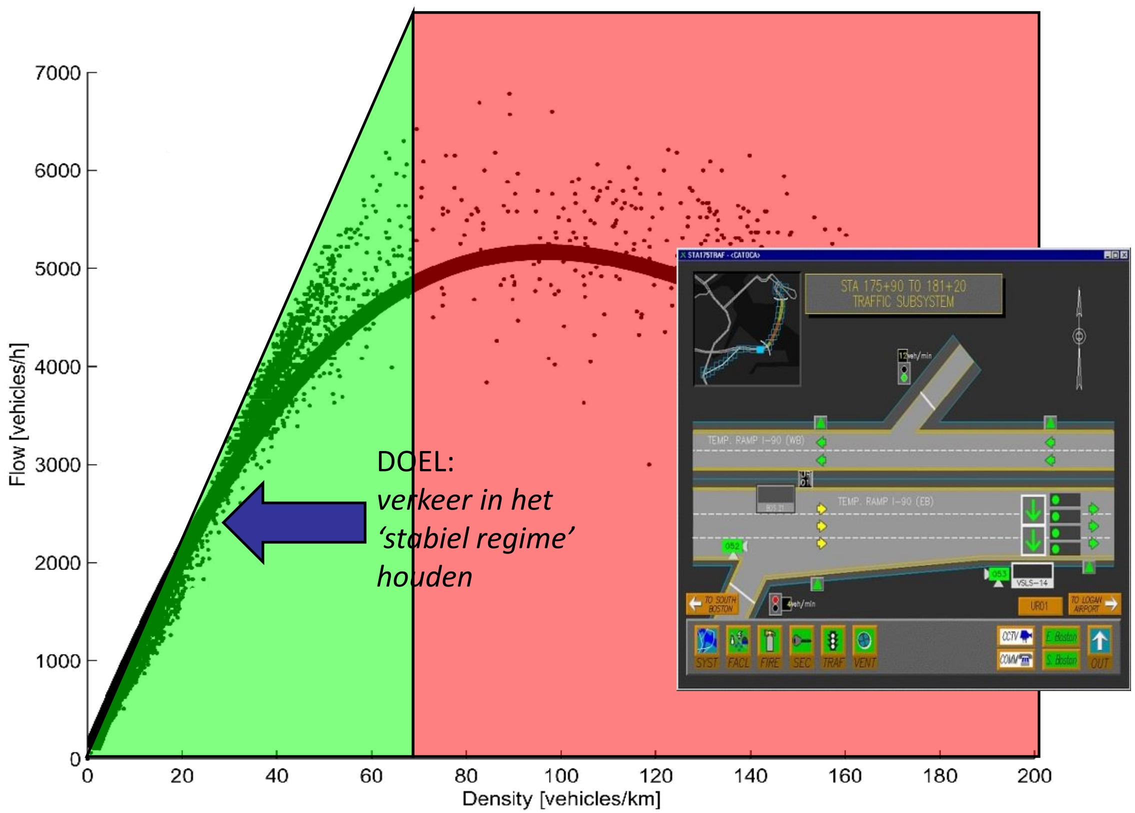
Variable speed limits on DRIPs

- In many cases a standard control algorithm is used
  - We can do better!
  - E.g. Craeybeckxtunnel (E19): KUL study yields +8 to 15%



ATMS/ATIS: ramp metering

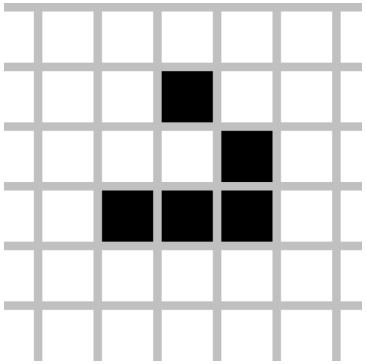
- *"The flow is drop by drop trickle-controlled "*



Sources: KUL-ESAT + TU Delft (2008, 2011)

Encouraging Urban Transport and Innovation at the Local Level

- Smart traffic management (traffic light control):
  - Via supercomputers (tendered)
  - Agent-based self-learning (research)



- Adopting open standards:

- Focus lies on ICT and ITS to:
  - Improve traffic flow
  - Enhance traffic safety
  - Reduce emissions
  - ➔ But also **spatial planning**!

- Increasing trend towards Mobility-**as-a-Service**

About data: the requirement to open up

- **EC Directives**
  - EC ITS Directive (2010/40/EG)
  - EC PSI Directive (2013/37/EU) [REUSE]
  - EC INSPIRE Directive (2007/E/EC)
  - Mandatory ITS Action Plans for MS
  - (ITS Action Plans for Cities)

- Uniform implementation via **Delegated Acts**
  - Emerging Open Data movements and PPPs
  - Especially at the local level of Cities

A city's first step: making data available to the public

- Example: Brussels
- Created an **Open Data Portal**
  - 508 open data sets (incl. metadata!)
  - Search functionality
  - Access through API (JSON)

- Specific licence governing (re-)use
  - Citation
  - Liability waiver
  - No previous IPR on the data

- Events
  - Hackathon (best prototype/business model/data use)
  - GirlsCodeEU workshop

Next step: sharing ideas and solutions

- Example: Ghent
- Upgraded portal:
  - Access through API (JSON, XML, CSV, KML, …)
  - Including dynamic information (real-time parking occupancies)
- Developers:
  - Can share/supply their own app
  - Can propose ideas

- Note: just making the data available is not enough to incentivise the market

Incentivising developers

- Example: Antwerp
  - Over 270 datasets
  - Provide better services
  - Stimulate the creative economy
  - Fusing data
  - Simple licencing (cf. Brussels)
  - Incl. catalogue of available/shared apps

- Organise a yearly **challenge**: Apps for Antwerp
  - Best developed app
  - Best concept
  - Distinction between amateurs and professionals

Example results of such a challenge

- Tracking moving signs
- Quality of living in a neighbourhood
- The ‘emotional state’ of a location
- “Let’s fix it” and “Pinitag”
  - Signal older, damaged, or annoying locations
  - Citizens can propose to help
- ACleanCity: centralises info wrt. waste sorting, disposal, and collection
- Where to put (extra) garbage bins?
- Locations of (public) toilets for disabled persons
- Geoplus: easier access to GIS data
- …

Going even further: ACPaaS

- ACPaaS = Antwerp City Platform as a Service
  - The goal is to re-use components and prevent from creating or buying them over and over again
  - Develop the platform in cooperation with startups
  - Reaching out via Meetups
- Stimulate co-creation and innovation
  - Separate apps (changing) front-ends from their back-ends
  - Back-ends move into (stable) engines
  - Accessible through APIs
- "Everyone can participate in building a digital city!"

Open Data in cities is a global phenomenon

- Various emerging Open Data movements and PPPs
  - Flanders' Open Data Day (incl. funded innovation projects)
  - Triangle Open Data Day
    - Open Data Education
    - Hacking for civic good
  - International Open Data Hackathon
    - Write applications
    - Liberate data
    - Create visualisations
    - Publish analyses
- Open Data Meetups:
  - Education
  - Sharing ideas
  - Incentivise politicians

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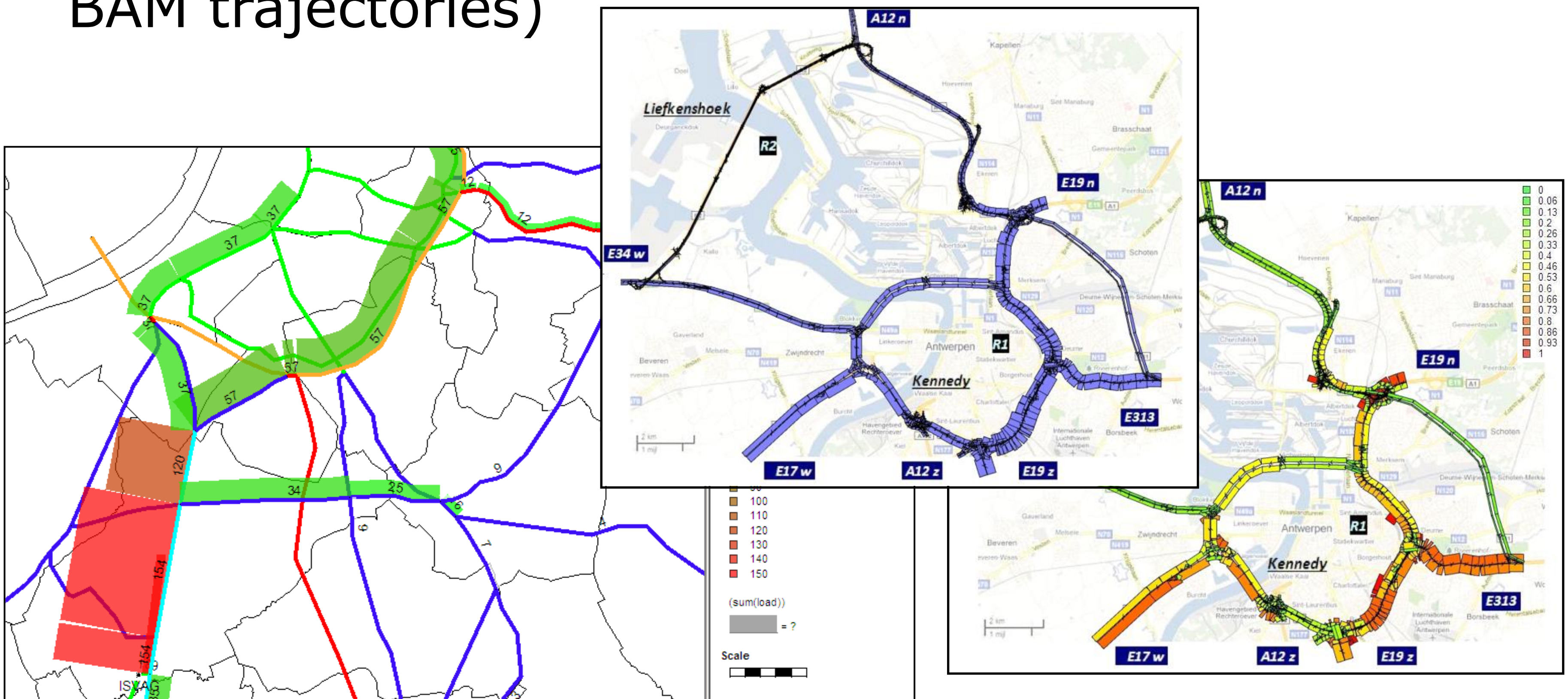
Macroscopic effects by means of OmniTRANS

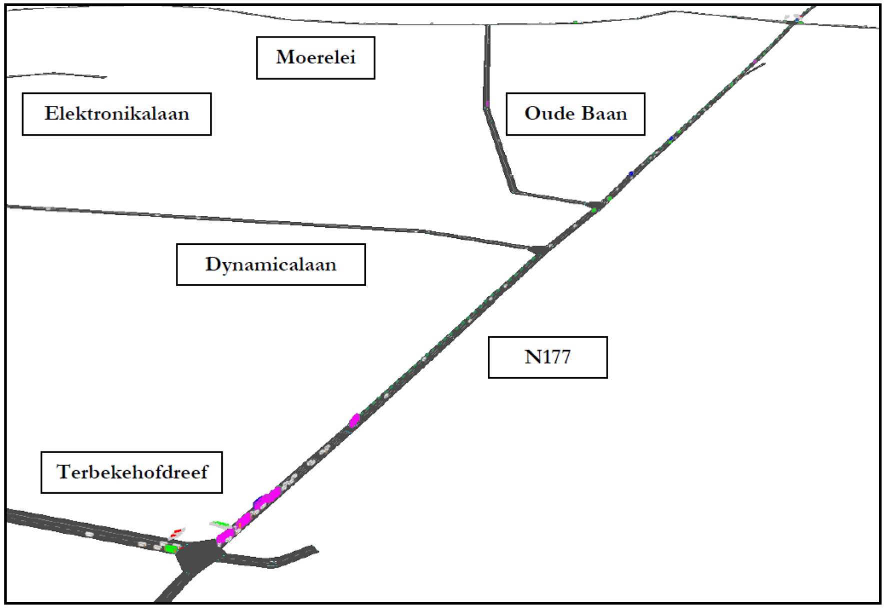
- Relocation ISVAG waste furnace
- Closure of the R1 ring around Antwerp (Meccano ⬄ BAM trajectories)

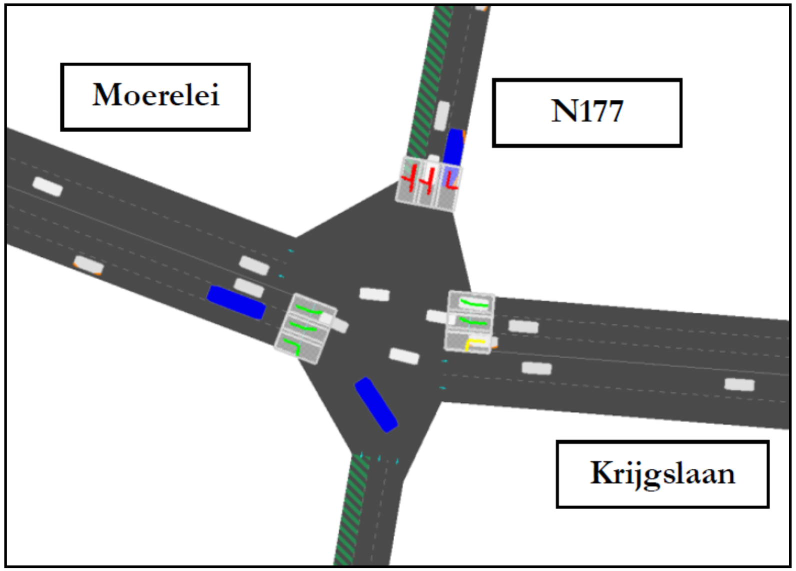


Source: TML (2010)

Microscopic effects by means of Paramics

- Accessibility Carrefour Korbeek-Lo + Herstal
- Tunnel under the Waterloolaan in Brussels
- Masterplan Antwerp (Moerelei)



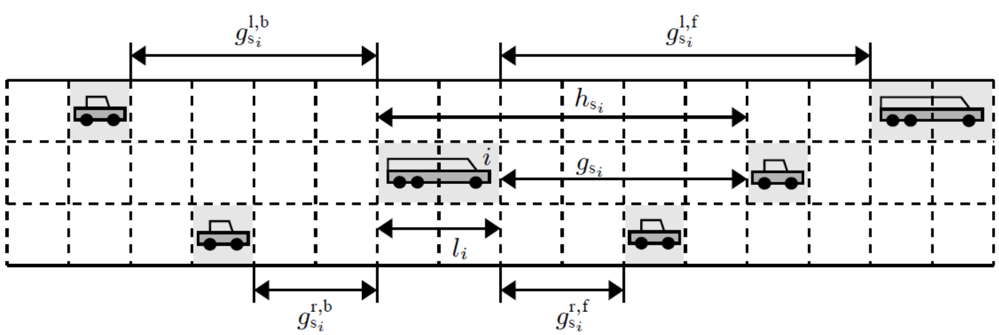


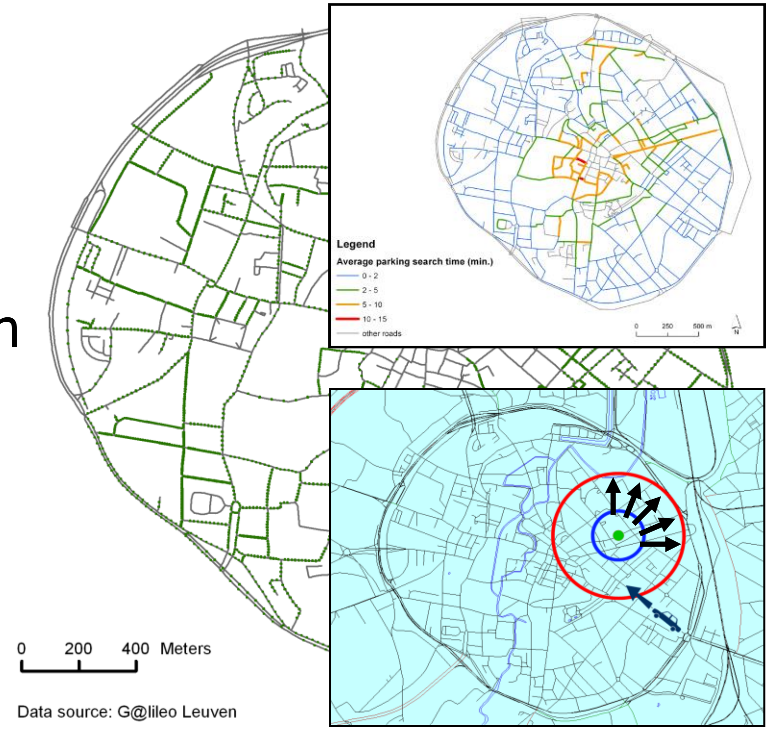
Source: TML (2012)

SUSTAPARK: sustainable parking with a TCA model

- <u>Goal:</u> simulate **the effects of changes in the parking situation and parking policy** of a city
  (Change the number of parking spaces, the price and duration of public parking, on-street versus below ground parking, …)

- Main components:
  - Modelling the parking demand
  - Modelling the search behaviour
  - Modelling the economic equilibrium





Sources: KUL (2006), TML (2009)

ANPR & PGS

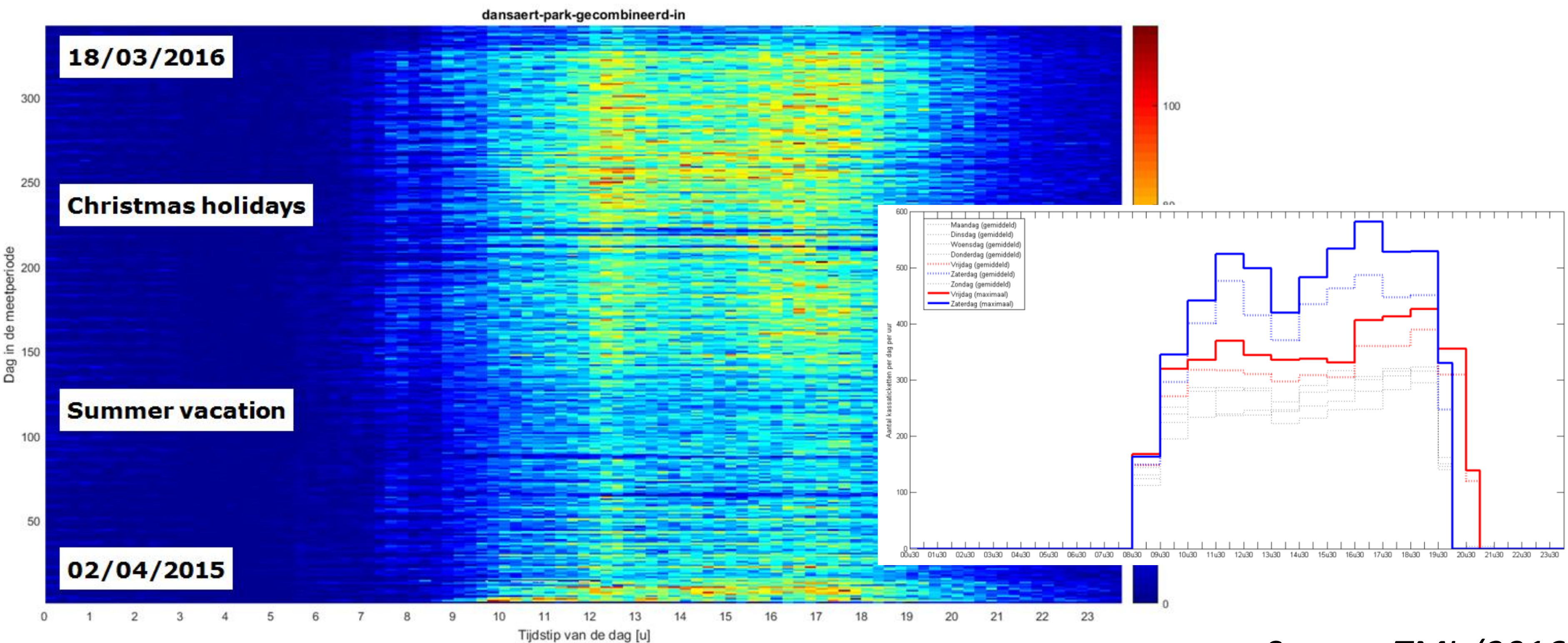
- Terminology:
  - **ANPR** = automatic number plate recognition
  - **PGS** = parking guidance system

- Used for:
  - Monitoring
  - Controlling access in/to a city

- Deployed in:
  - Leuven
  - Vilvoorde
  - Mechelen

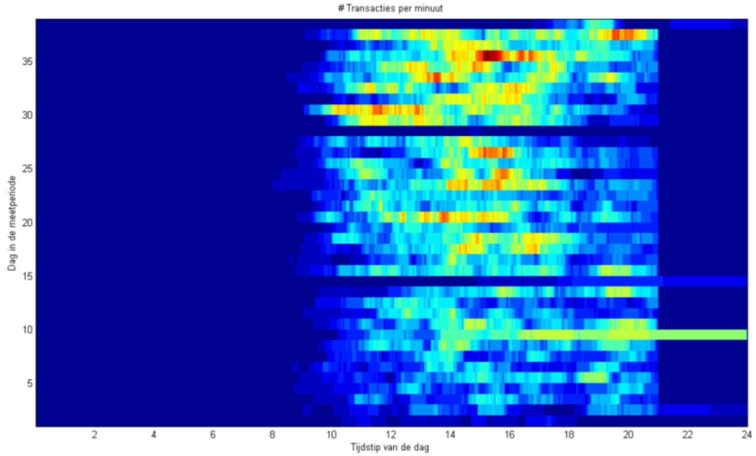
ShopMob (avoiding shopping during rush hours)

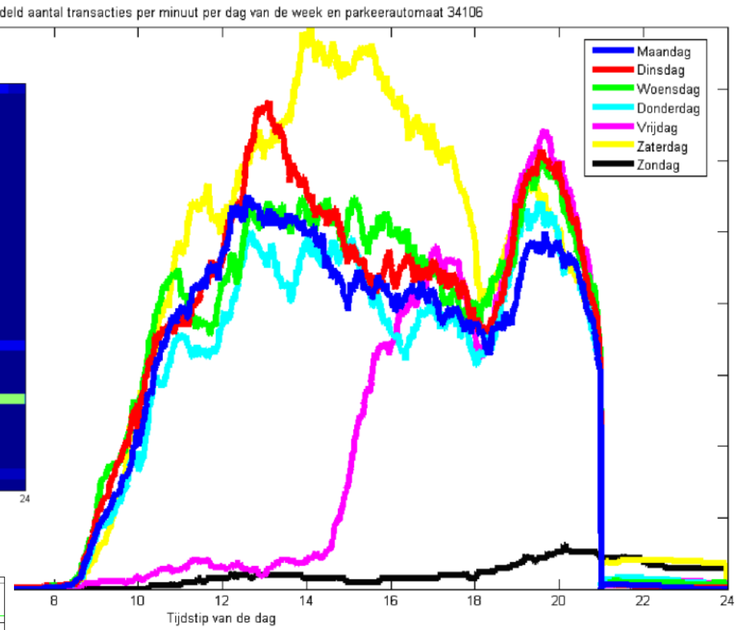
- Colruyt gave incentives to people:
  - To shop outside the rush hours during the day
  - To leave the car and use public transport and/or bike

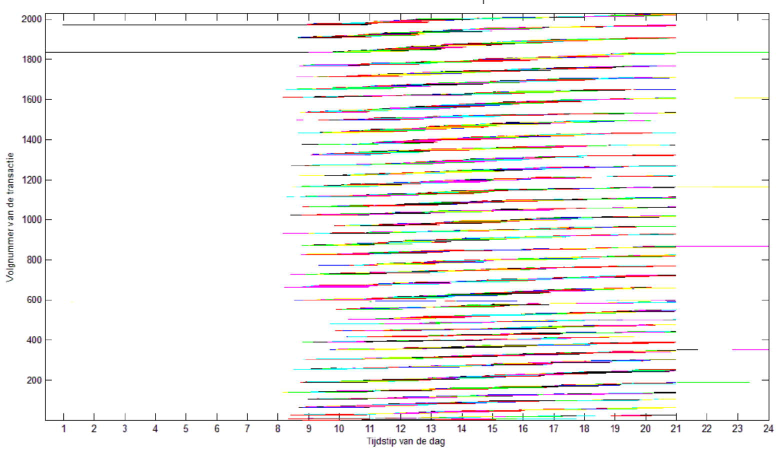


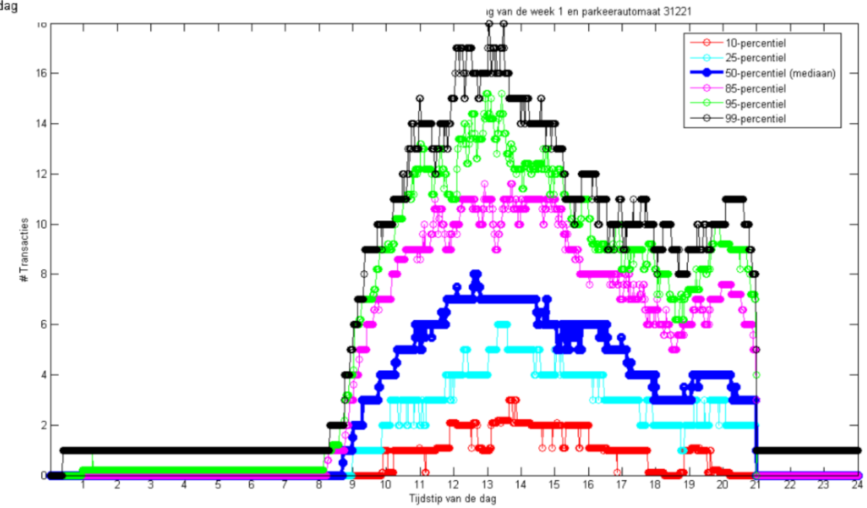
Source: TML (2016)

Statistical analysis of SMS-transactions for parking





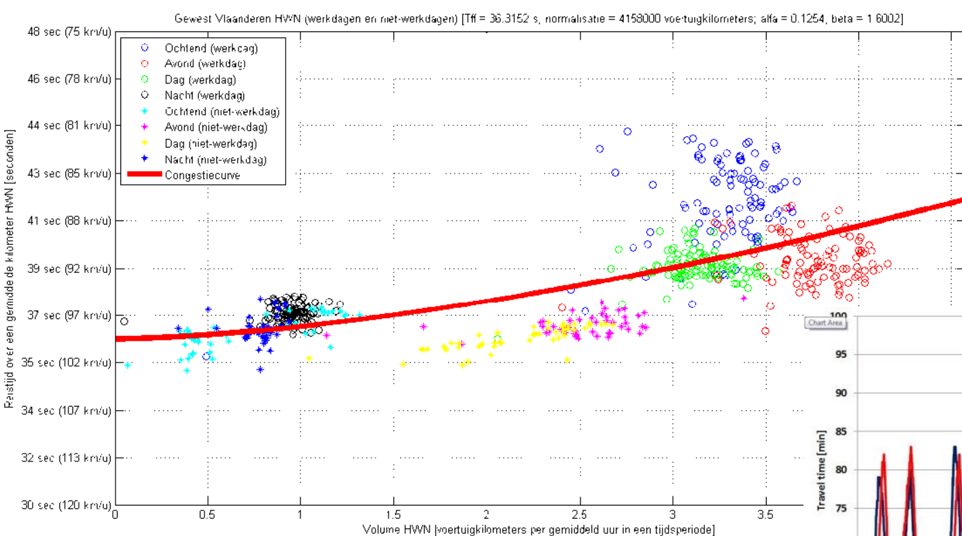


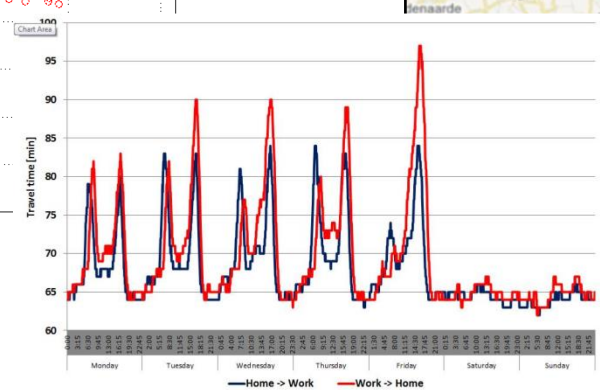


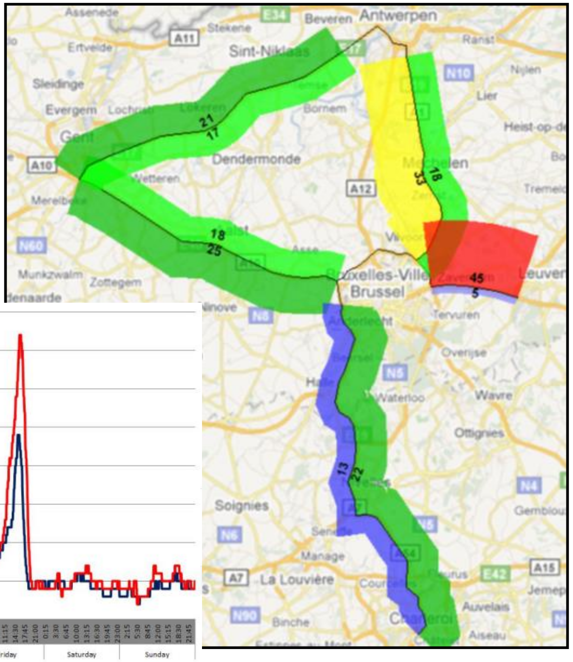
Source: TML (2009)

Studies based on traffic measurements

- Traffic indices on Belgian motorways
- Analysis of the congestion in Belgium
- Impact of reduced maximumspeeds on motorways
- How much time is spent in congestion during a career?

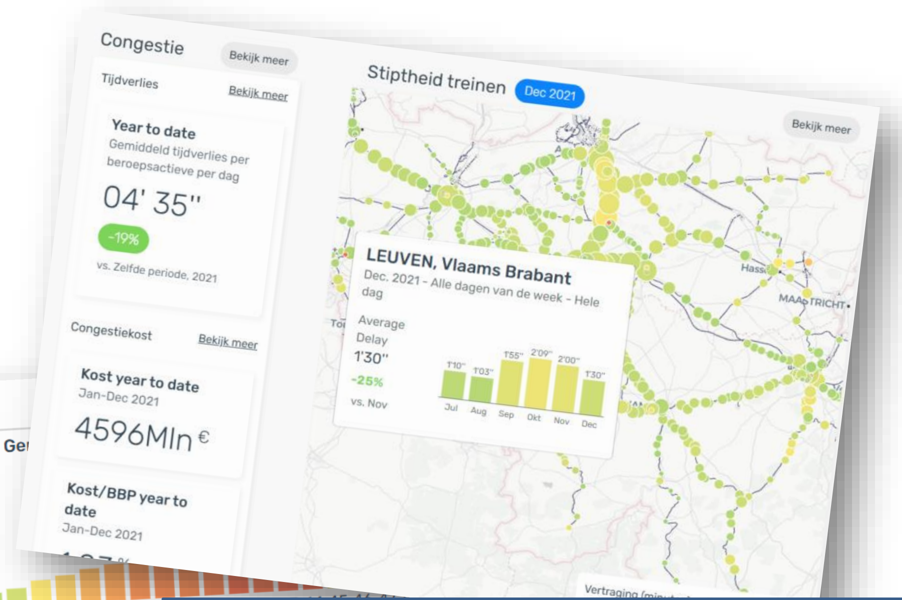


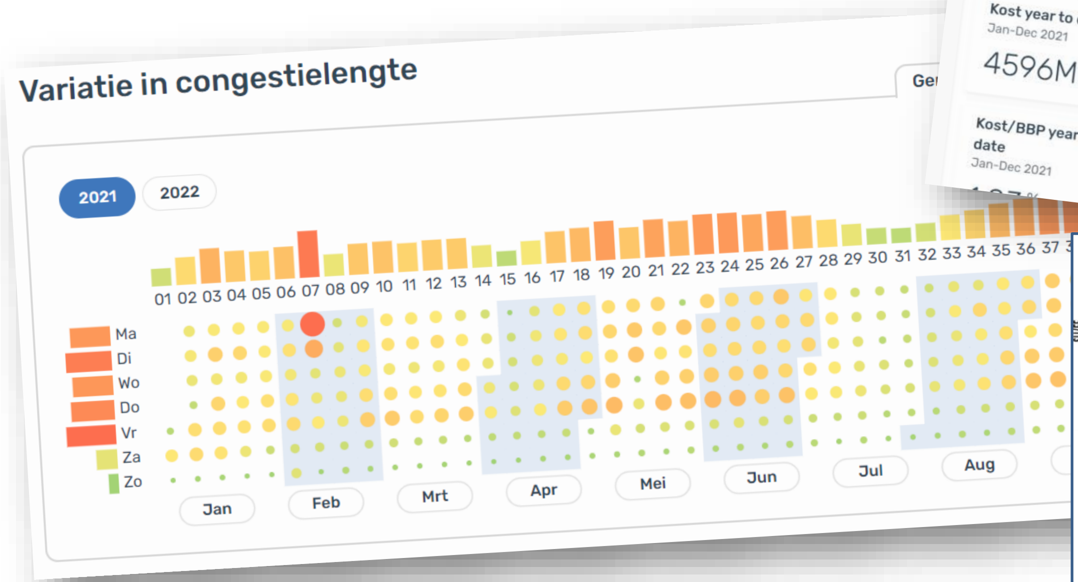


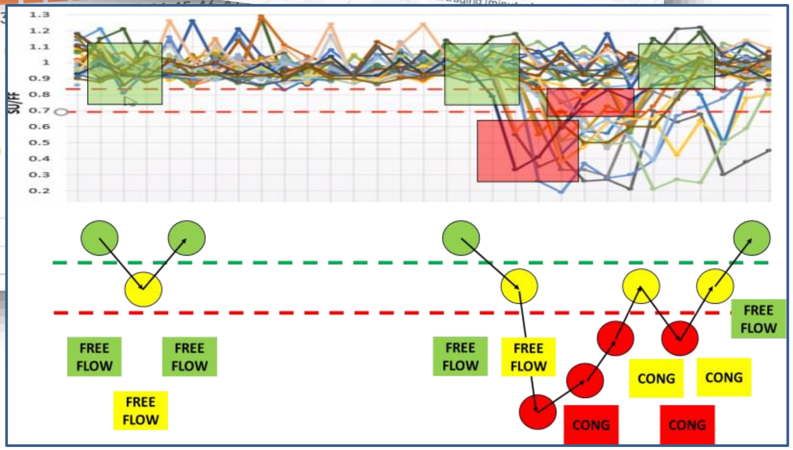


Sources: TML (2005, 2008, 2011)

- Steunend op wetenschappelijke onderbouwde analyses
- Mét TML expertise



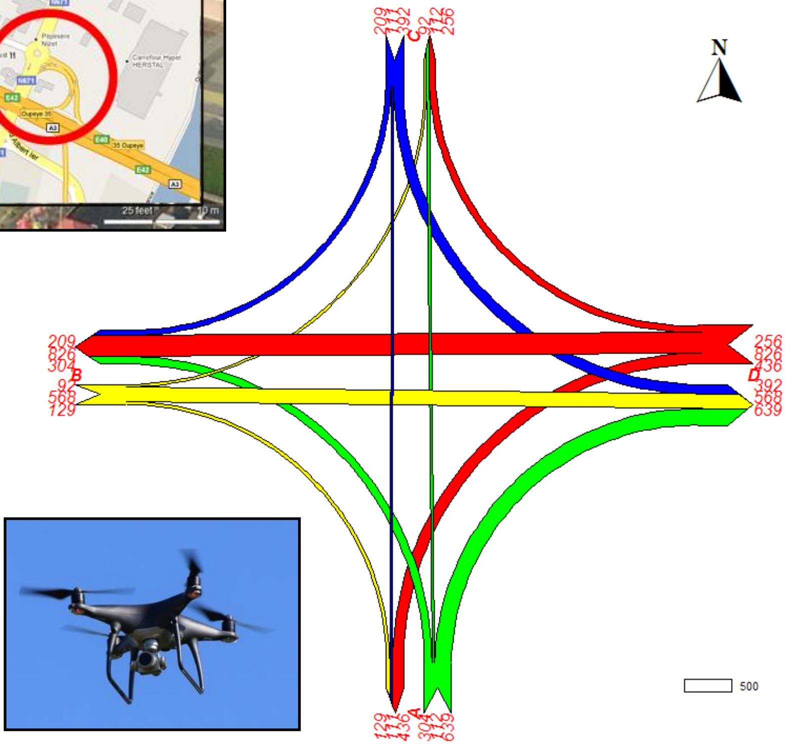




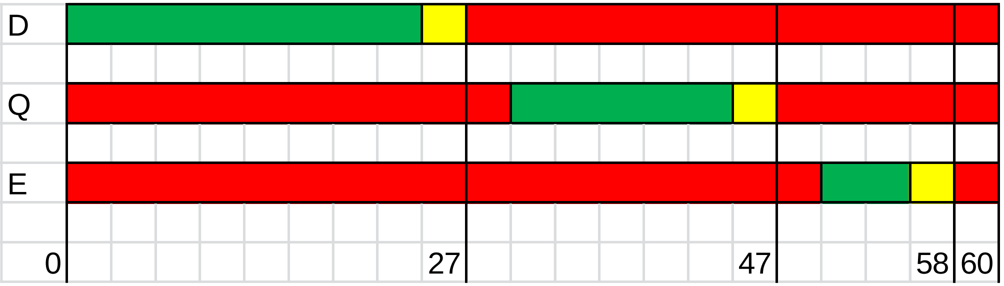
Sources: TML-FEBIAC (2021, 2022)

Visualising measurements: counts at intersections

(*turn-fractions*)



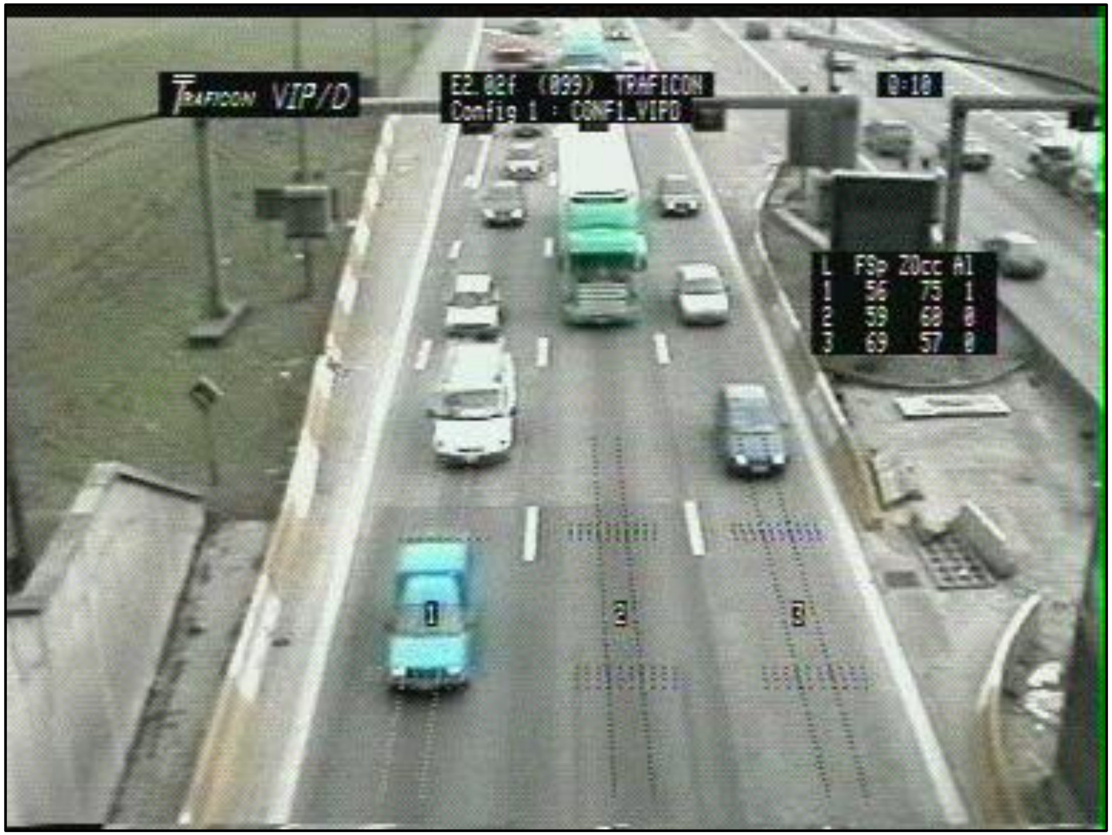
(*traffic signal plans*)



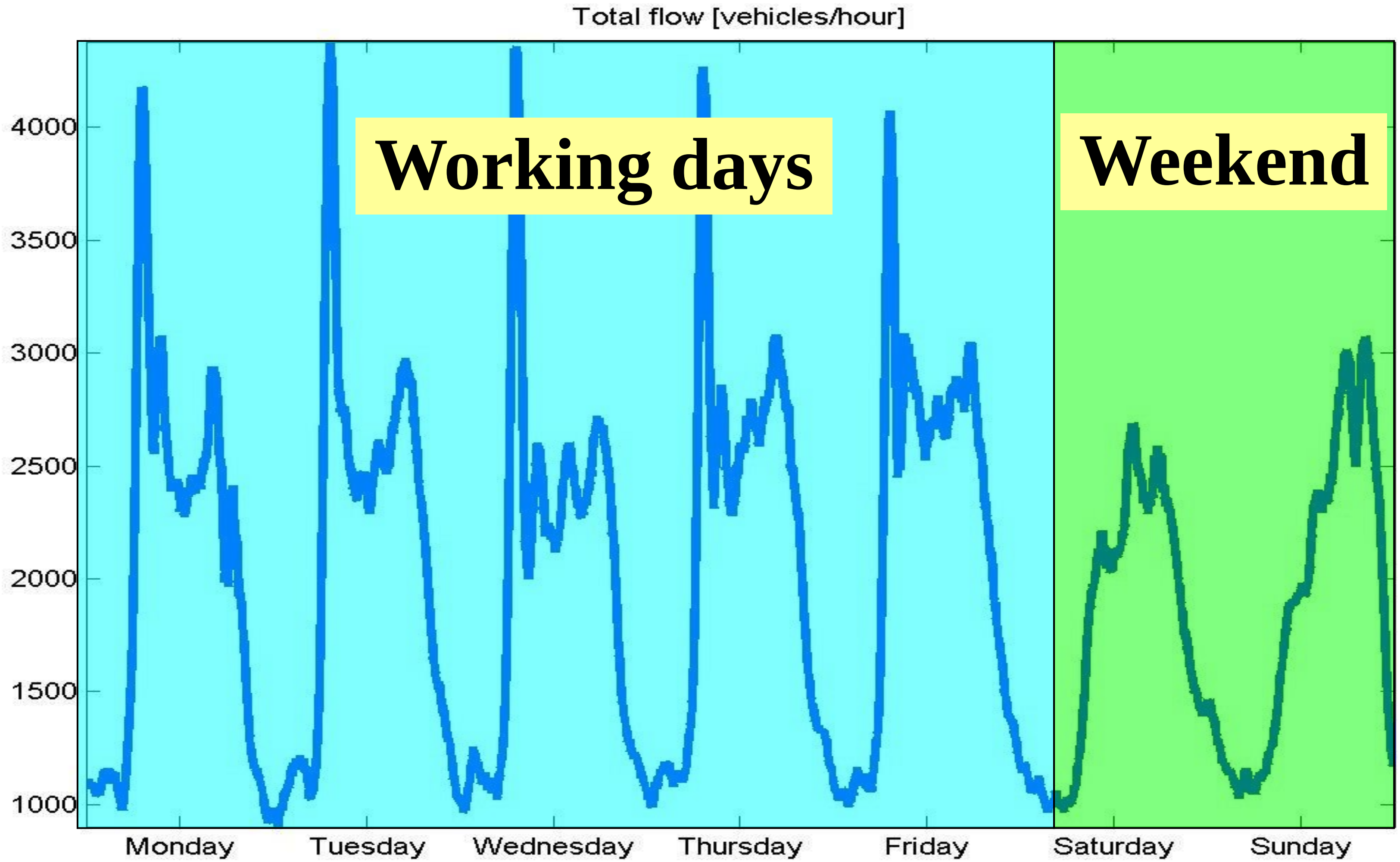
Sources: TML (2009, 2011)

Fixed datasources

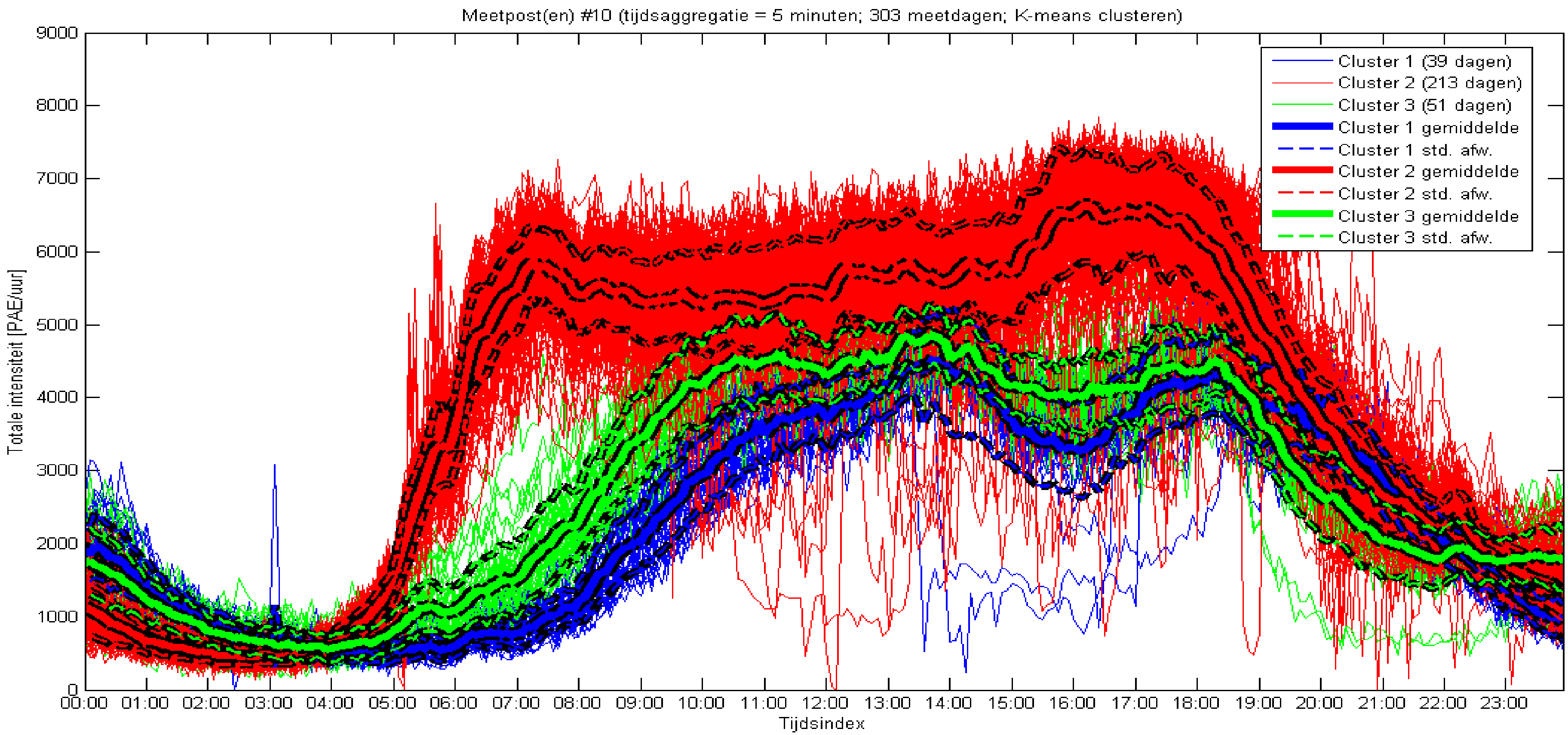
- Single/double inductive loop detectors in the pavement, radars, cameras, pneumatic tubes, ...

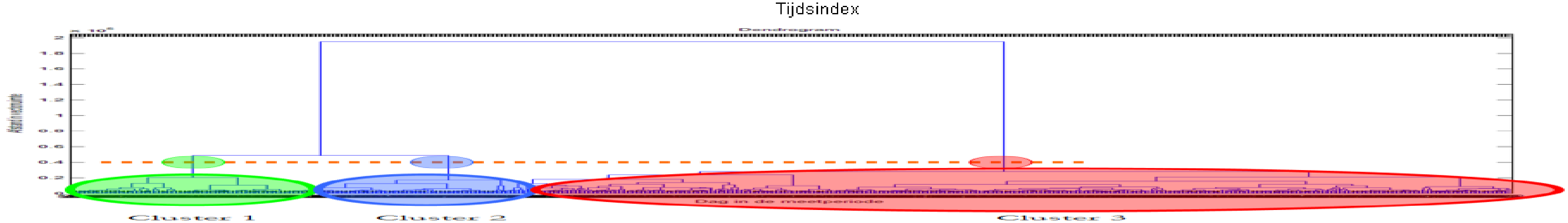


Visualising measurements: patterns

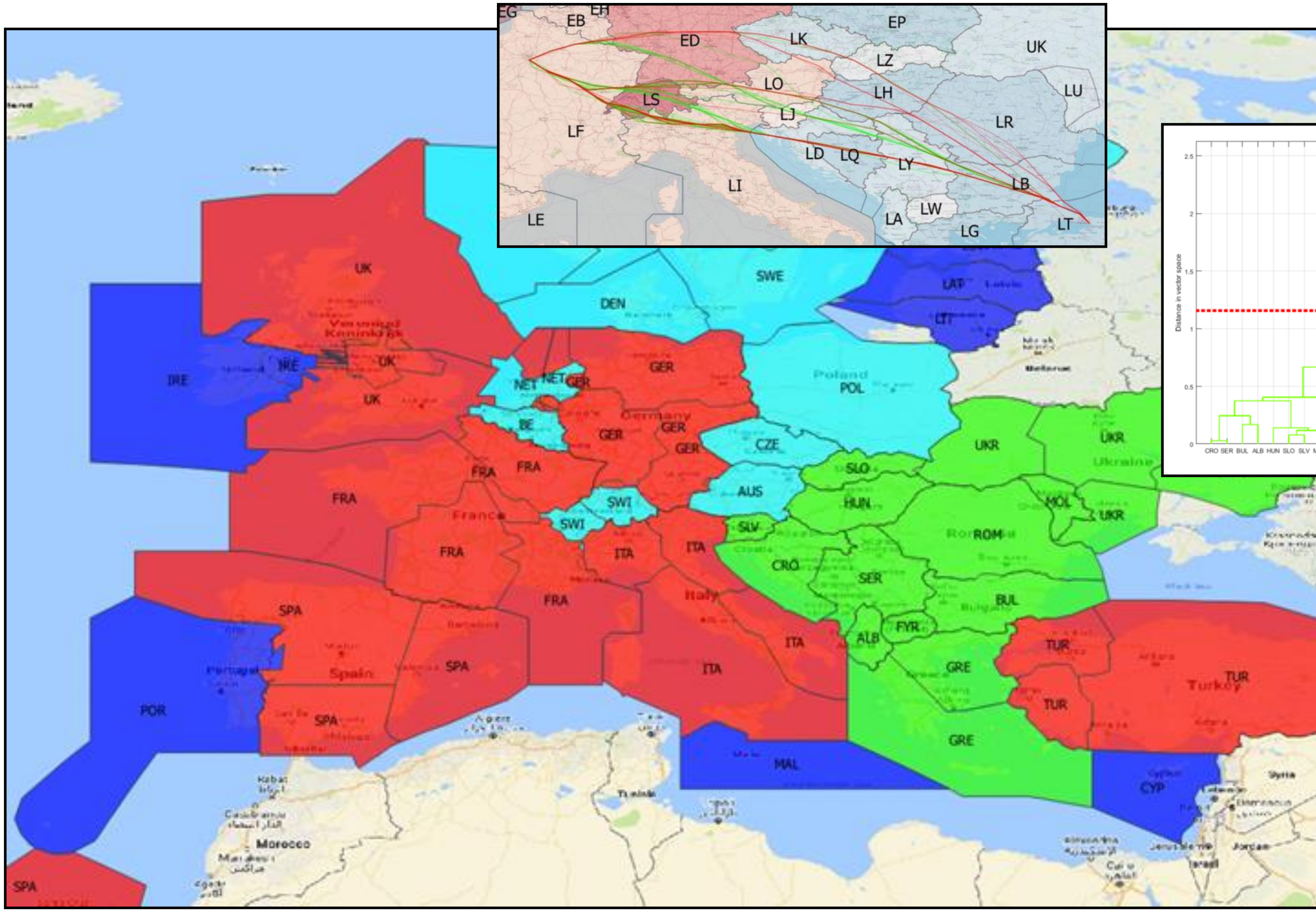


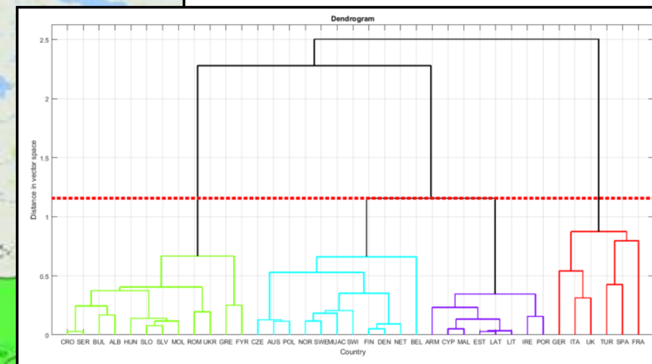
Clustering measurements: patterns



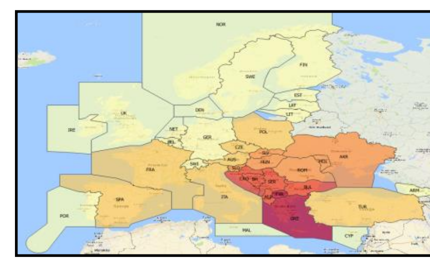


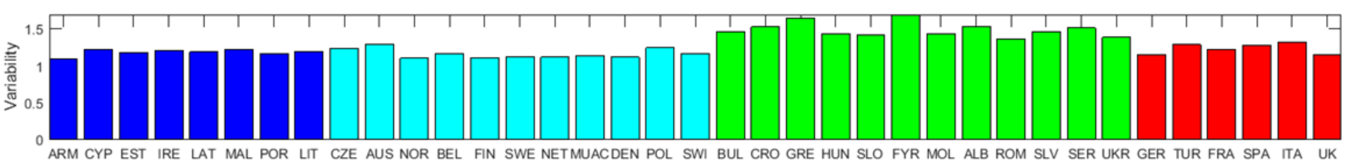
Clustering measurements: patterns (aviation sector)





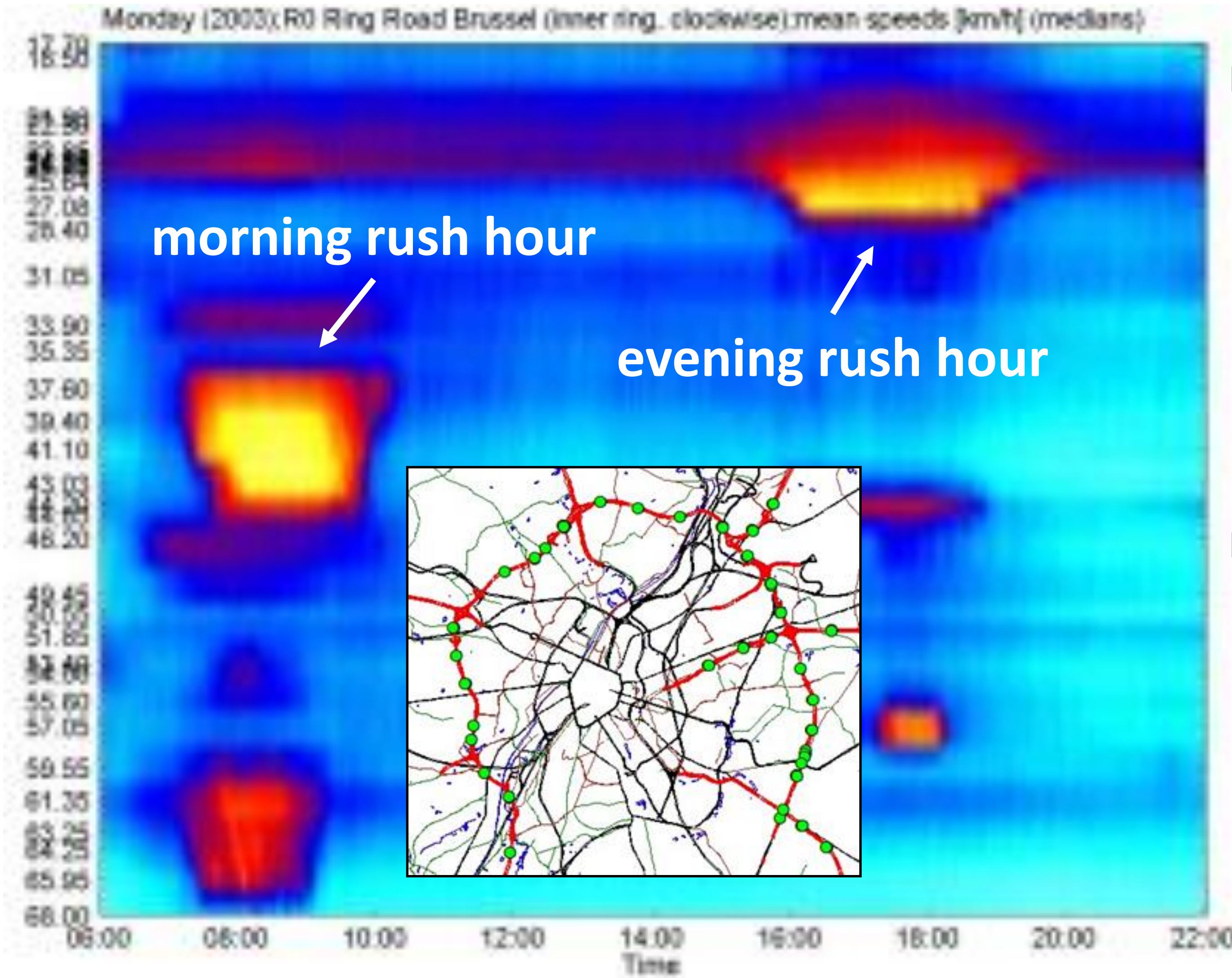
- Seasonal traffic variability
- Kilometres controlled
- Traffic complexity
- Number of sectors





Source: TML (2018)

Historical patterns are essential to understand



Morning:

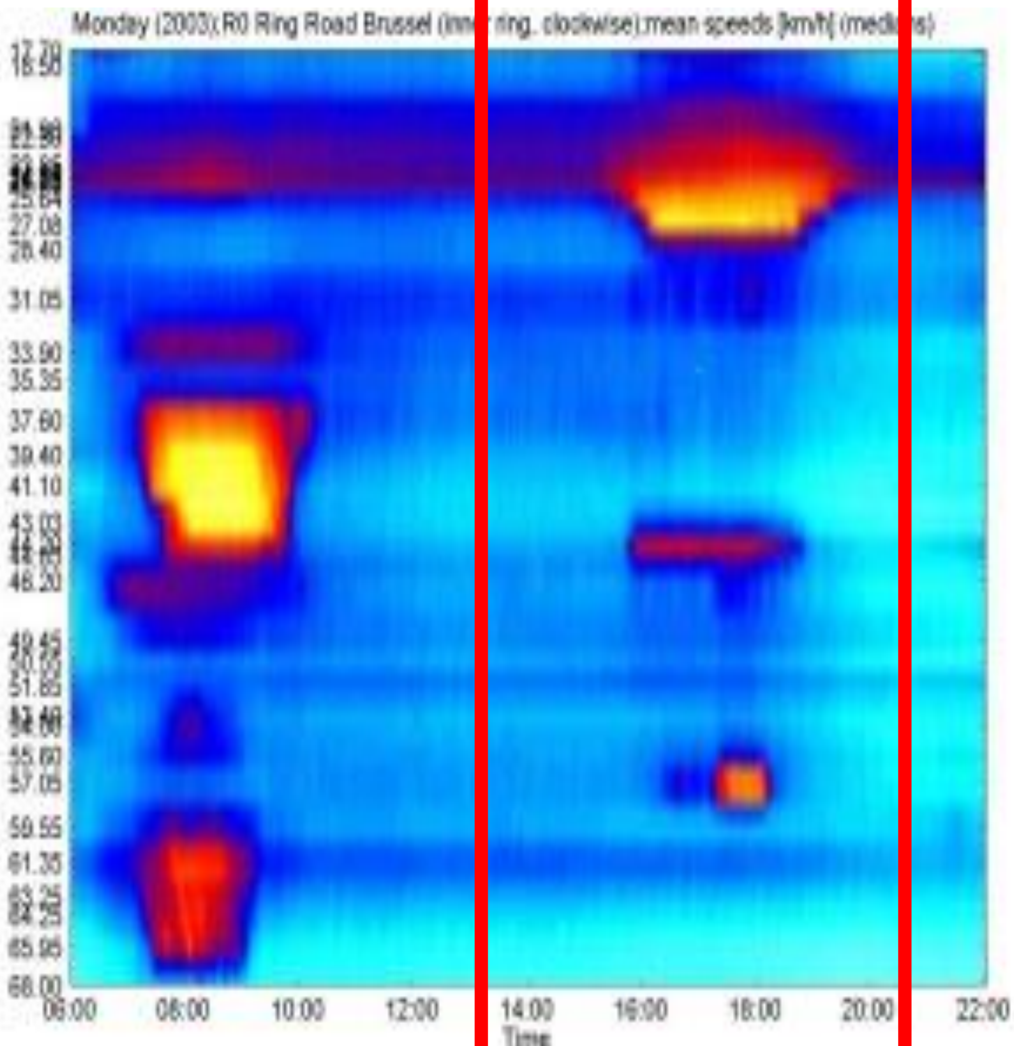
- *Heavy jams at Vilvoorde and Strombeek-Bever*
- *Slower traffic at the junction with the E19 and E40*

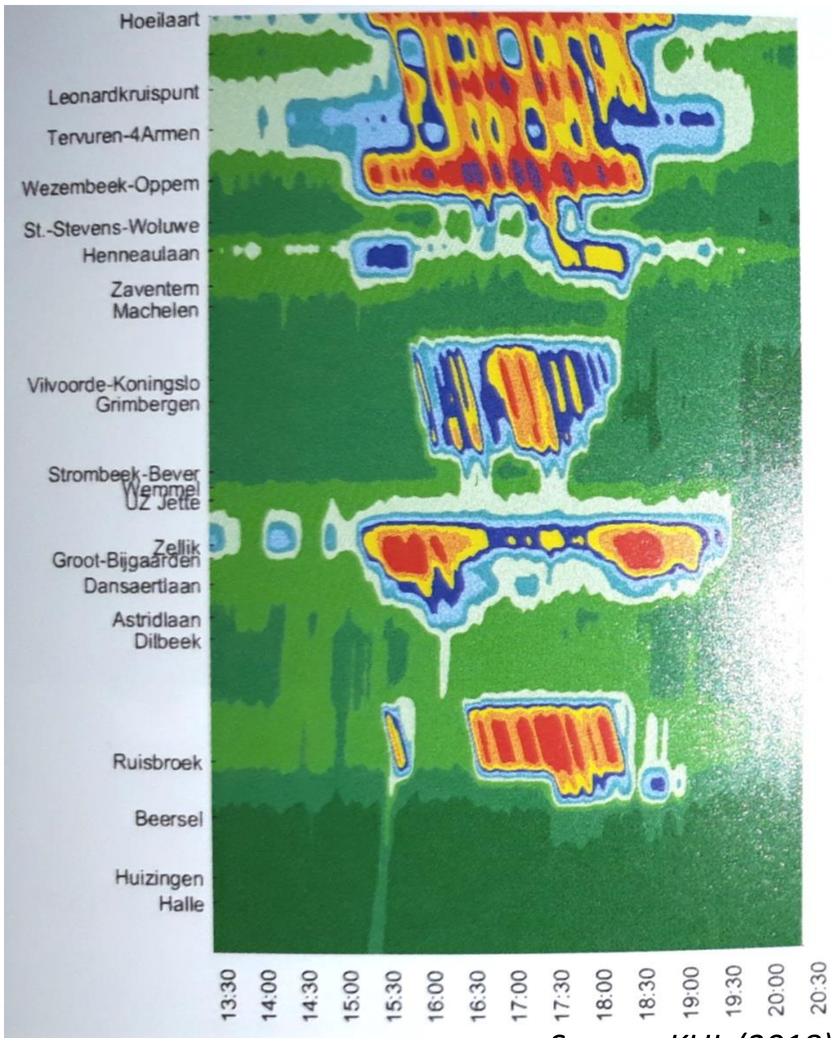
Evening:

- *Heavy jams at the Vierarmenkruispunt, Tervuren and Wezembeek-Oppem*

Source: KUL (2003)

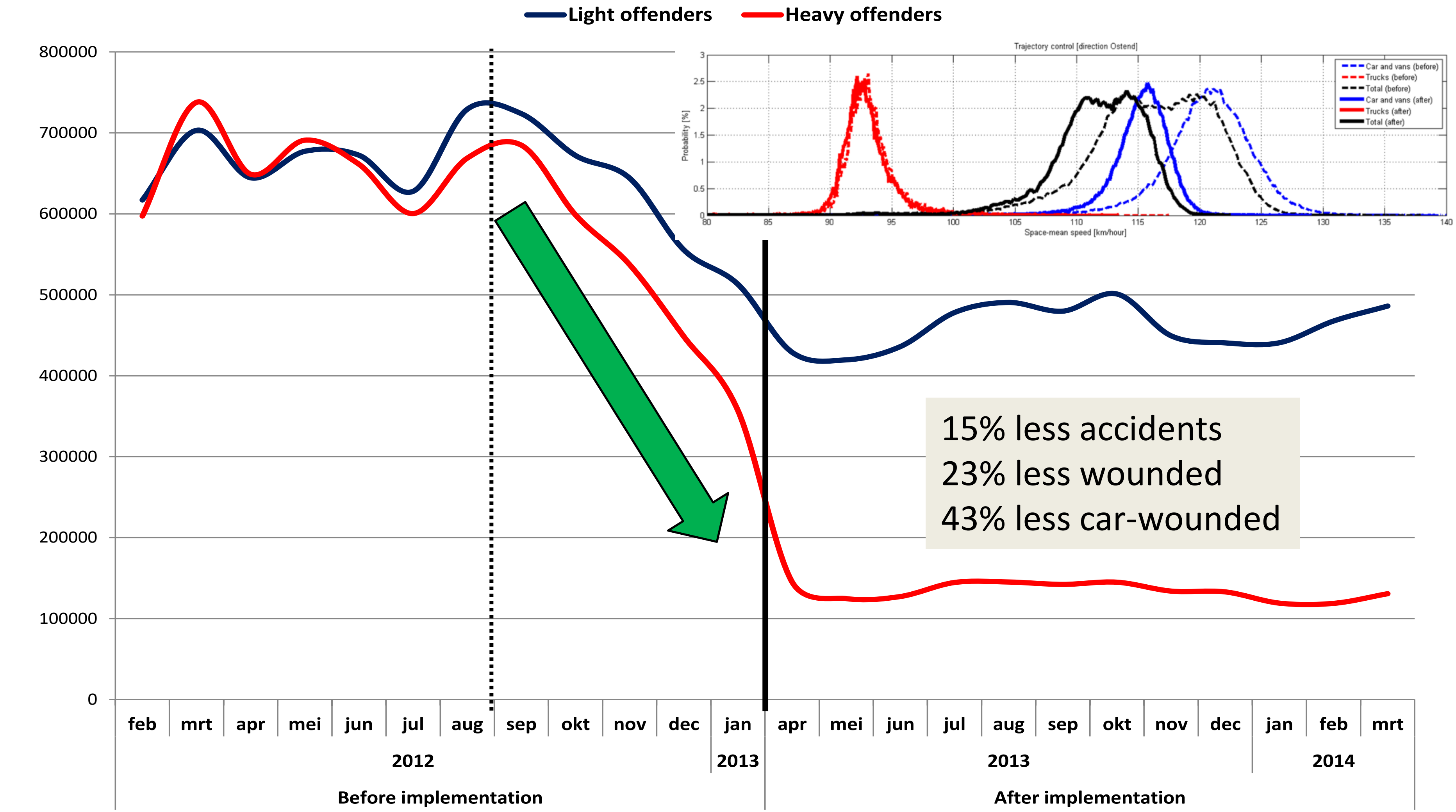
Example: evolution of congestion on R0





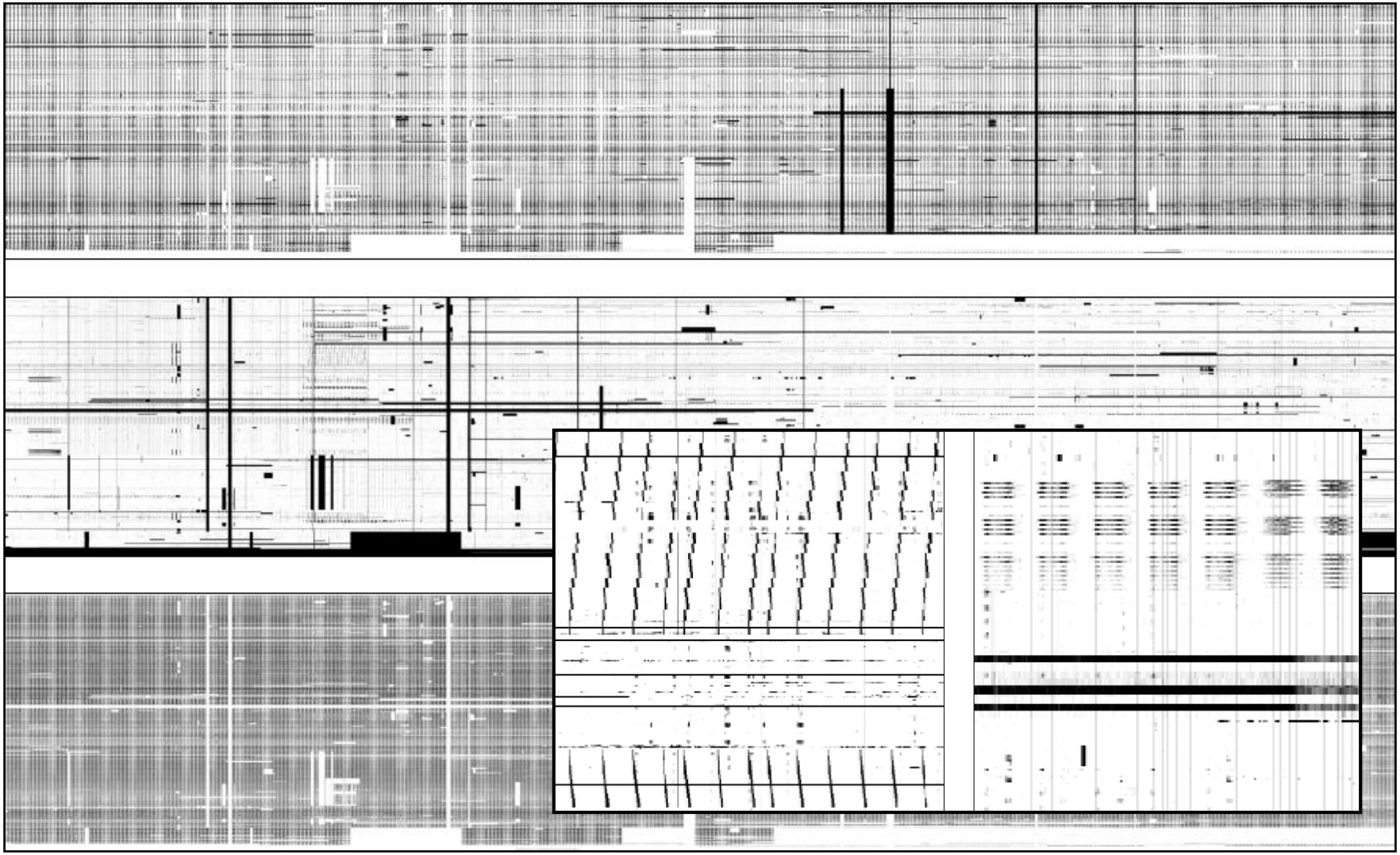
Source: KUL (2018)

The impact of an average speed control



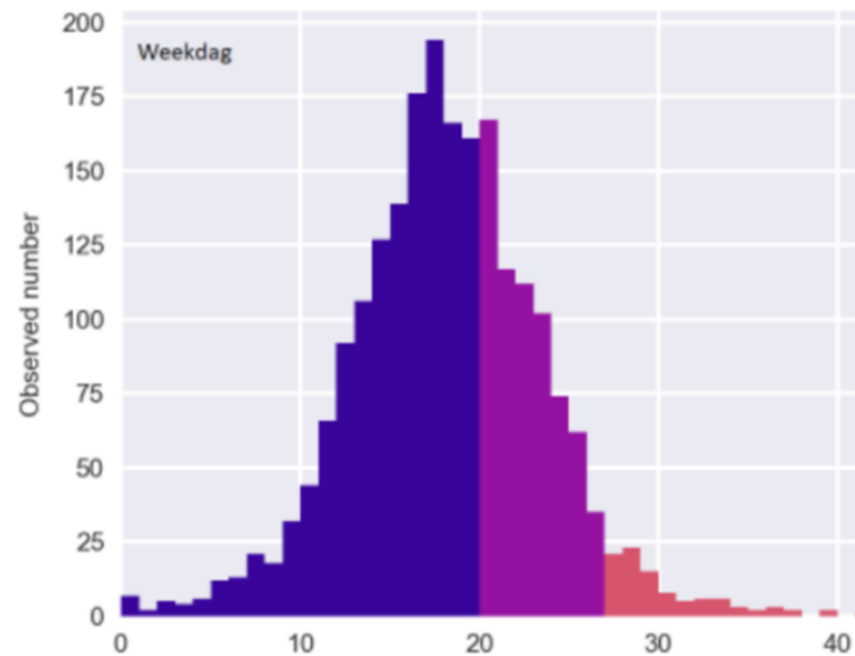
Source: TML (2014)

Insight into quality of measurements



Crowd sourcing of traffic counts: Telraam

- User management and web interface
- Front-end (contour detection)
- Back-end database (classification)

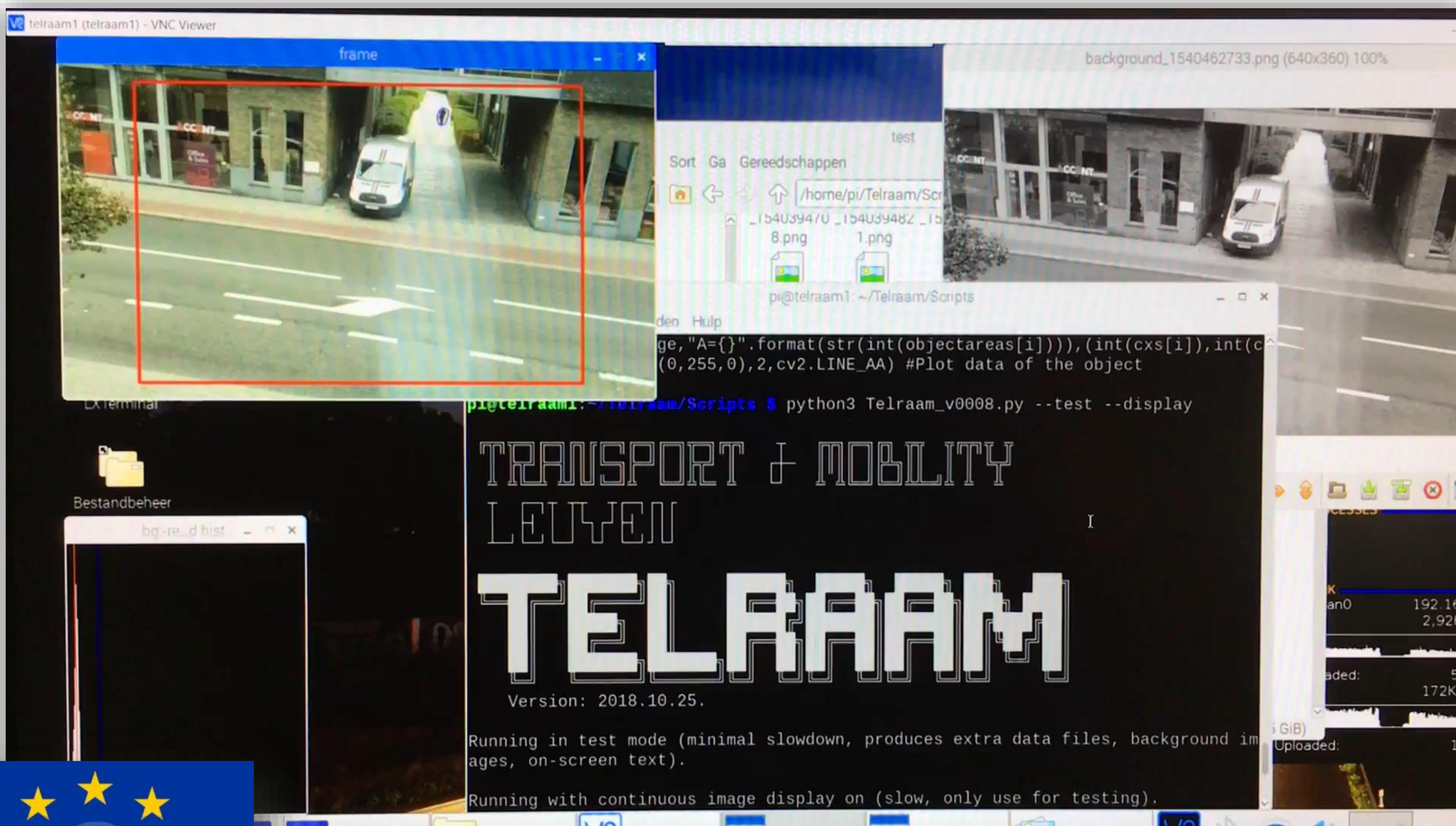


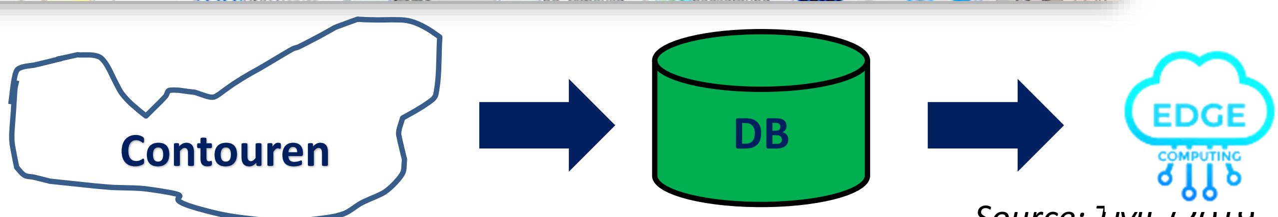
OpenStreetMap

Telraam

Source: TML (2019, 2020)

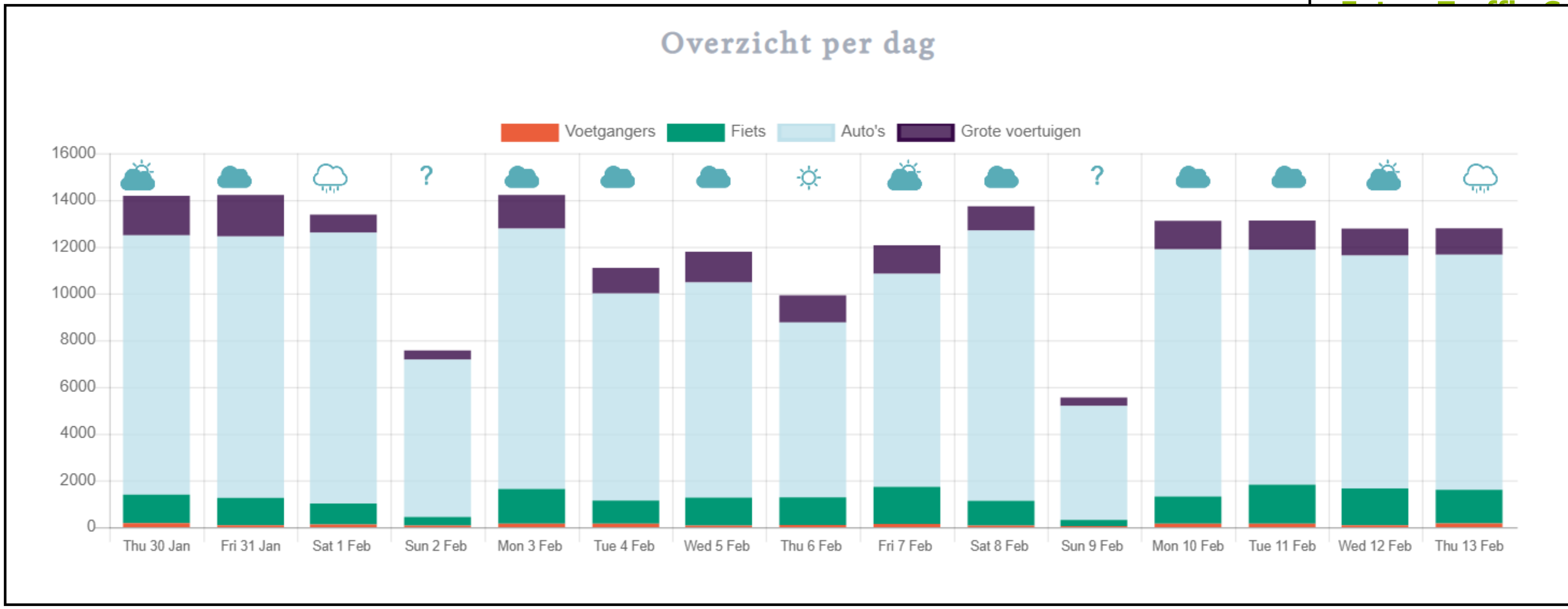
Crowd sourcing of traffic counts: Telraam

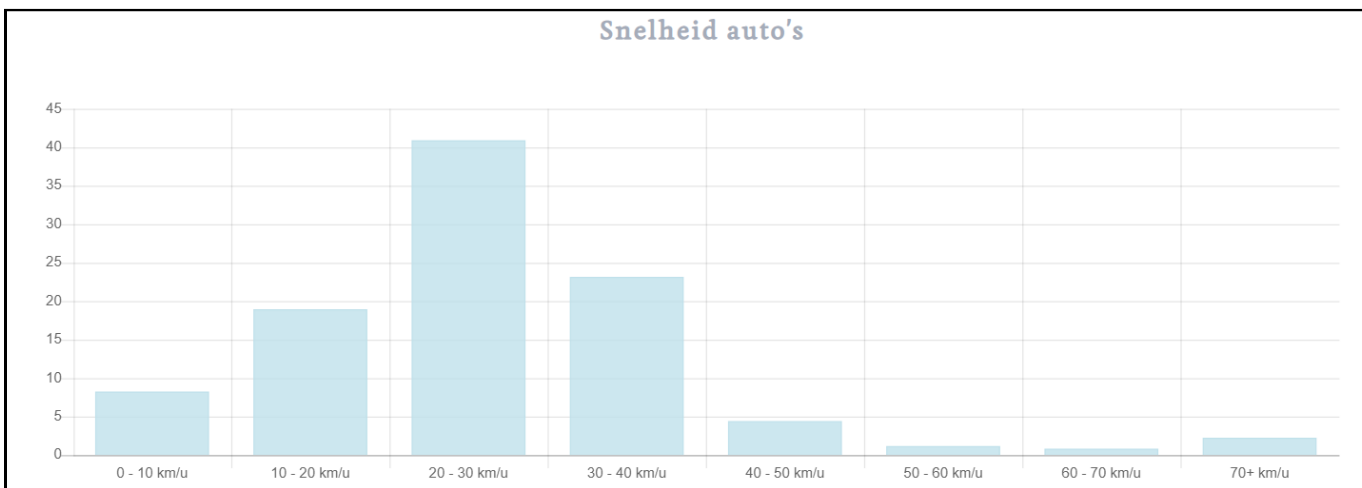




Source: TML (2019, 2020)

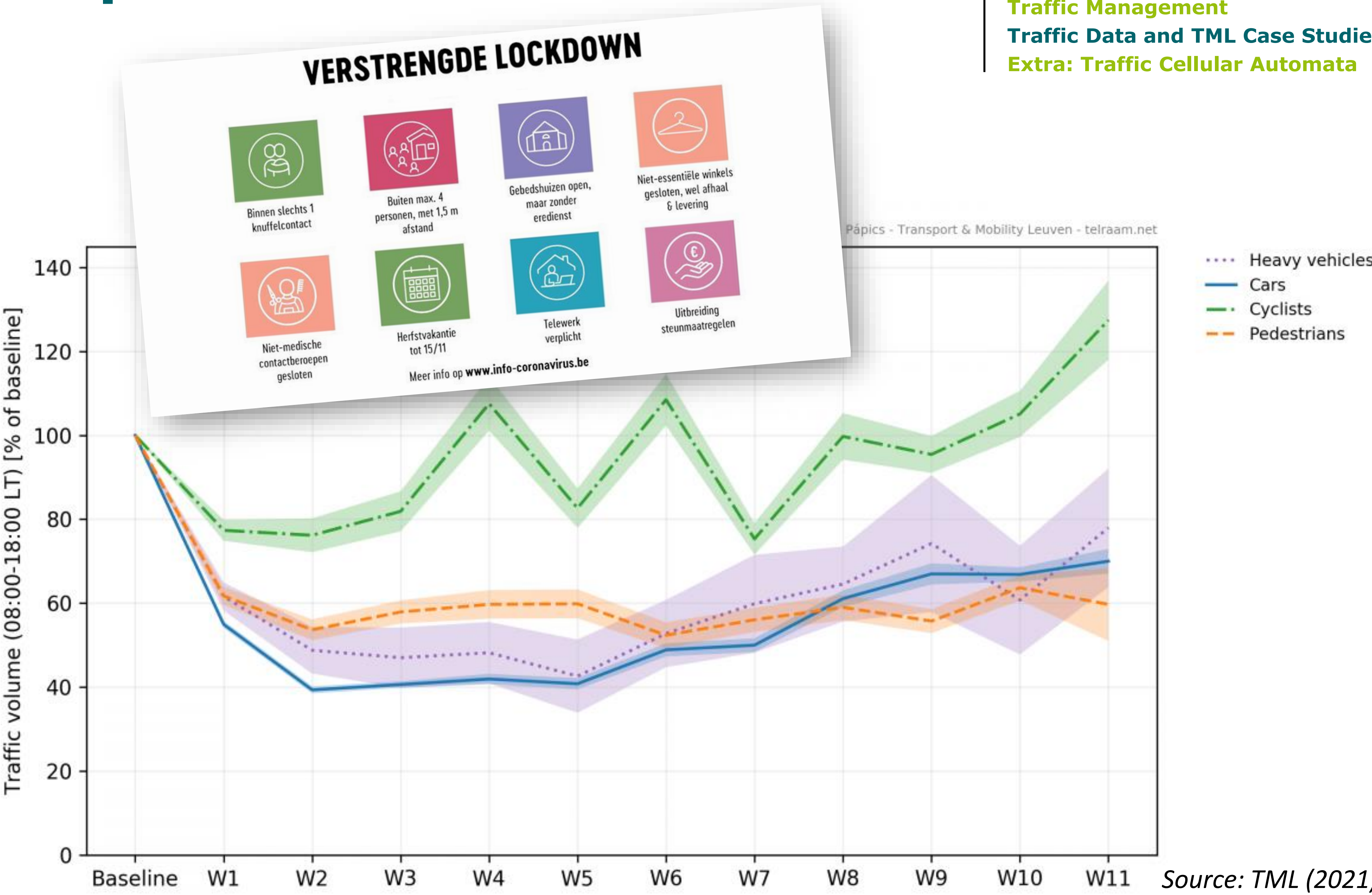
Image processing for speeds





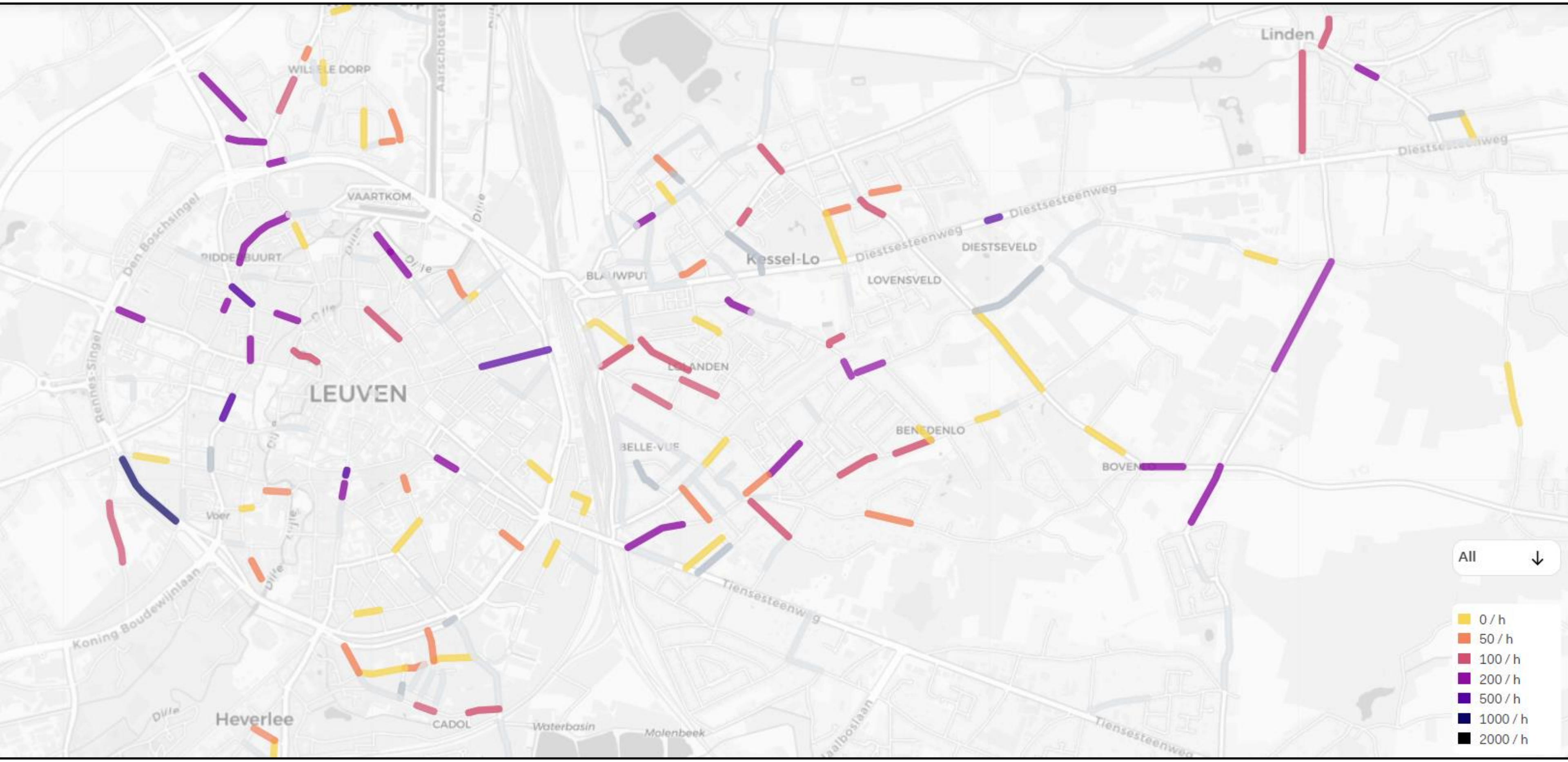
Source: TML (2020)

Impact assessment



Source: TML (2021)

Started with a small network in Leuven



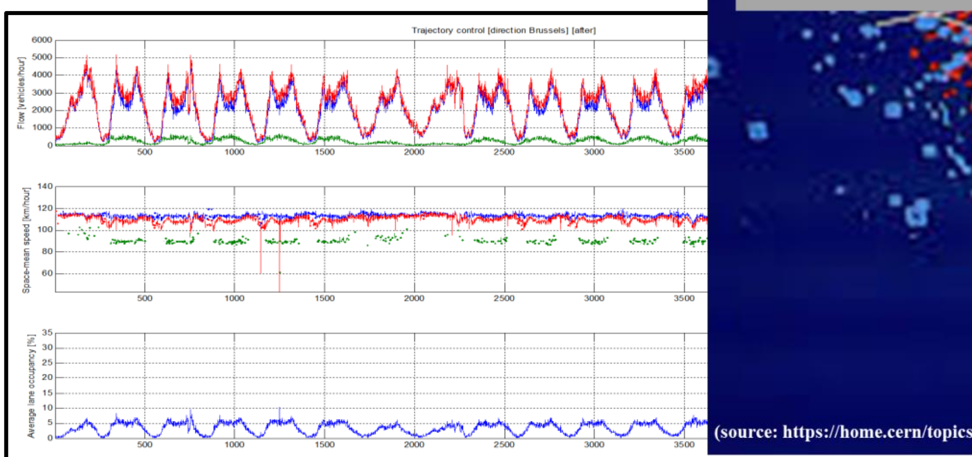
Source: TML (2019, 2022)

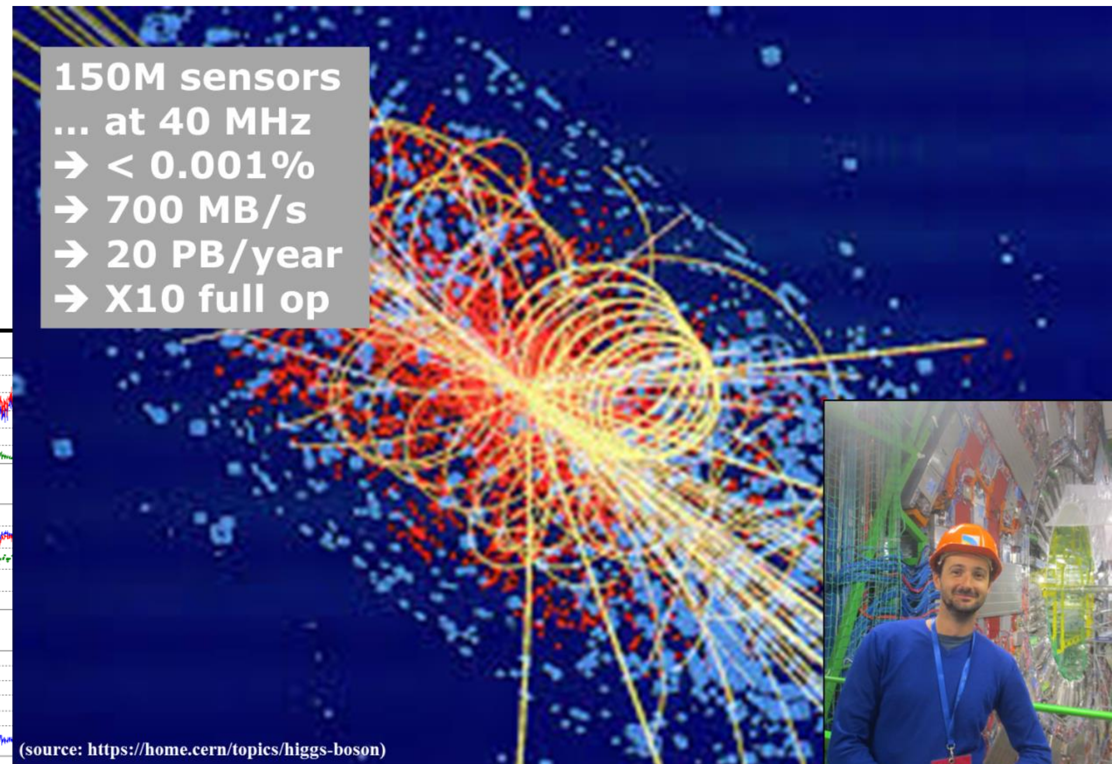
Growing the network

TML (2019-2022)

Want some data!? Yes, big and open please!

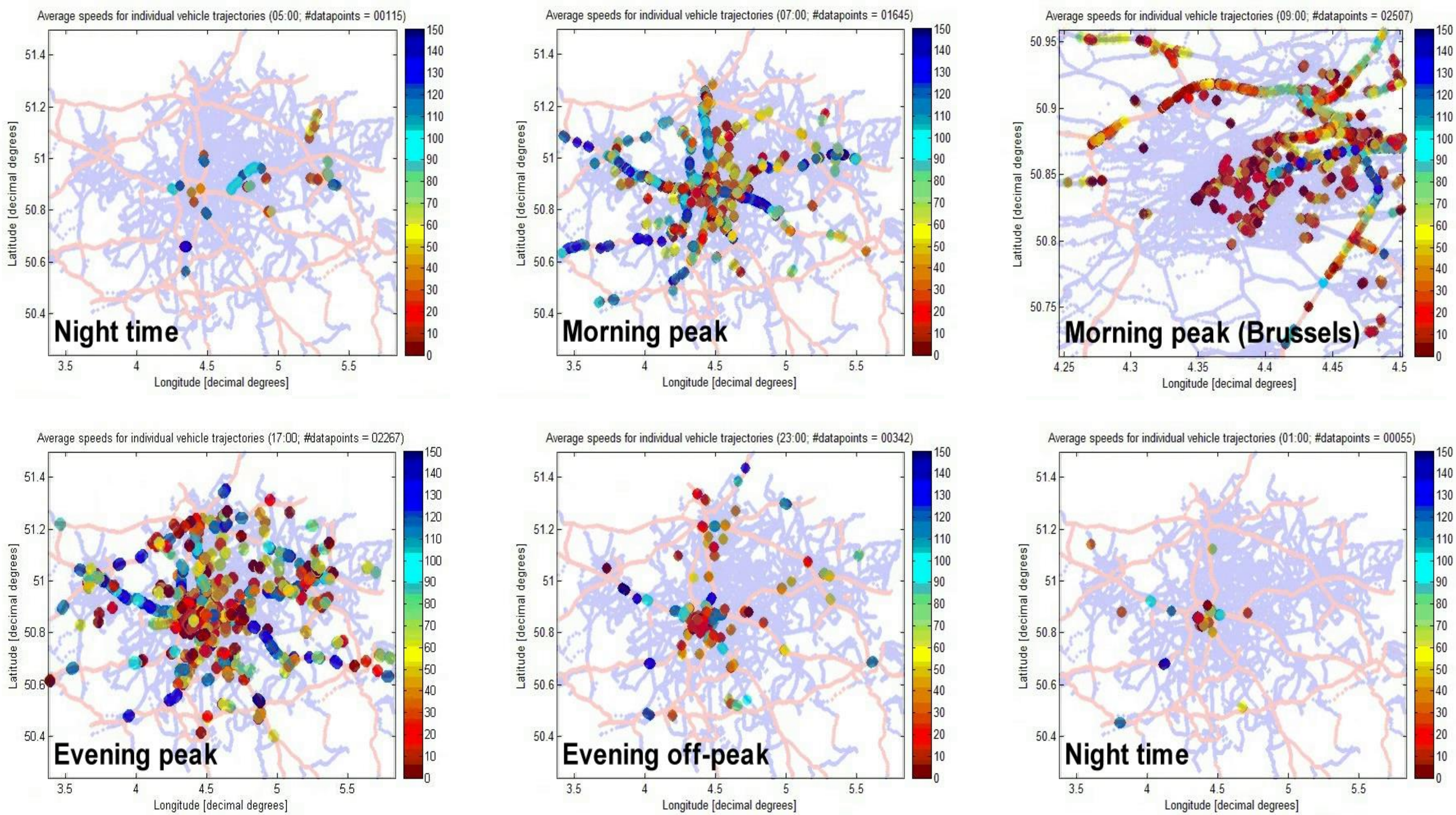
- Volume (size)
- Velocity (speed of change)
- Variety (different forms)
- Veracity (uncertainty)
- Value (complexity)





"Big" is an evolving, yet relative concept

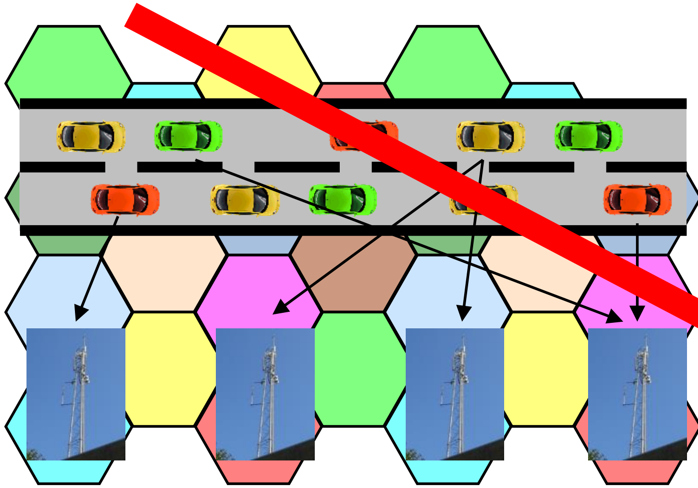
Mobility just seems Large, but is becoming Big: patterns

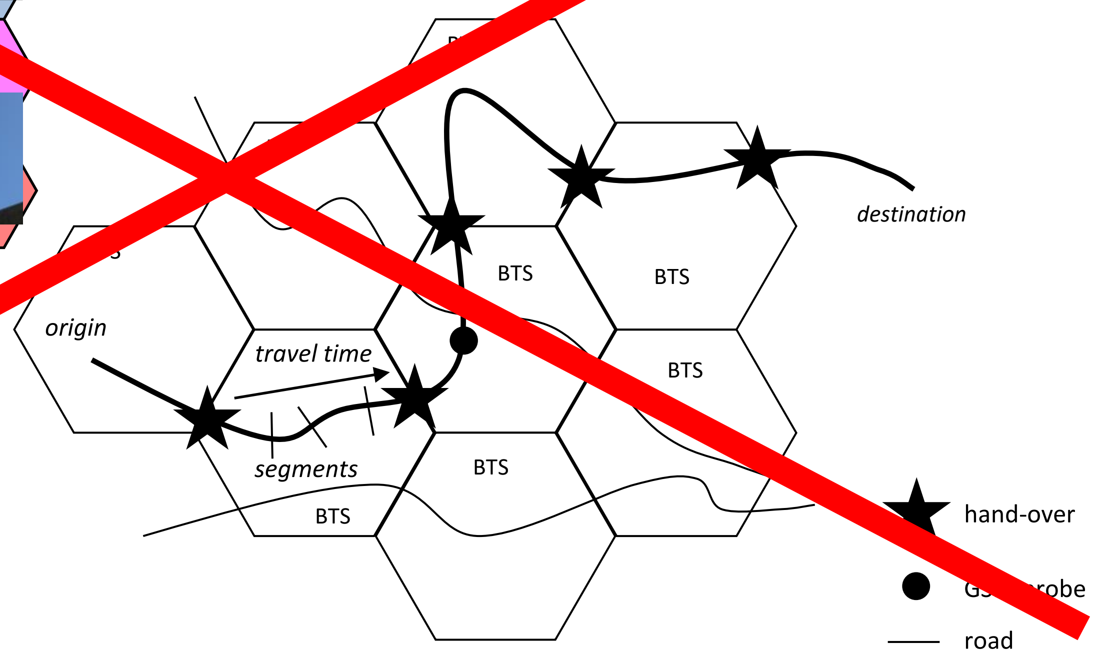


Source: TML (2011)

Technology: validation of CFVD (GSM)

- Tracking of *hand-overs* at cell boundaries during conversations

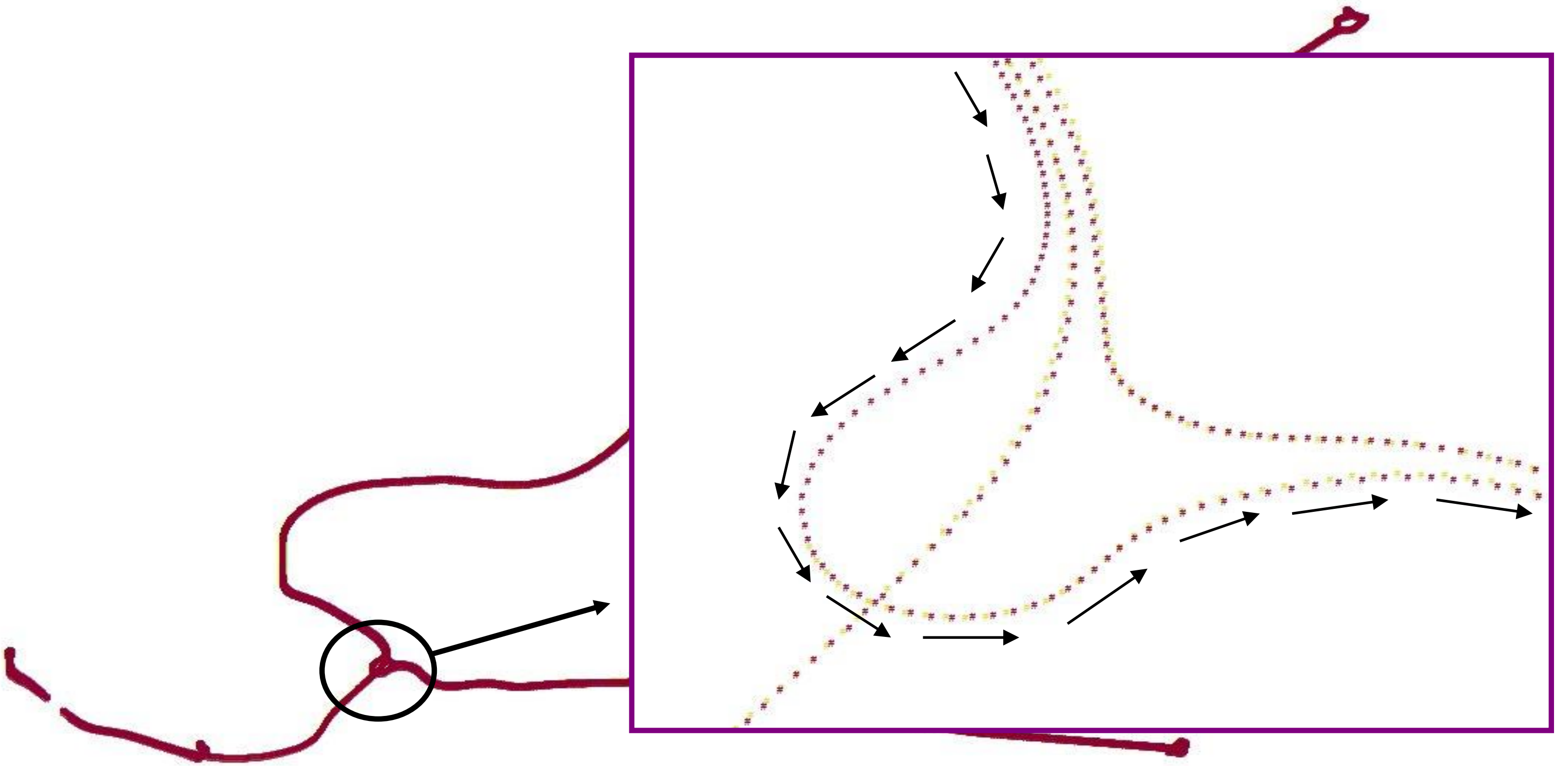




Source: TML (2006)

Higher accuracy: GPS

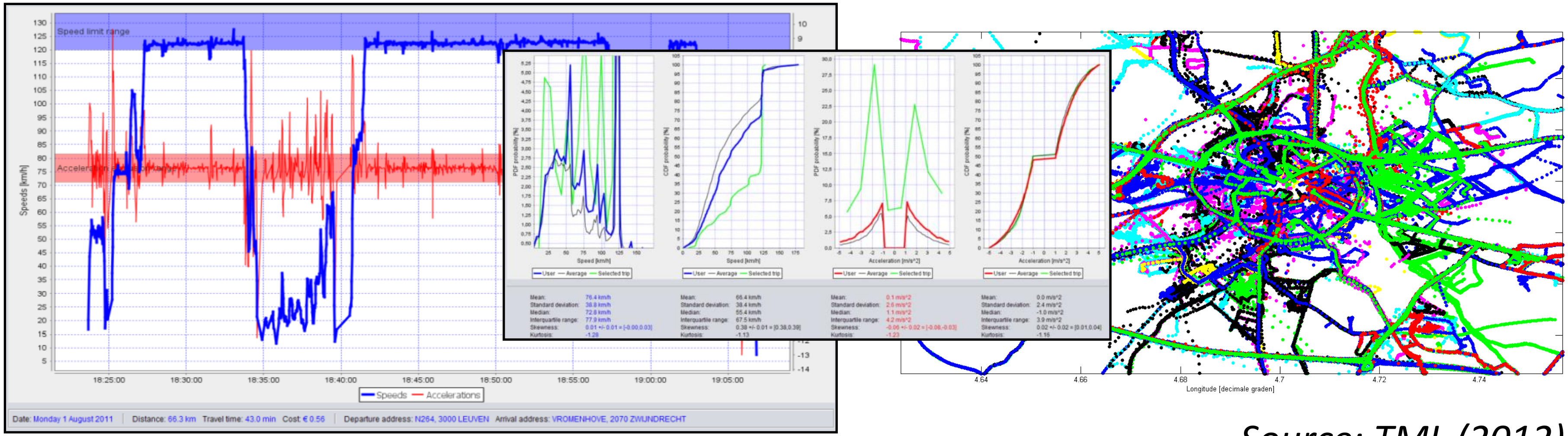
- **GPS-probe vehicles** (e.g. trucks, lease cars, taxis, …)
- NASA GPS (24 satellites) / Europe (ESA) Galileo



Source: TML (2006)

From large data to really big data

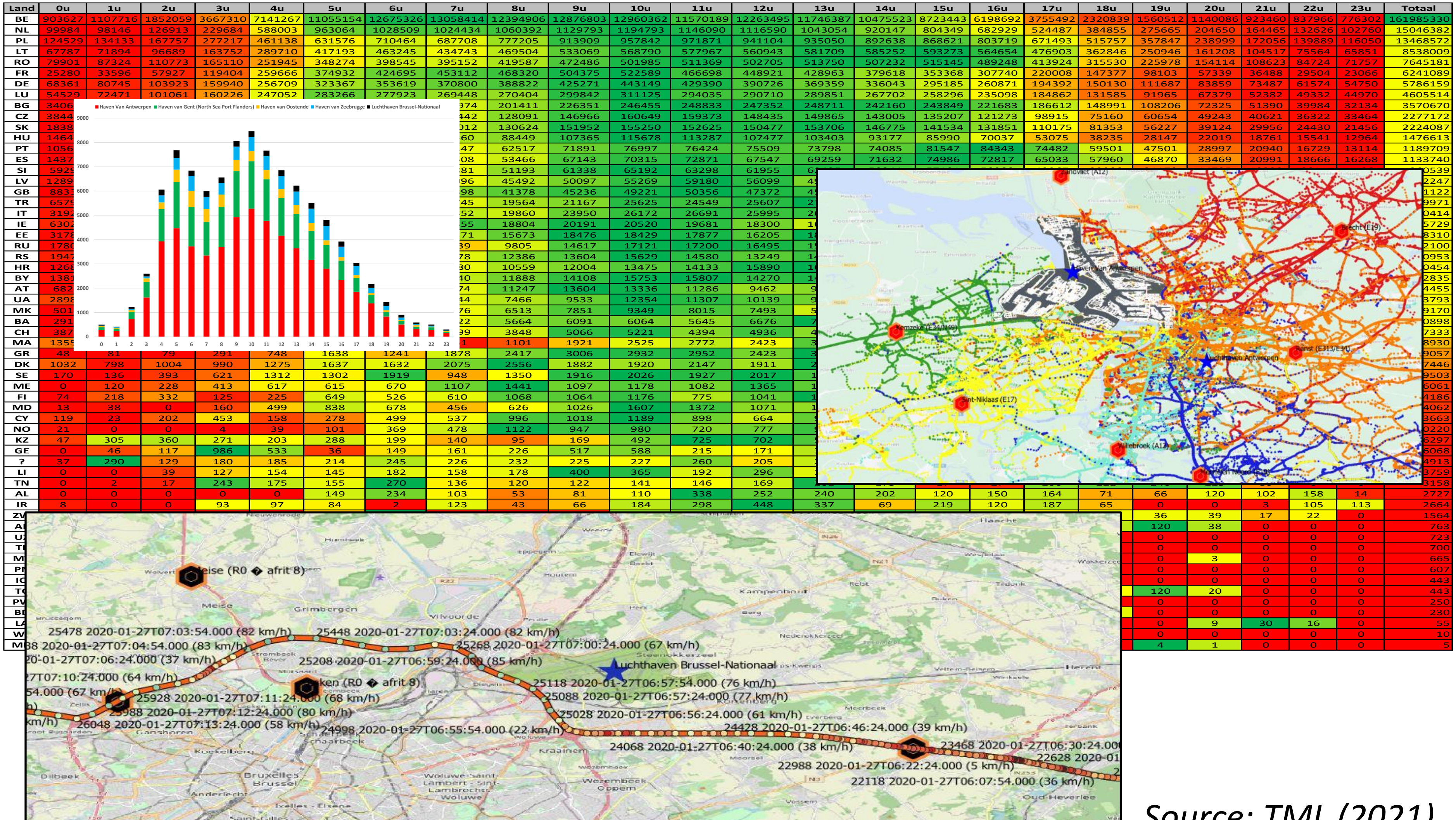
- The new generation of mobile data
  - GSM is kinda ‘out’, GPS is more than in!
  - Less and less problems with estimation of traffic volumes.
    ➔ Fusion with available measurements (via traffic centres)



Source: TML (2012)

- Going beyond (X-)FCD:
  - E.g., mobility patterns from Bluetooth-scanners, Twitter feeds, Android locations, …

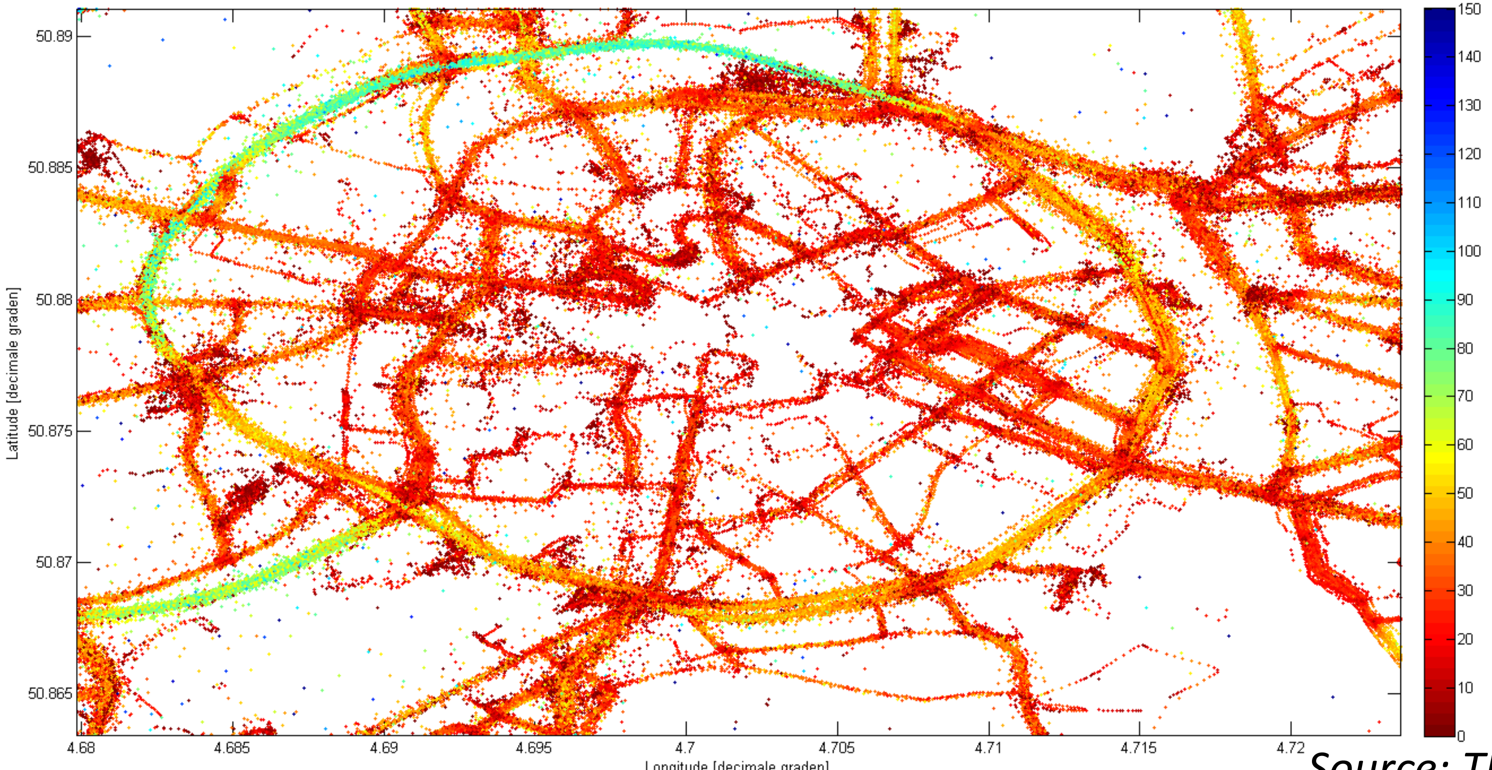
Analysis of trucks OBU data



Source: TML (2021)

Micro level: speeding infractions

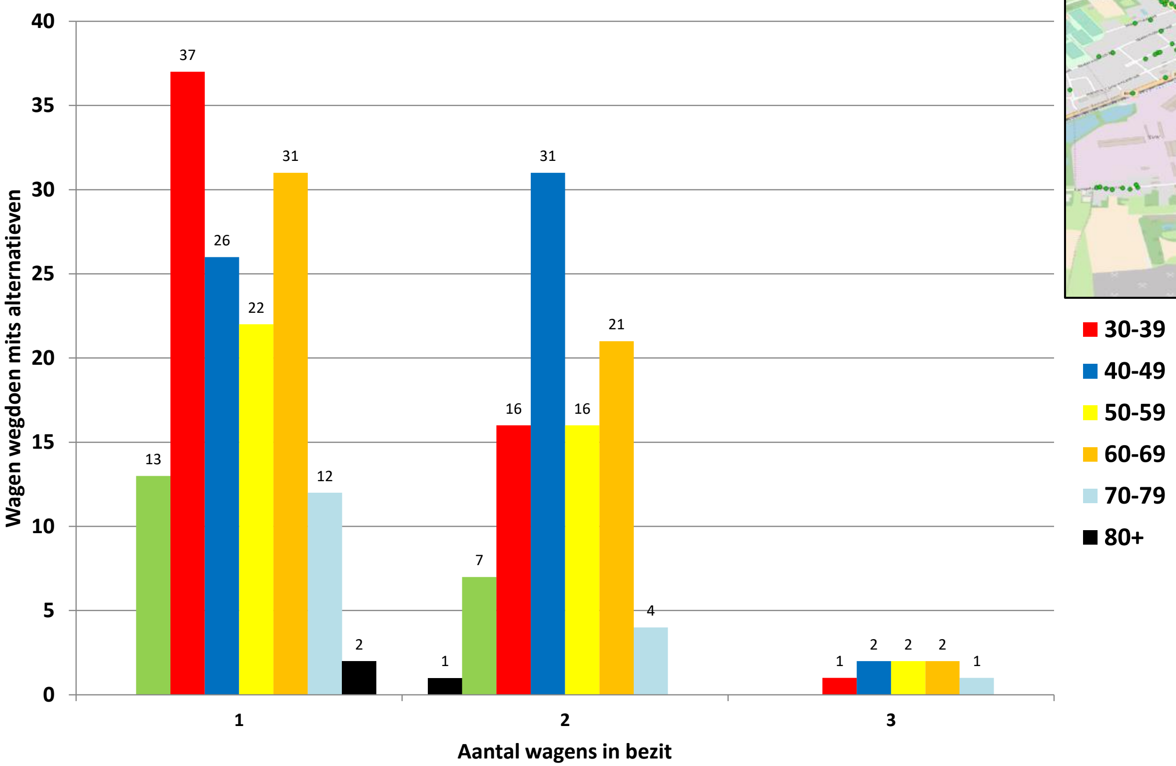
- Detailed speed measurements can be correlated with reigning traffic speed limits at specific locations
- Right-of-way, following distances, interactions, …



Source: TML (2012)

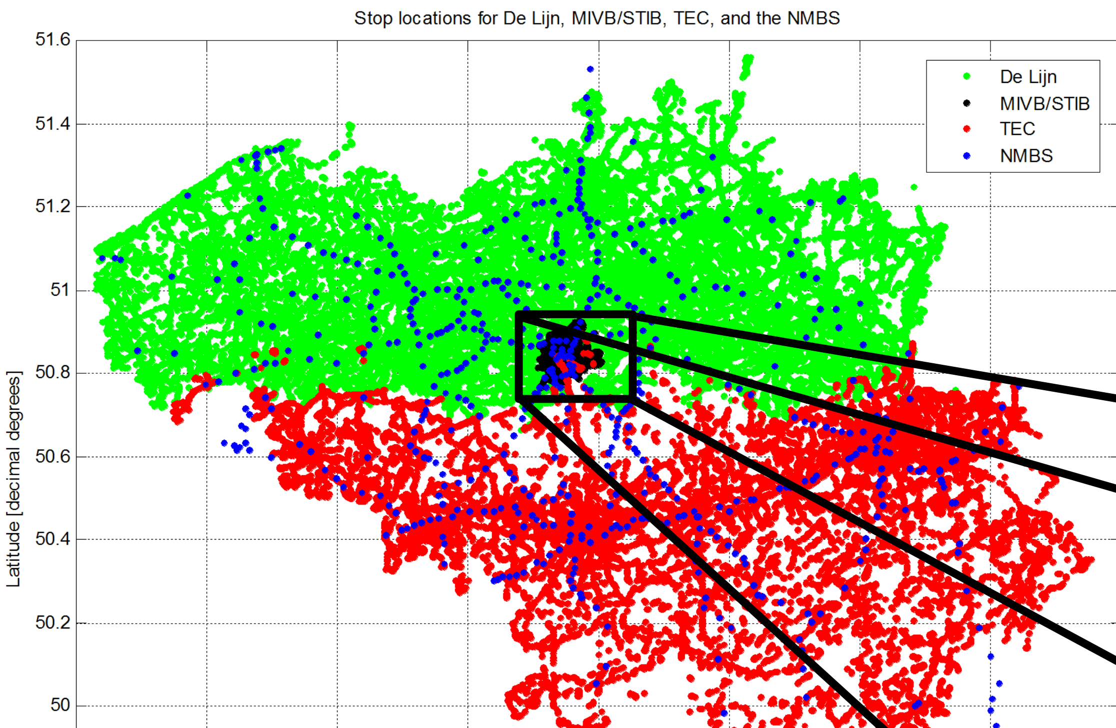
Garage Swap

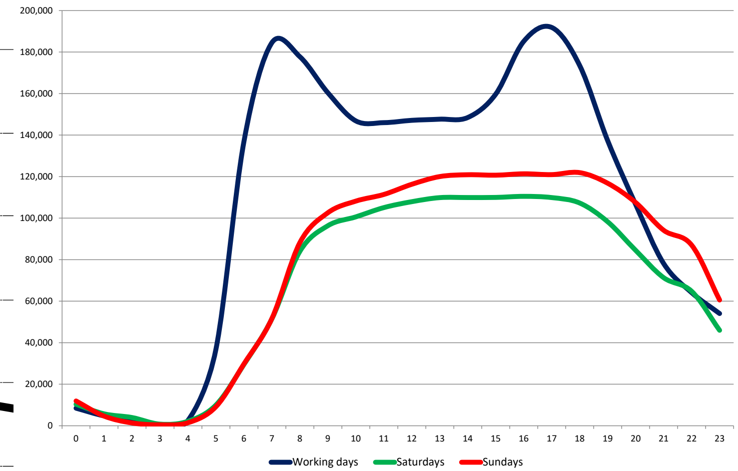
- Willingness for car sharing / abandoning cars
- Organising large-scale surveys (e.g., Sint-Niklaas)
- Statistical analyses of results

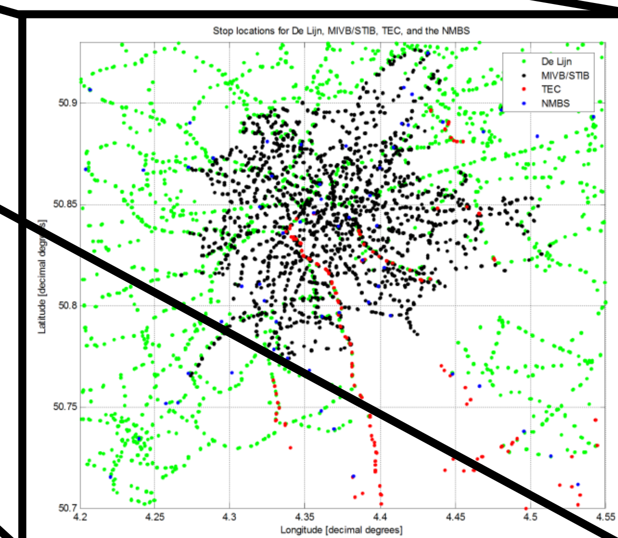


Source: TML (2019)

Integration with public transport: co-modality





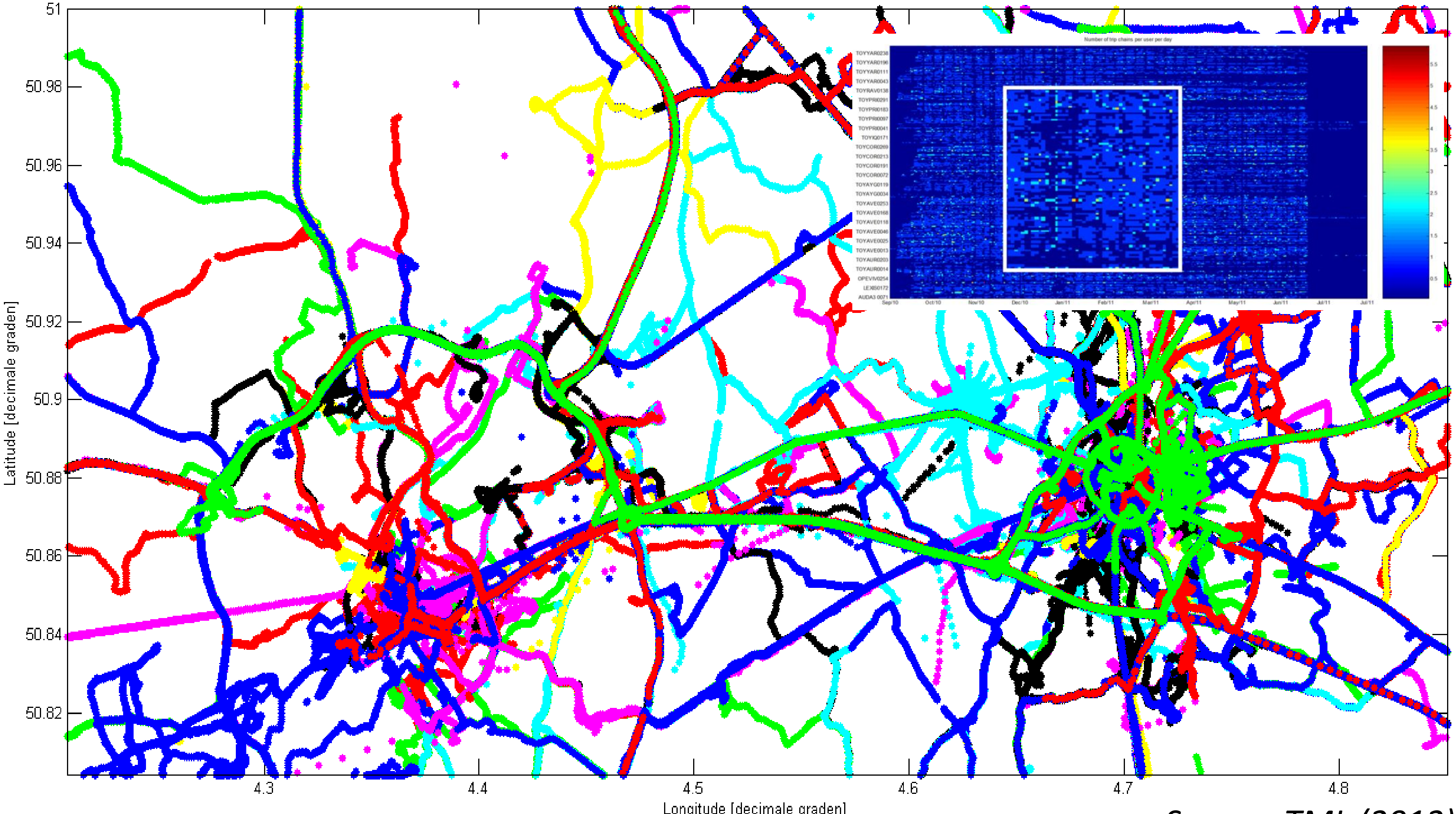


Comodality = the new multimodality!

Work

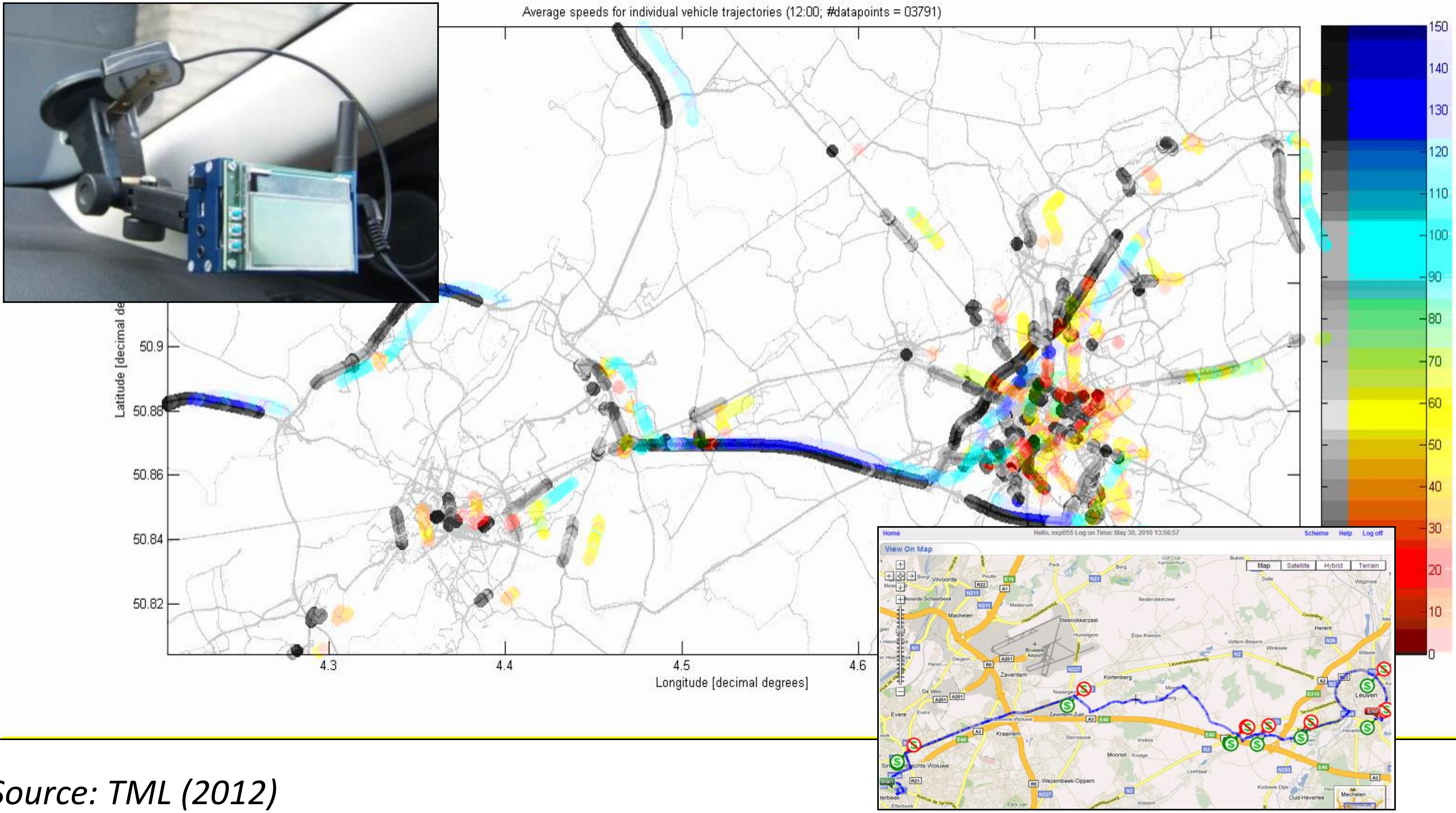
Source: TML (2011)

Discovering travel patterns beyond classic OVG



Source: TML (2012)

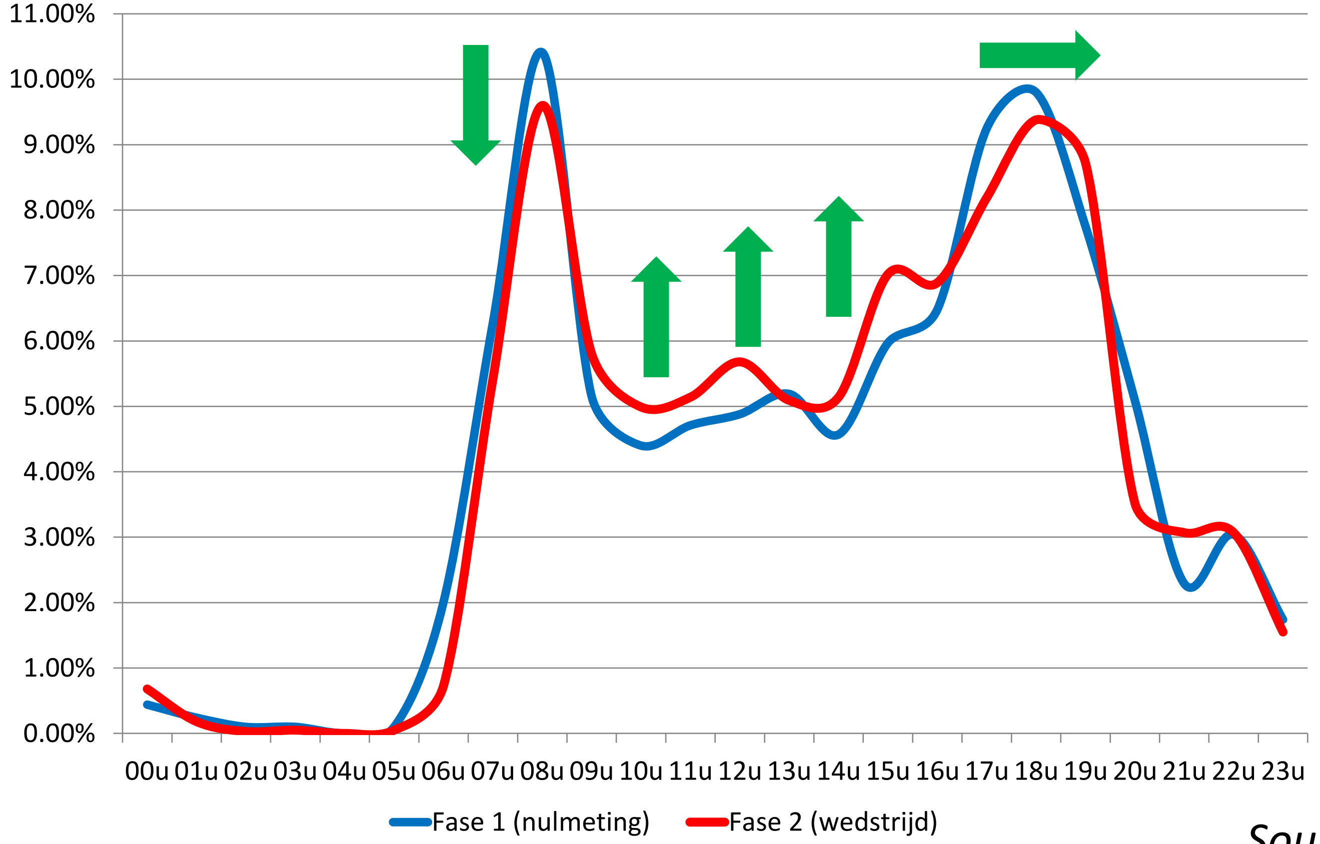
A behavioural experiment with road user charging



Source: TML (2012)

Peak shifting due to road user charging

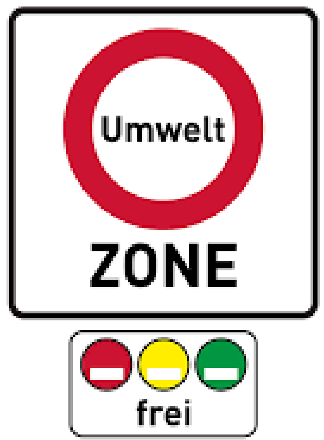
- People drove less during the morning rush hour, more during the day and later during the evening rush hour

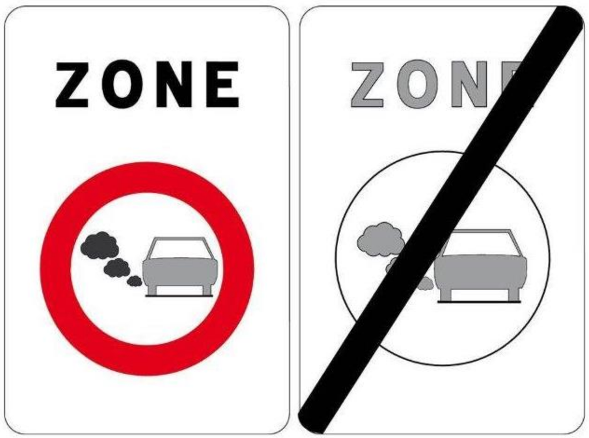


Source: TML (2012)

LEZ… say what?

- (Ultra) Low-Emission Zones (**(U)LEZ**):
  - Restrict access by some polluting vehicles (e.g., ≥ EURO IV)
  - Have the explicit goal to improve the air quality
- Zero-Emission Zones (**ZEZ**):
  - Only allow all-electric vehicles (ICEs are banned, incl. hybrids)

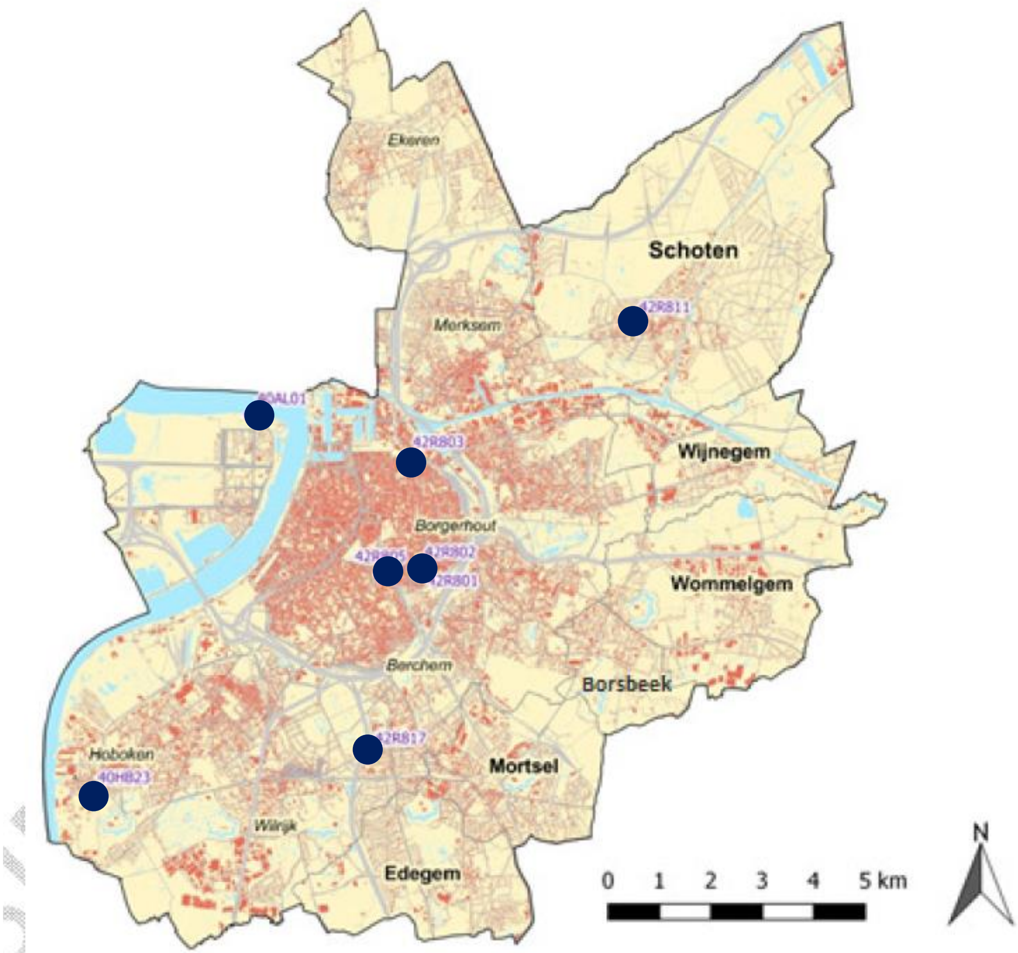




- Vehicle fleet changes → healthier (but no effects on mode/destination/trip choice!)

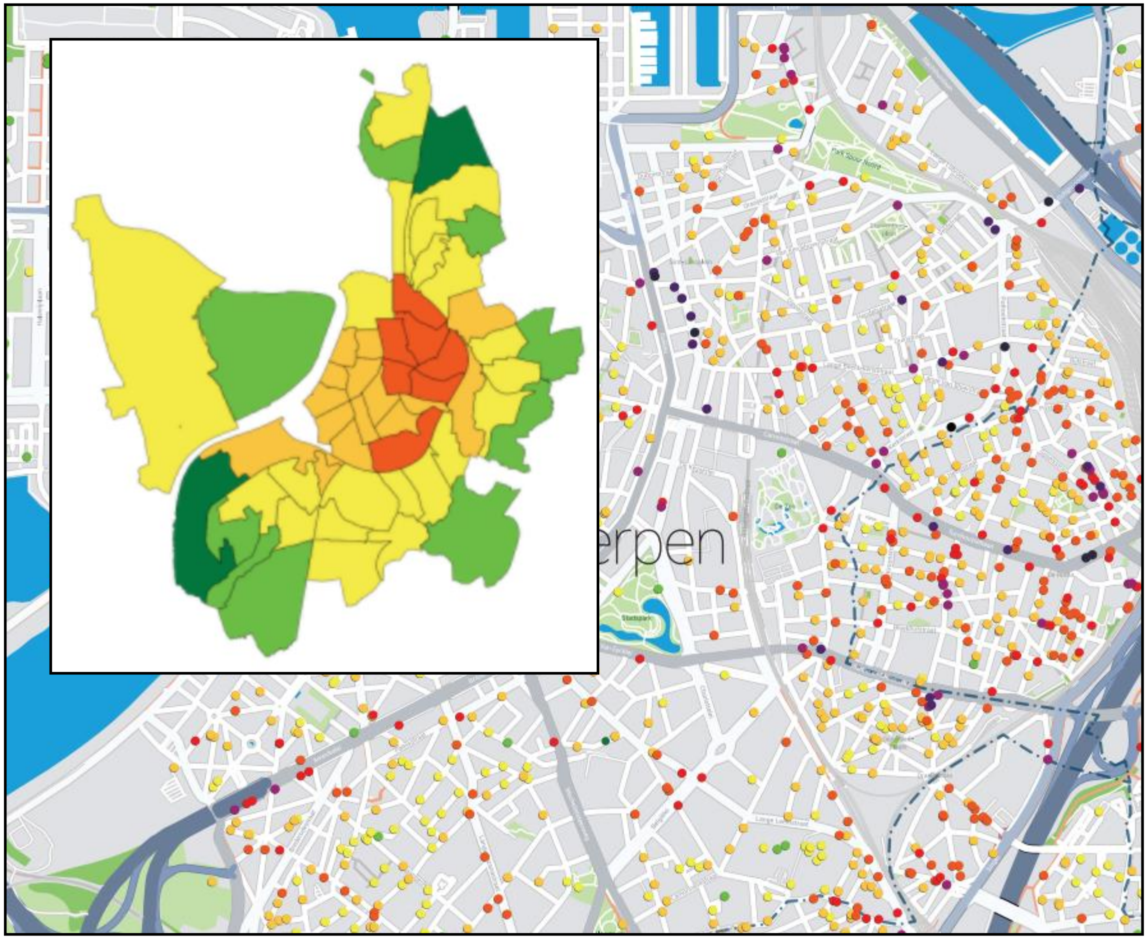
Measuring emissions: the classic approach

- Only a selected number of stations available:



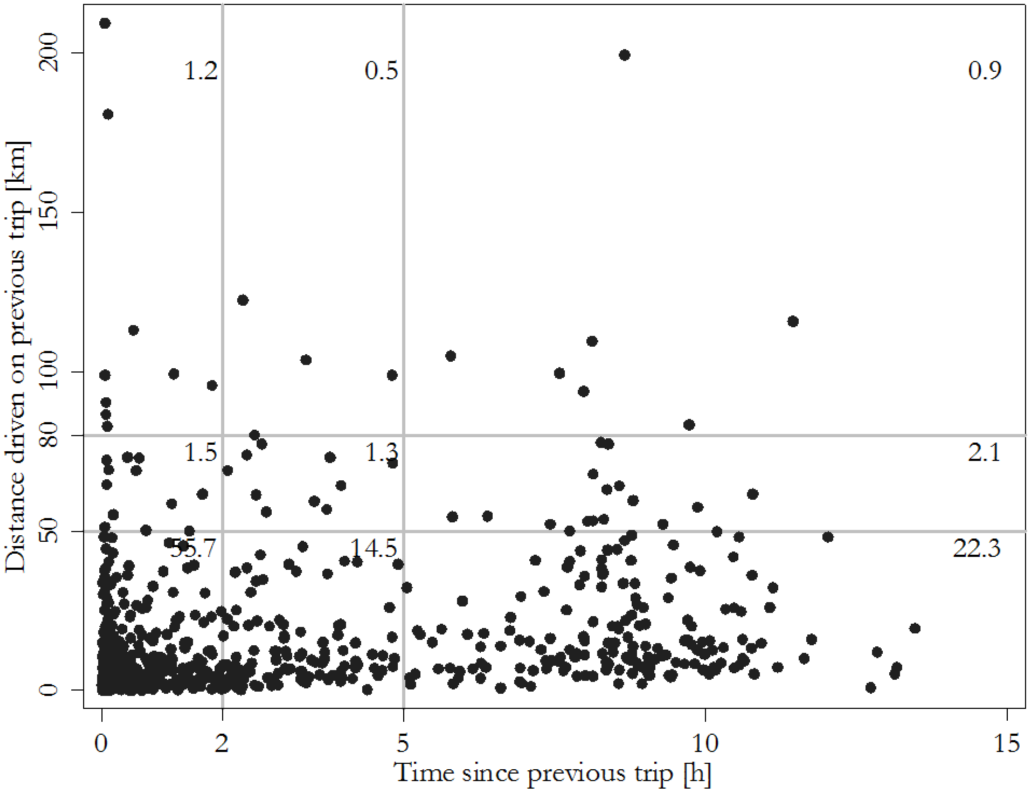
Measuring emissions: the modern approach

- Crowd-organised 635 measurement locations:



Macro level: EV potential

- Which trips can be substituted by an electric vehicle?
  - Based on vehicle usage patterns
  - Trip distance (~ **range**) vs. inter-trip time (~ **recharging**)



Different perspectives:

- Market potential
- Car vs. user

Source: TML (2012)

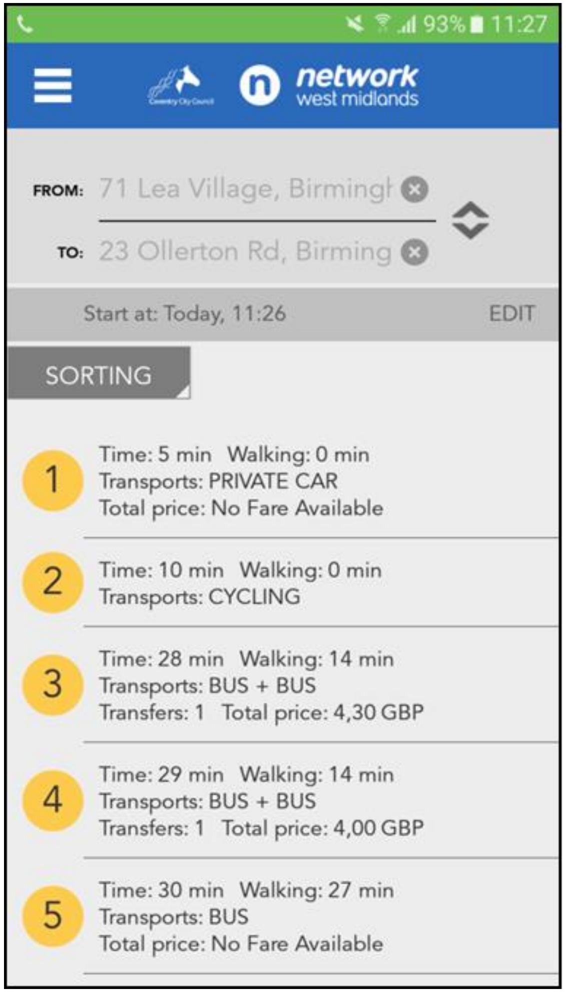
An new generation of urban route planning and parking

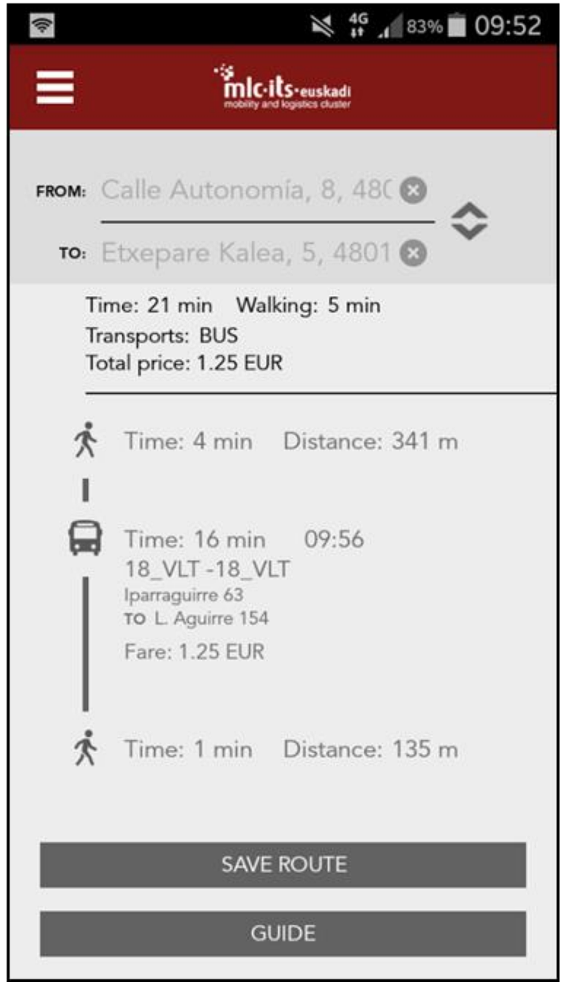
- Next-generation route planners:
  - Incl. green and predictive routing
  - Incl. tourist planning

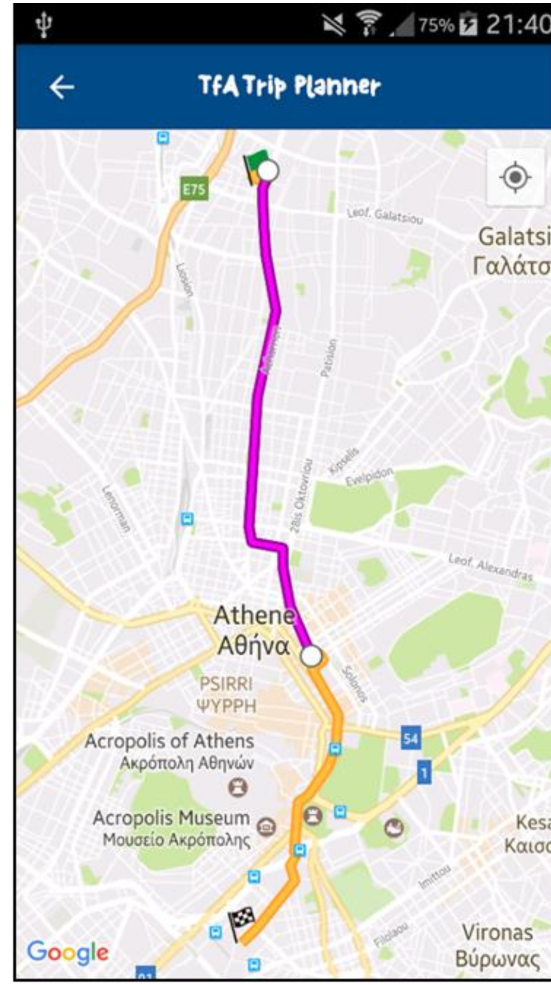
Source: TML (2014, 2017)

- Culminating in:
  - Incl. Integrated Fare Management (IFM)
- Smart parking apps:

Multimodal route planning

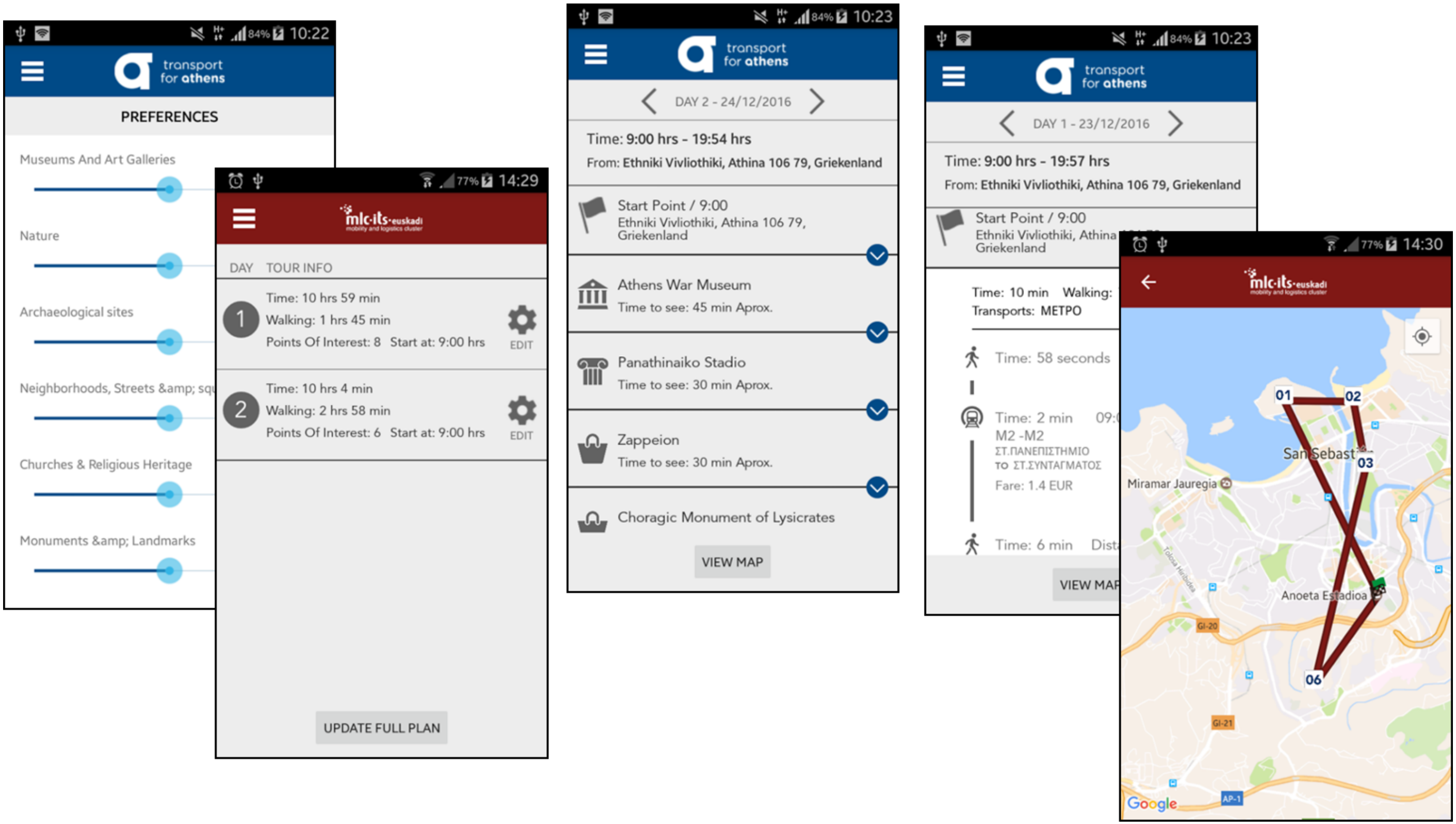






Source: TML (2017)

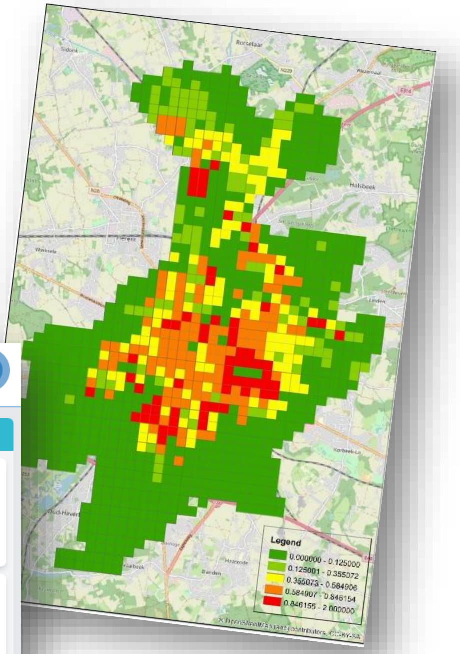
Tourist tour & event planning

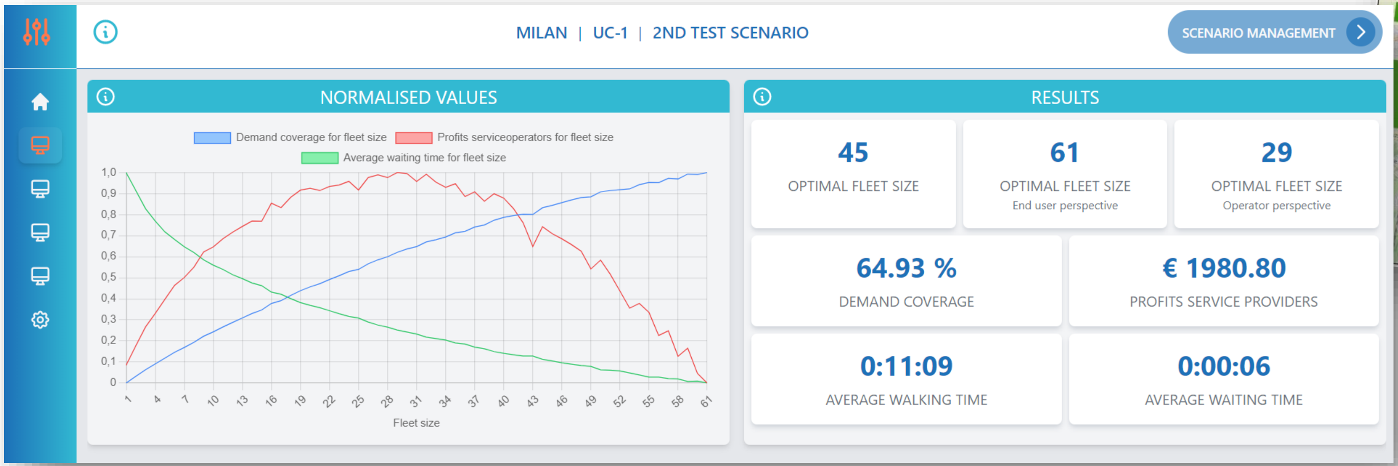


Source: TML (2017)

New Mobility Data & Solutions Toolkit

nuMIDAS





Source: TML (2022)

Sharing Knowledge and Best Practices

- Exchanging via EU programmes and platforms

2020 CIVITAS
Cleaner and better transport in cities

THE CIVITAS INITIATIVE IS CO-FINANCED BY THE EUROPEAN UNION

European Platform on Sustainable Urban Mobility Plans

ViajeoPLUS

OPTICITIES
ENHANCING SMART MOBILITY

iMobility Forum

POLIS

HORIZON 2020

EUROPEAN GREEN CAPITAL
An initiative of the European Commission

Horizon Europe

CityMobil2

Urban Mobility Challenge Berlin 2030

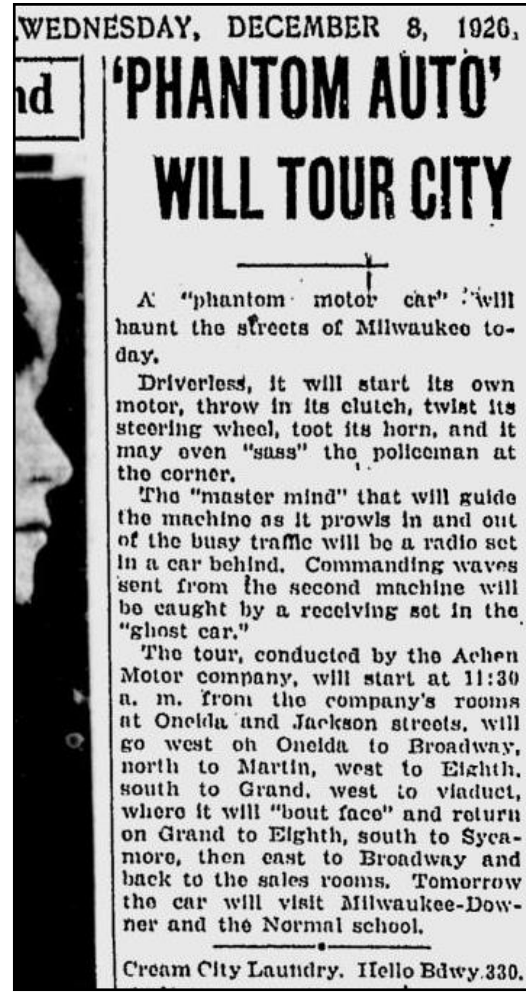
CH4LLENGE

FourC

The first signs of autonomy

- Radio controlled in 1926!
- 1980 – 2003:
  - Strongly dependent on infrastructure
- From 2004 on:
  - DARPA Grand Challenge
  - 240 km in the Mojave desert
  - Heavily equipped vehicles

Source: DARPA (2007)



WEDNESDAY, DECEMBER 8, 1926.

'PHANTOM AUTO' WILL TOUR CITY

A "phantom motor car" will haunt the streets of Milwaukee today.

Driverless, it will start its own motor, throw in its clutch, twist its steering wheel, toot its horn, and it may even "sass" the policeman at the corner.

The "master mind" that will guide the machine as it prowls in and out of the busy traffic will be a radio set in a car behind. Commanding waves sent from the second machine will be caught by a receiving set in the "ghost car."

The tour, conducted by the Achen Motor company, will start at 11:30 a. m. from the company's rooms at Oneida and Jackson streets, will go west on Oneida to Broadway, north to Martin, west to Eighth, south to Grand, west to viaduct, where it will "bout face" and return on Grand to Eighth, south to Sycamore, then east to Broadway and back to the sales rooms. Tomorrow the car will visit Milwaukee-Downer and the Normal school.

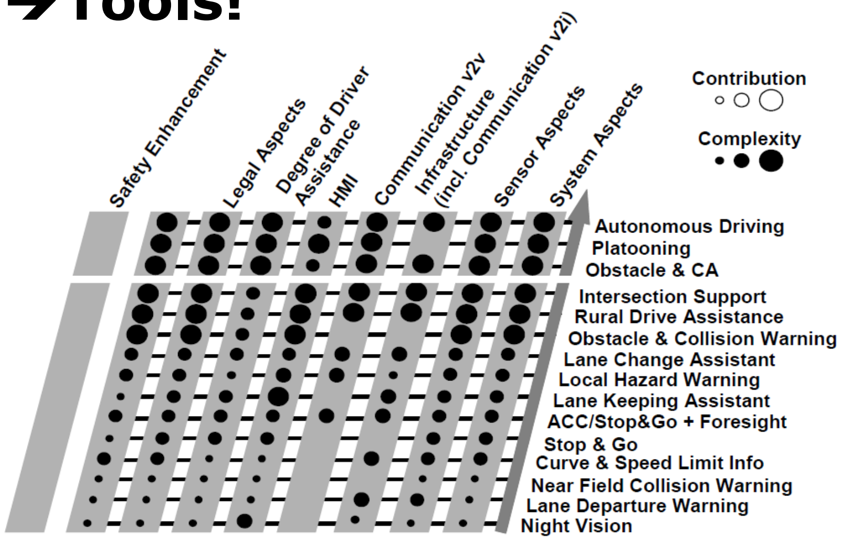
Cream City Laundry. Hello Bdwy.330.

Source: The Milwaukee Sentinel (1926)

The long run to autonomous vehicles

- Advanced Driver Assistance Systems (ADAS)
  1. Safe speeds and following distances
  2. Lane guiding
  3. Detection of obstacles and collision avoidance
  4. Satefy of intersections and complex situations

  → **Tools!**

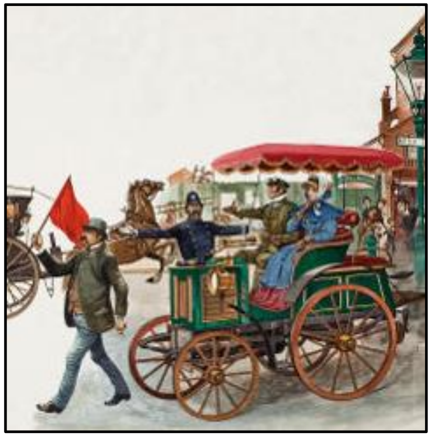


- Autonomous driving

Source: ADASE II Extension (2004)

Evolution in legislation

- Locomotives 'Red Flag' Acts (1865)
  - Max 3 km/h in cities
  - Required: driver + stoker + flag
  - Background: protection of rail and horse carriage industries



Source: Jackson (2016)

Vlaams Parlement

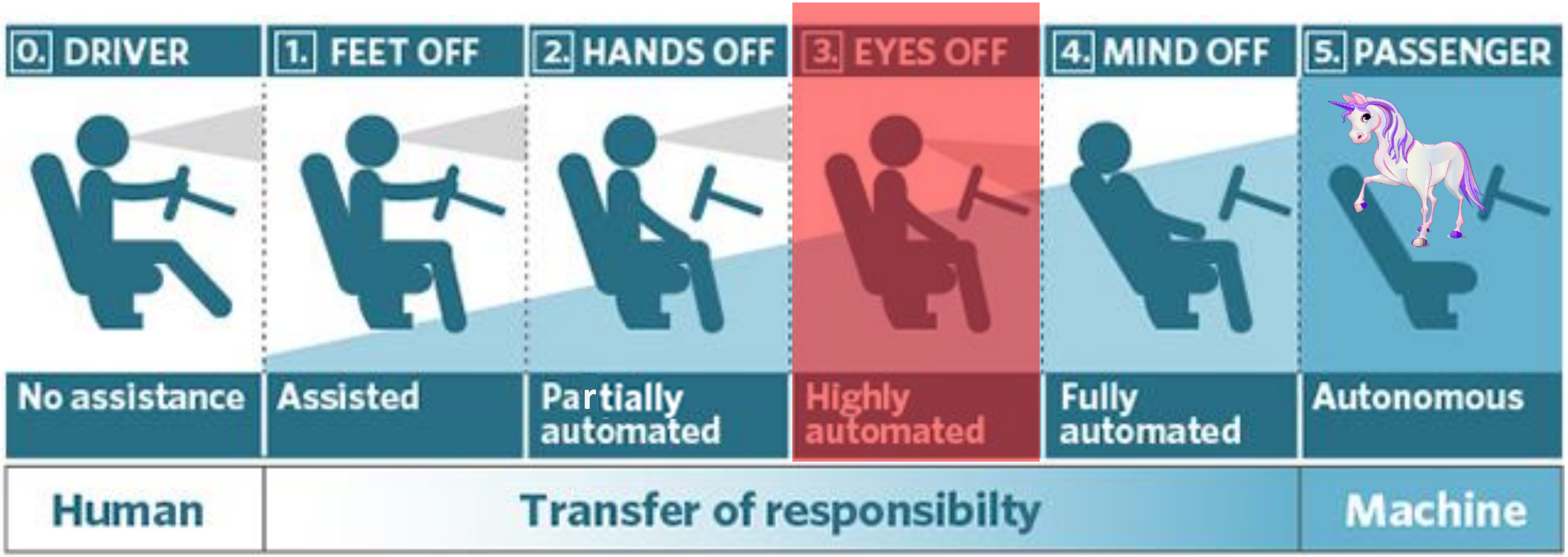
- Vienna Convention wrt. road traffic (1968)

ARTICLE 8

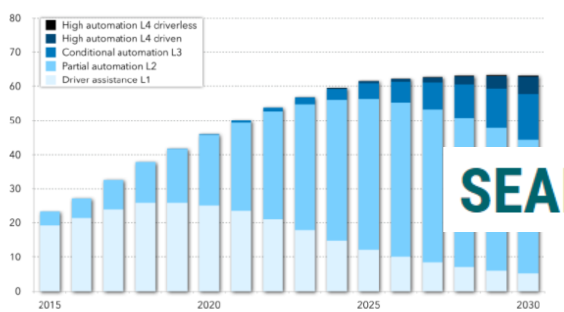
<u>Drivers</u>

1. Every moving vehicle or combination of vehicles shall have a driver.

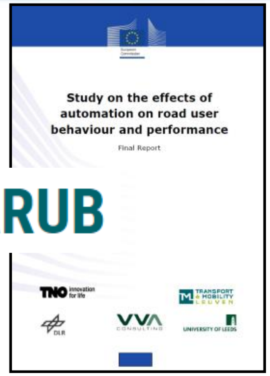
Different levels of autonomy

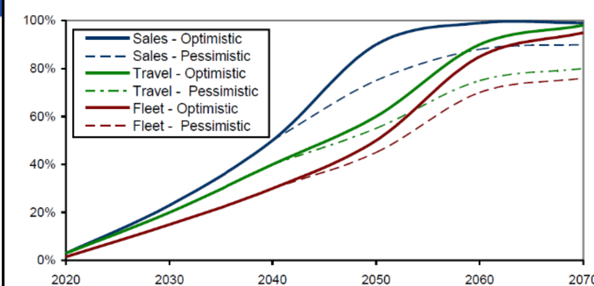


INTERNATIONAL



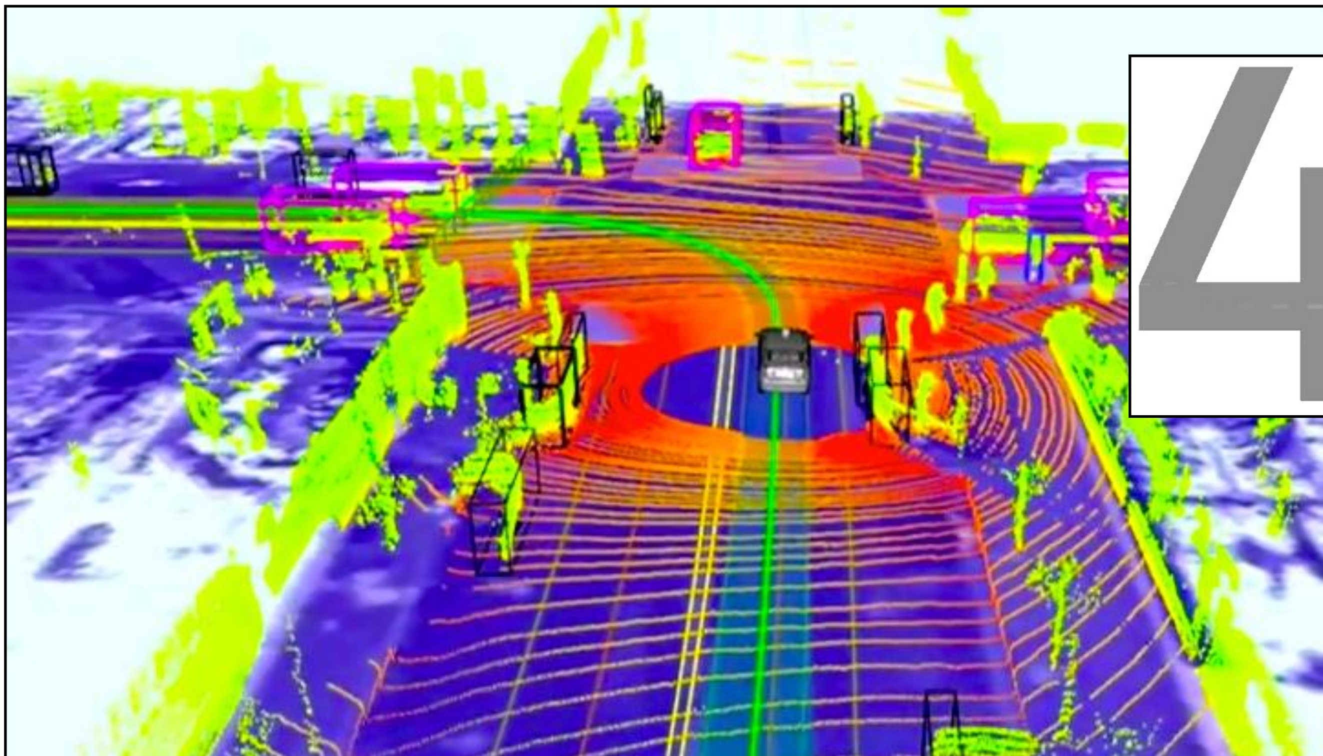
SEARUB





Autonomy with integration of V2V and V2I (V2X)

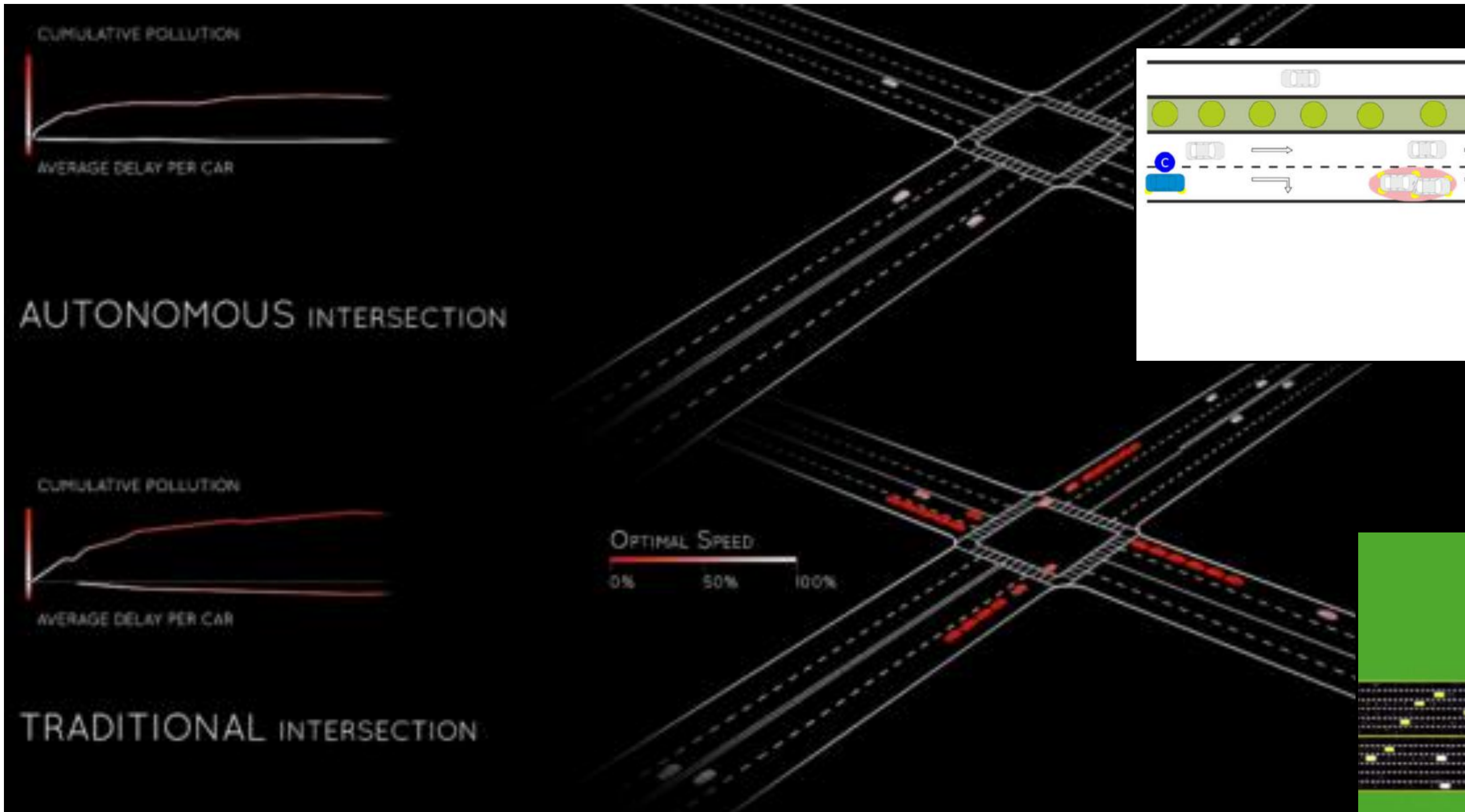
- VANETs (mesh grids) + cooperative driving
- Communication with (intelligent) intersections
- Note: Google Car contains a very detailed map

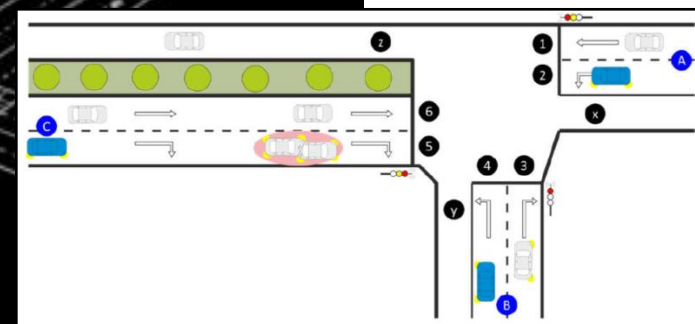


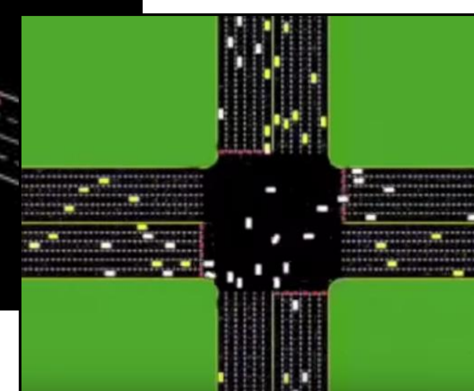
Source: Google (2014)

CAVs negotiating intersections

- Slot-based (platoons ⇔ individual vehicles)

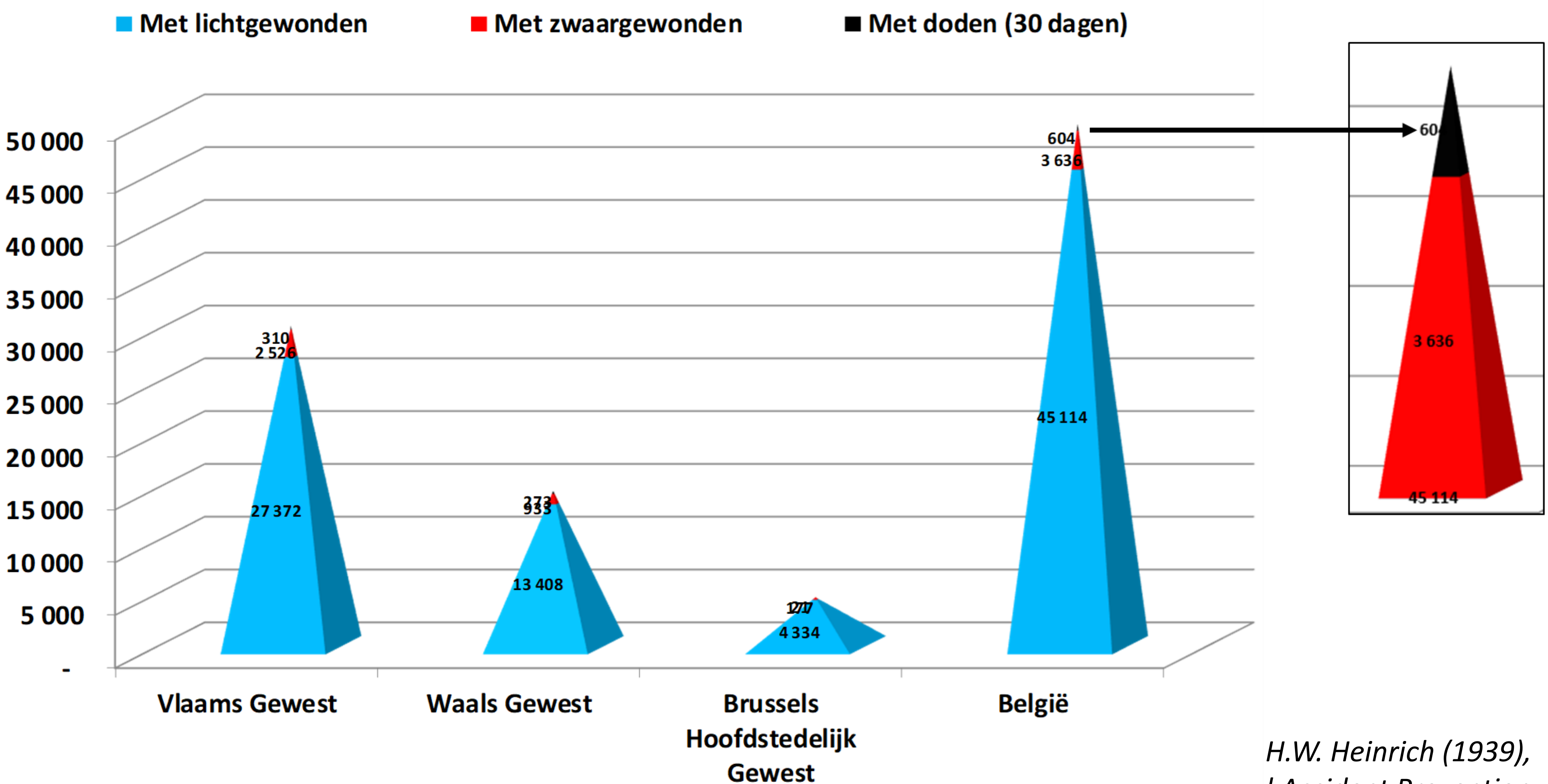






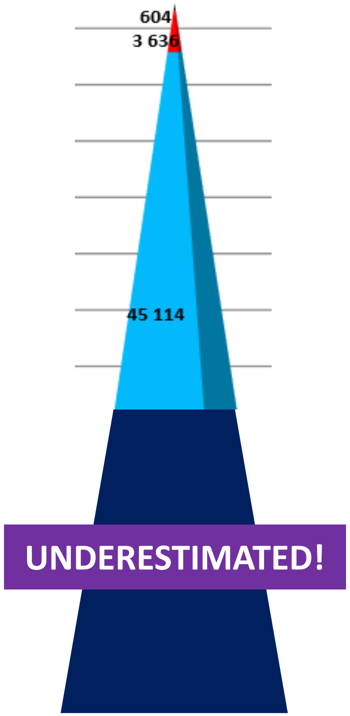
A single human can screw up the system

Traffic safety: Heinrich pyramid (“factor 10”)



H.W. Heinrich (1939),
l Accident Prevention

The real work today is for the "almost-accidents"



Zero-fatality is practically unattainable

- Already better safety due to:
  - Better vehicle construction (wrinkle zones, energy dissipation, lower impuls, …)
  - Existing ADAS
- Focus on:
  - Extra supporting measures
  - Traffic education
  - Enforcement

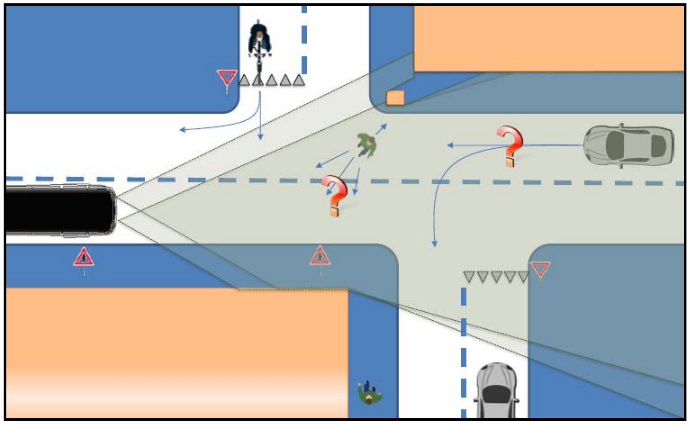
➡ Good effectiveness by considering the <u>psychology</u> of humans





EMDAS (collective of Flemish companies/research institutes)

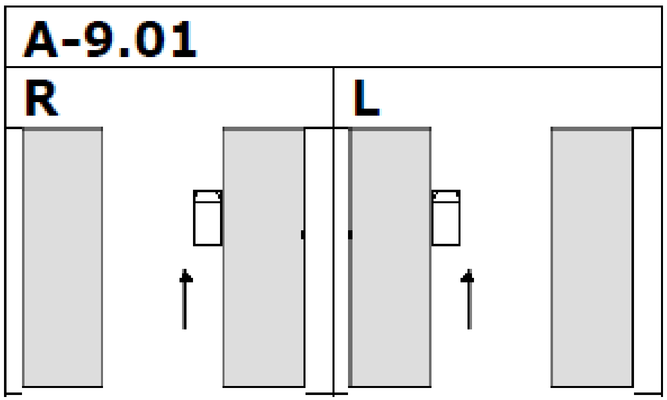
- Goal: develop a longitud. self-driving bus (v < 30 km/h)
- TML develops an objective framework for the assessment of safety impacts:
  - Compare accident risk with and without AVs
  - Change in accident risk ifo. the level of autonomy
  - Understand the interactions between driver and vehicle
  - Insight into unsafe behaviour that follows from this

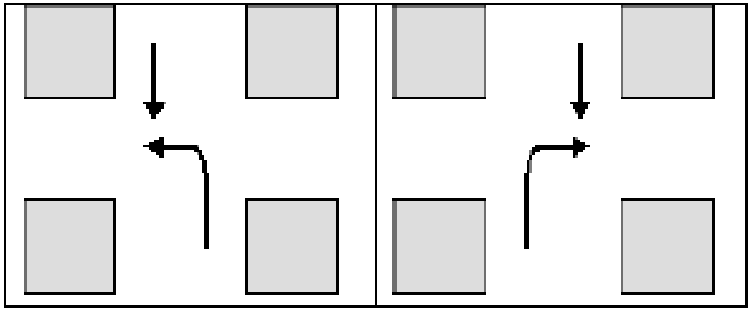


- Need on a dedicated analysis of accidents

Analyse common accident schemadata (CADAS / GIDAS)

- Derive accident typologies
- Validate with existing research (BIVV, VSV, IMOB, …)





We get 'equipped vehicles'

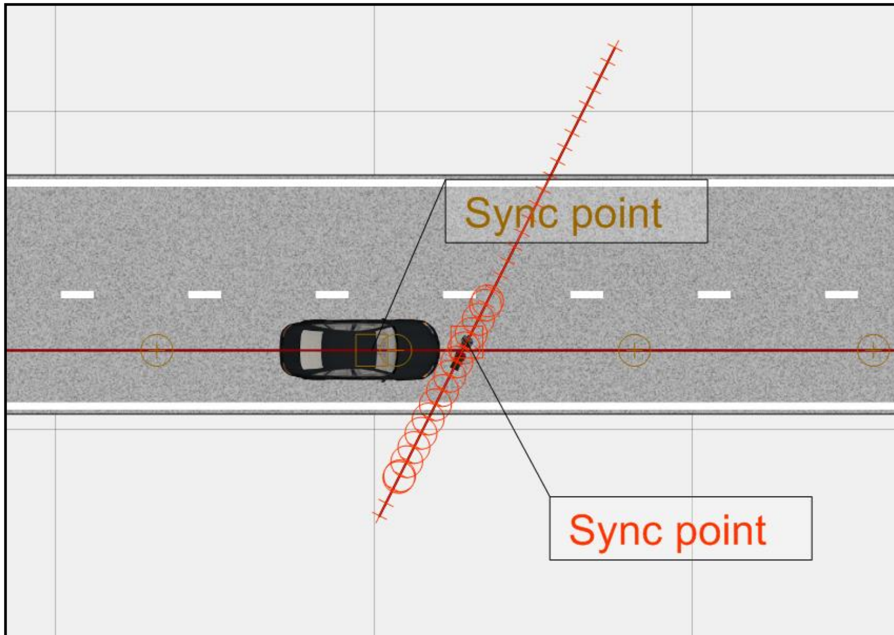
↓

Simulation test

↓

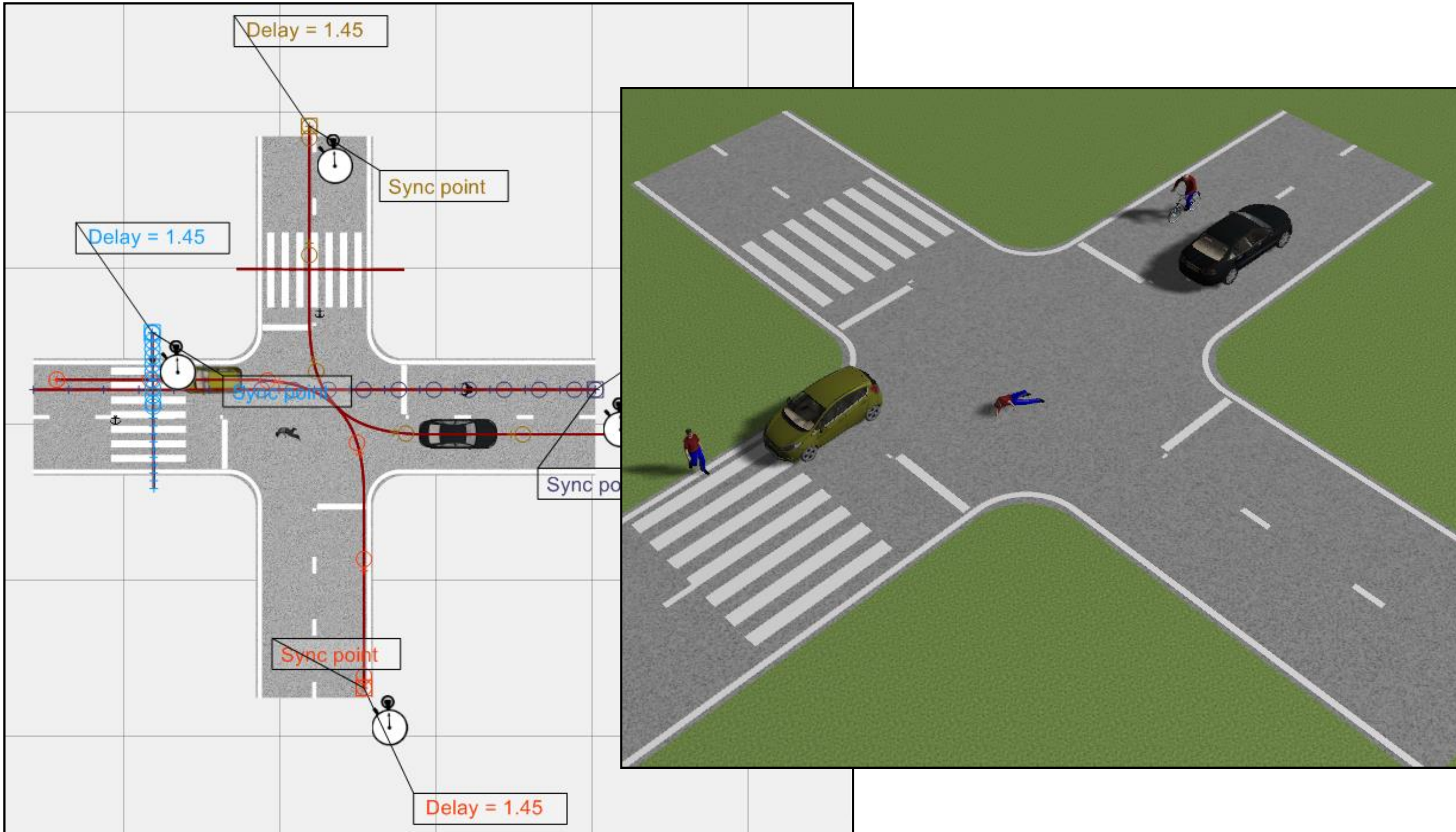
Provide feedback (sensor specs.)

Creating PreScan experiments



Source: TML (2017, 2019)

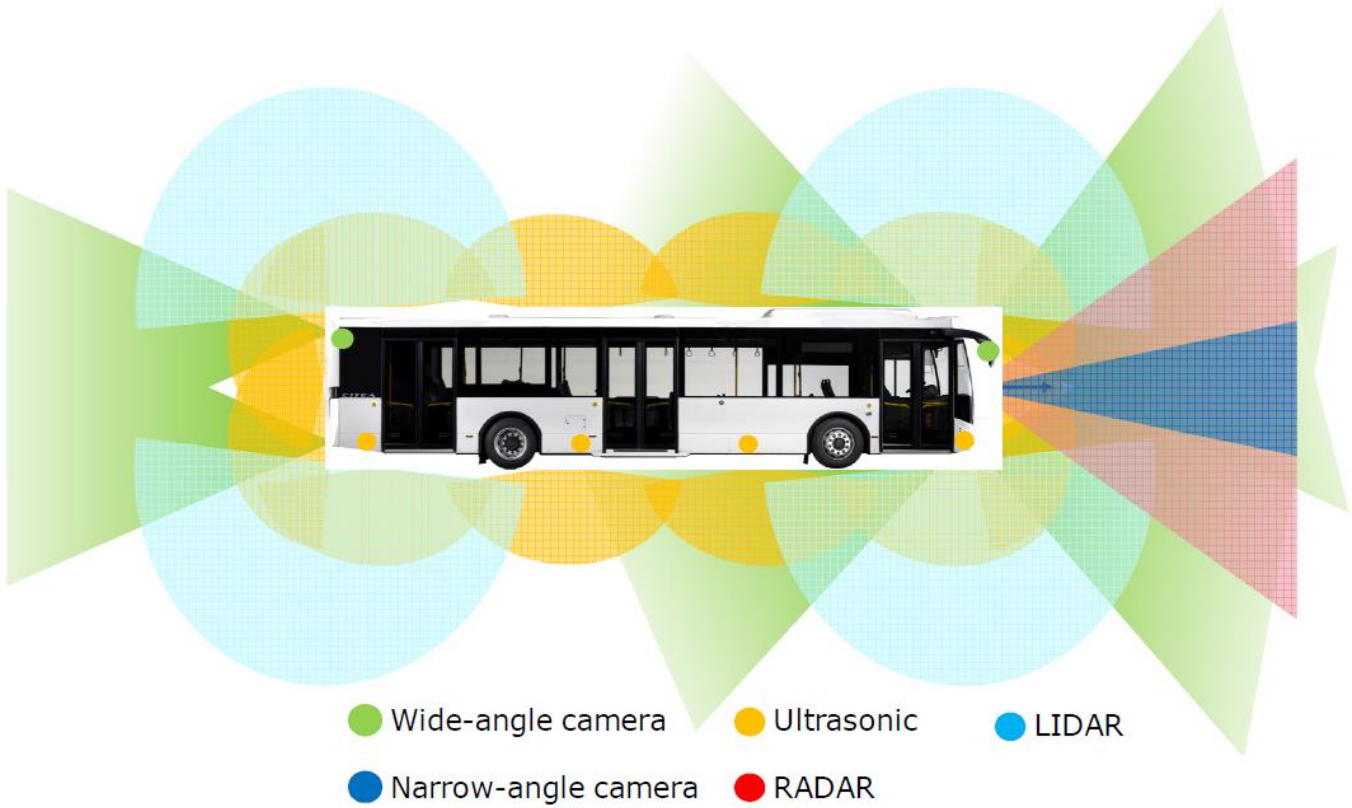
Beyond longitudinal control: safety at intersections



Source: TML (2017, 2019)

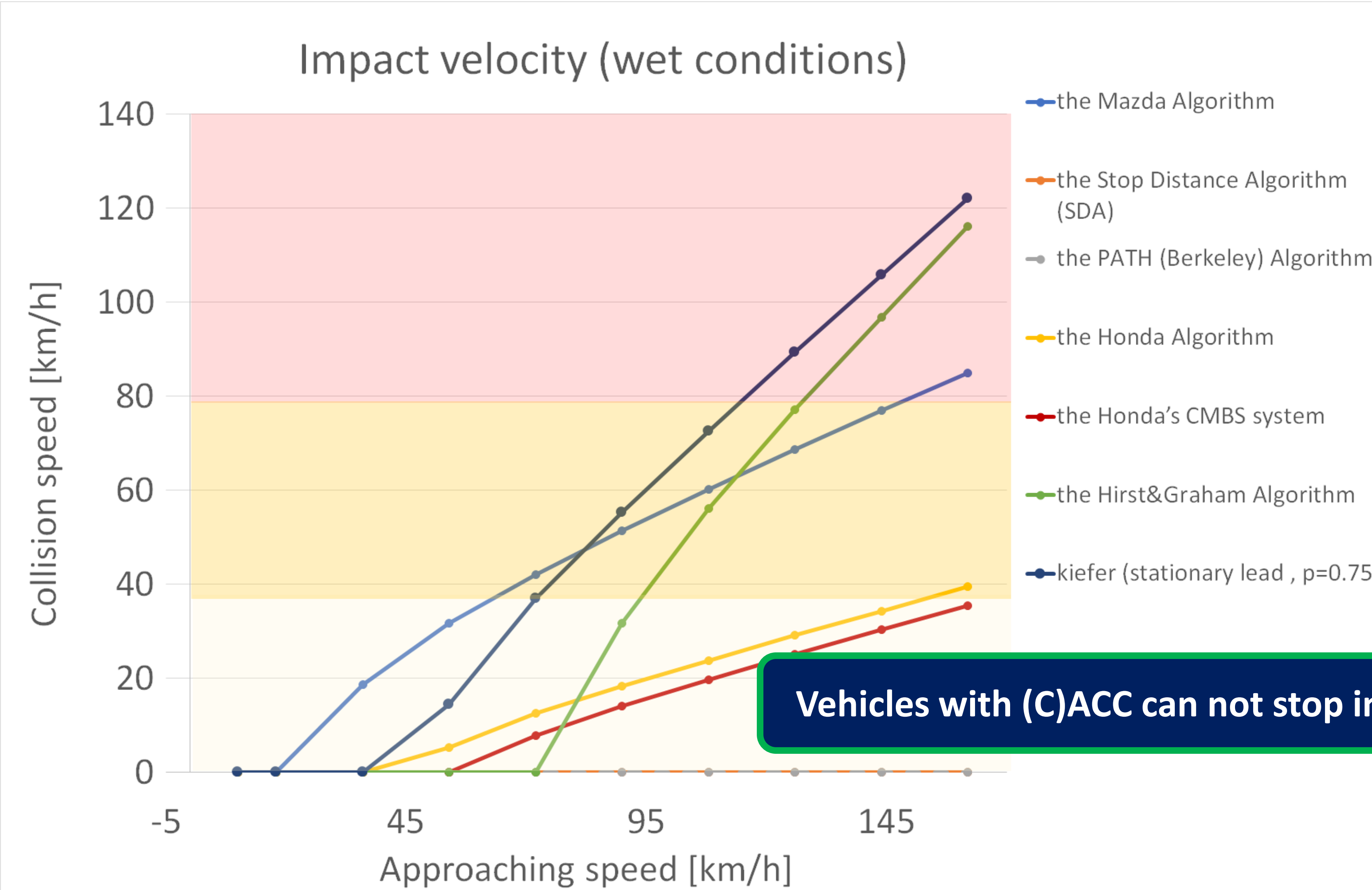
Context-aware traffic management: safety⇔throughput

EMDAS (2017)



Limited detection range (e.g, 150 m)!

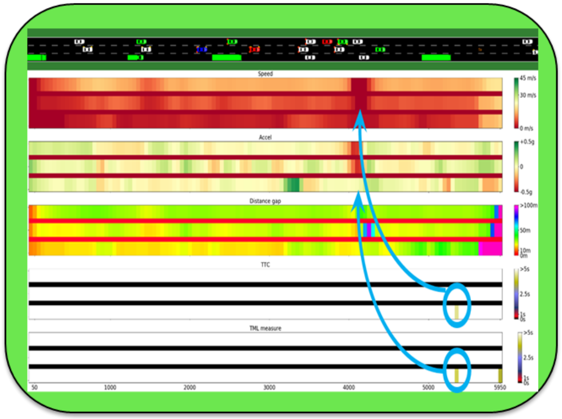
Context-aware traffic management: safety⇔throughput



Vehicles with (C)ACC can not stop in time!

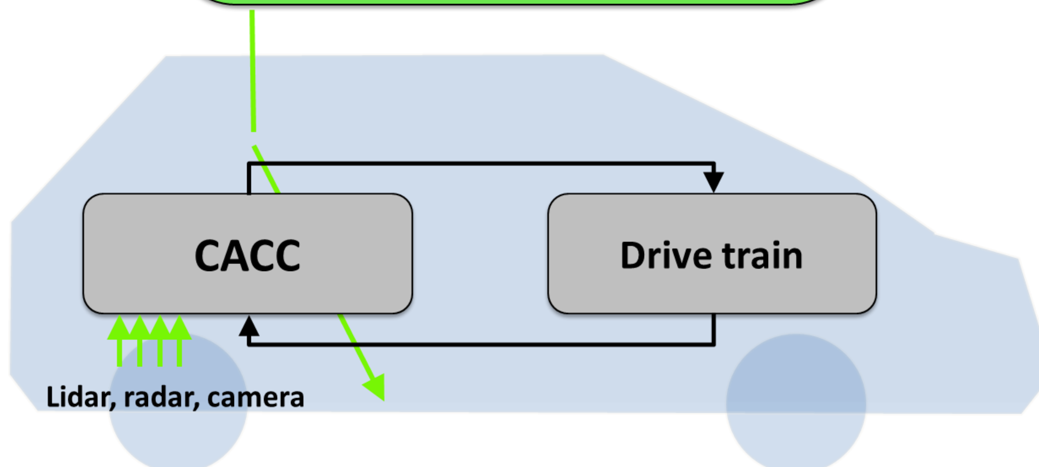
Context-aware traffic management: safety⇔throughput

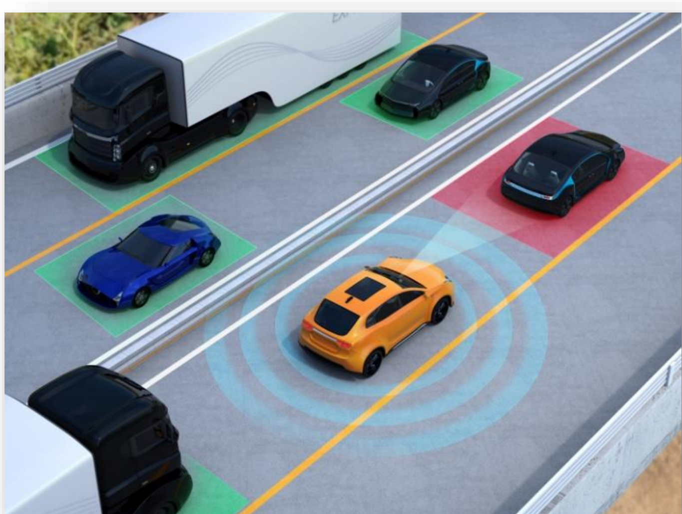
Context



Traffic control

- Adapt distance to lead vehicle
- Adapt speed
- Increase cooperation (lanes)



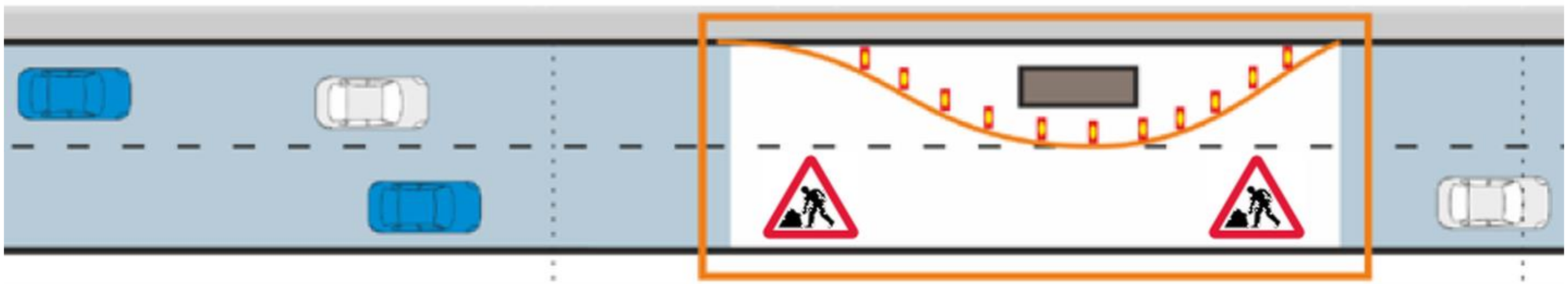


VLAAMS CONGRES VERKEERSVEILIGHEID

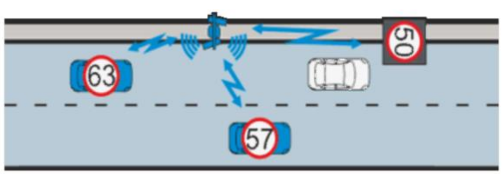
Source: TML (2019, 2020)

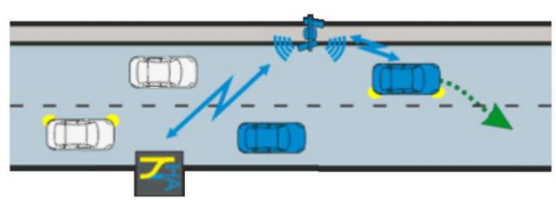
TransAID (Horizon 2020)

- Transition Areas for Infrastructure-Assisted Driving



- Research:
  - Simulations (SUMO, ns-3, iTETRIS)
  - Hierarchical traffic management
  - V2X message sets
  - Field implementations (Germany)
  - Guidelines and roadmap for stakeholders

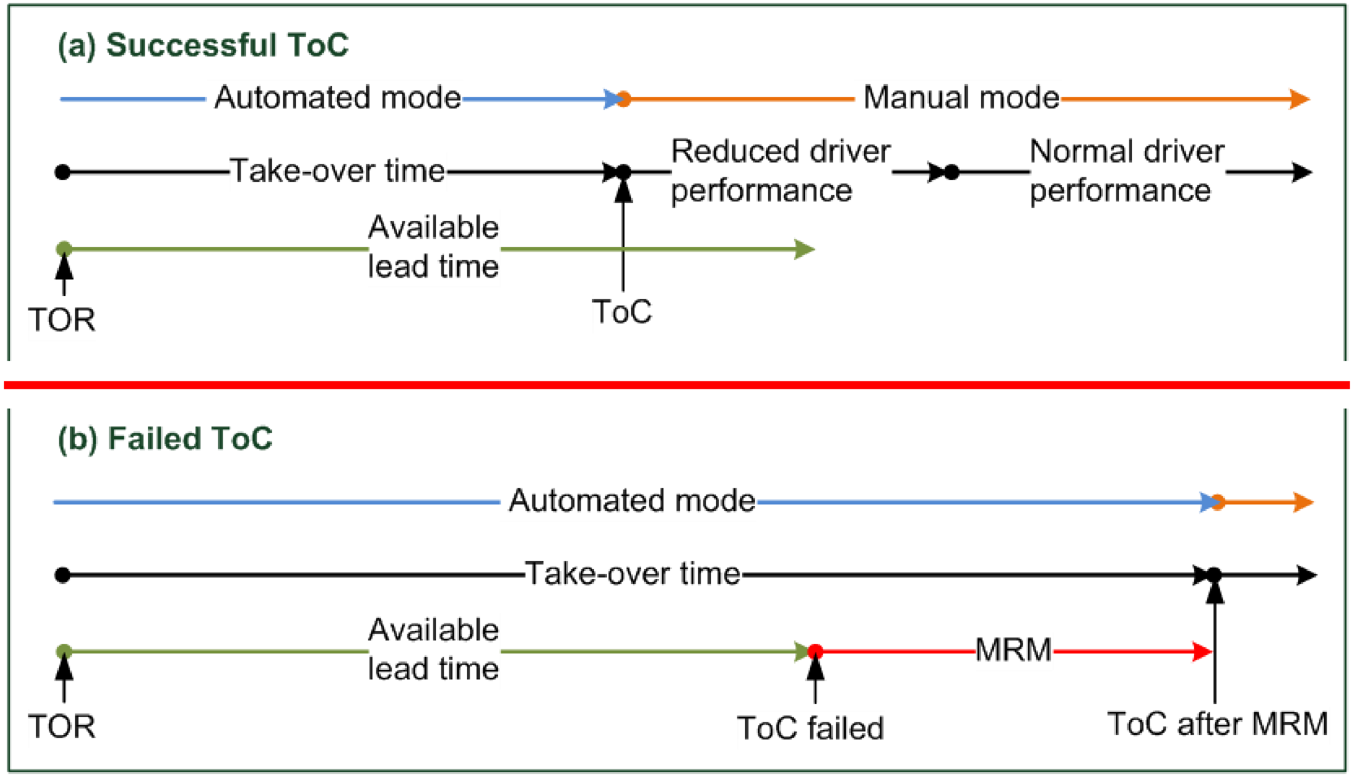




Source: TML (2019, 2020)

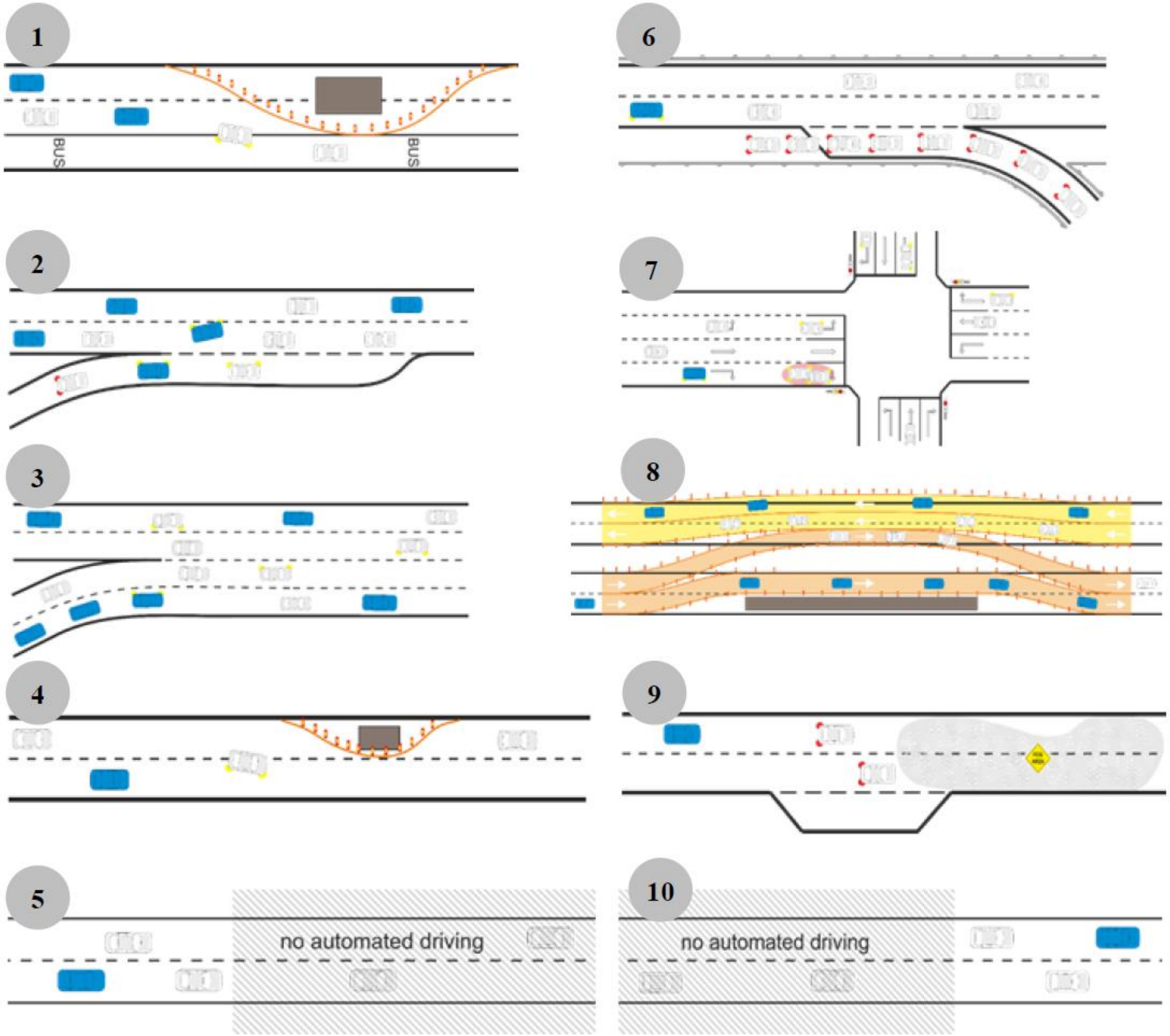
When automated driving is no longer possible

- Take-over request (**TOR**) issued by the car
- Transition of Control (**ToC**) from car to driver
- Minimum-Risk Maneuver (**MRM**) by the car



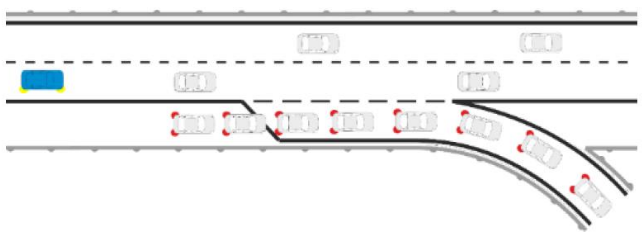
Source: CRT (2019)

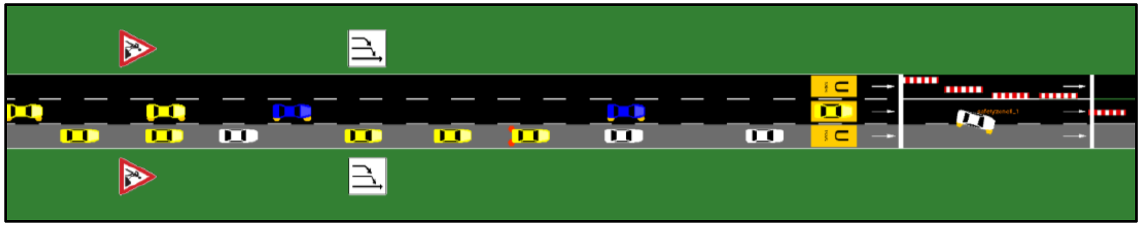
TransAID (EC Horizon 2020)



Source: TML (2020)

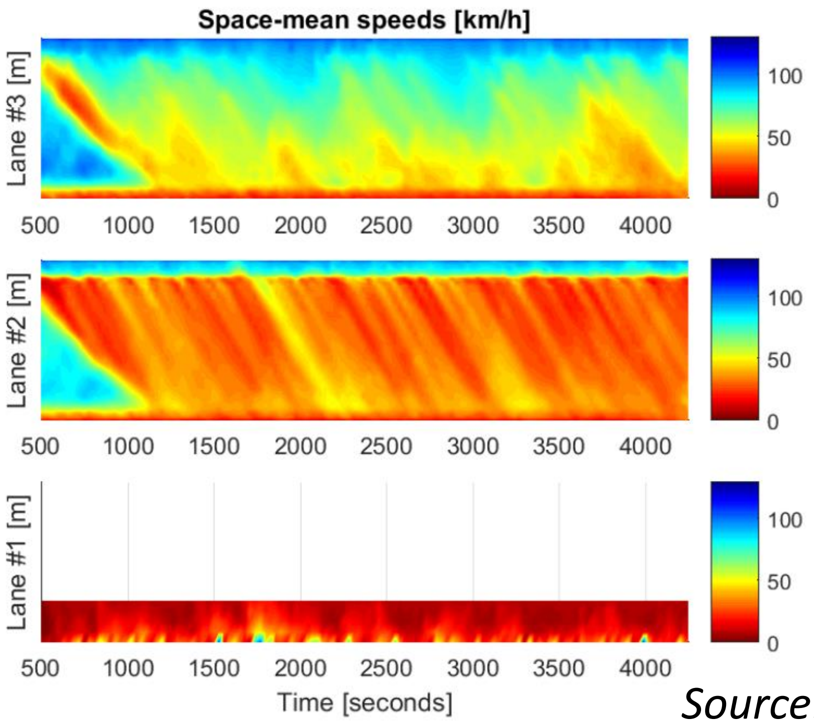
TransAID (EC Horizon 2020) (use case example)

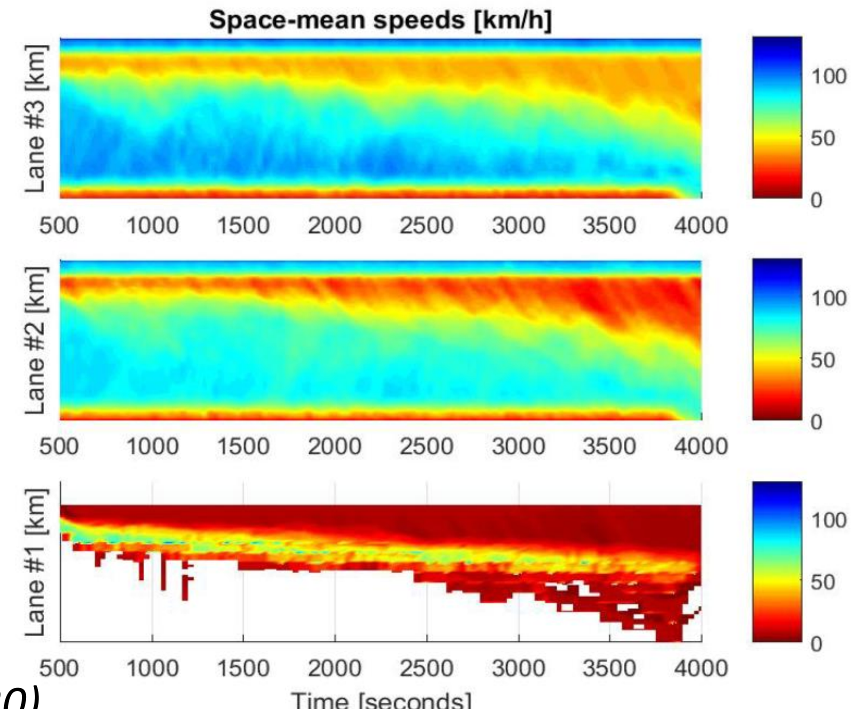




WITHOUT TRAFFIC MANAGEMENT

WITH TRAFFIC MANAGEMENT

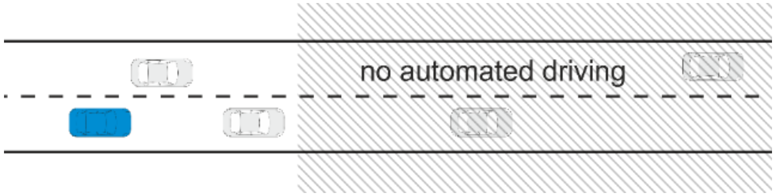




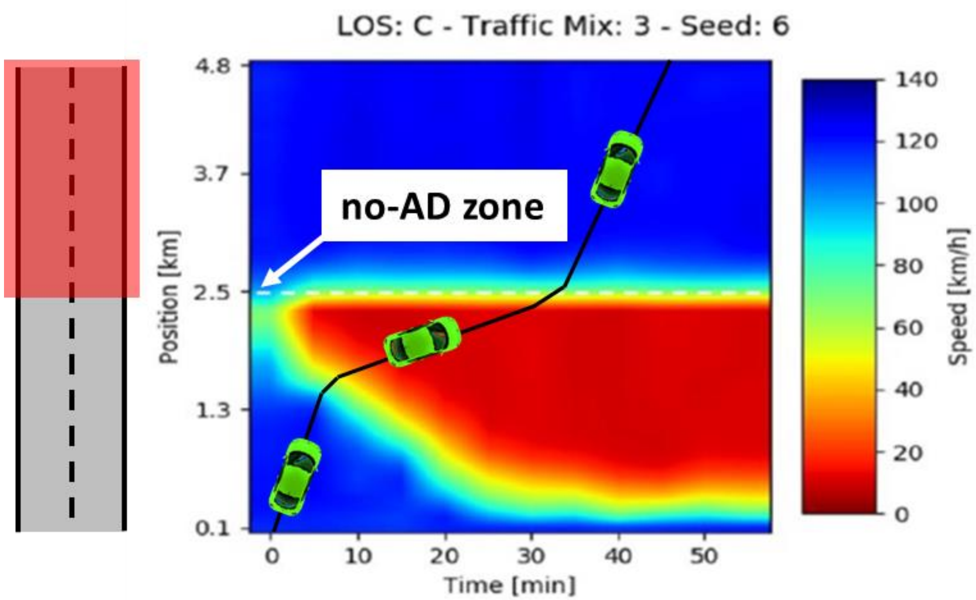
Source: TML (2020)

TransAID (EC Horizon 2020) (use case example)

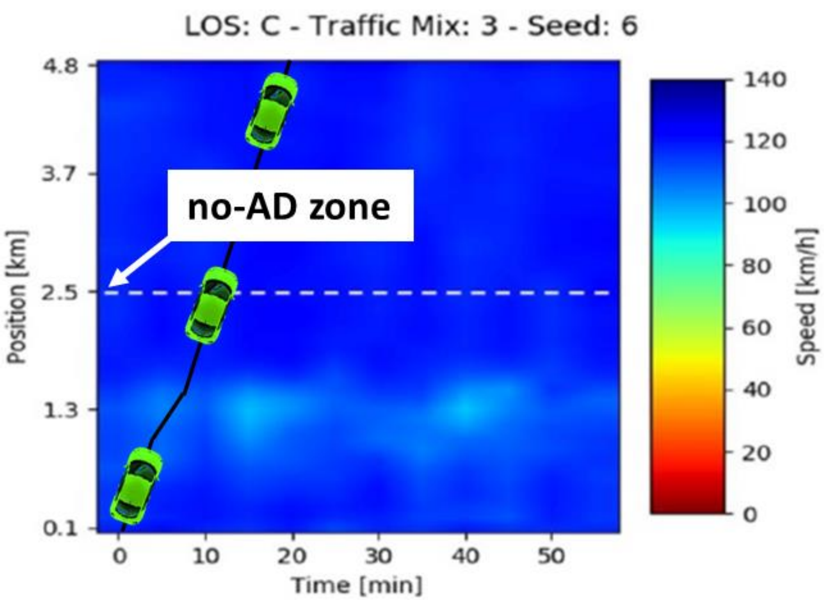
Distribute the TORs within a dedicated TOR area



Without traffic management



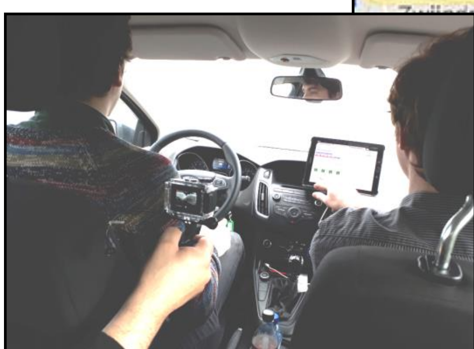
With traffic management



Source: TML (2020)

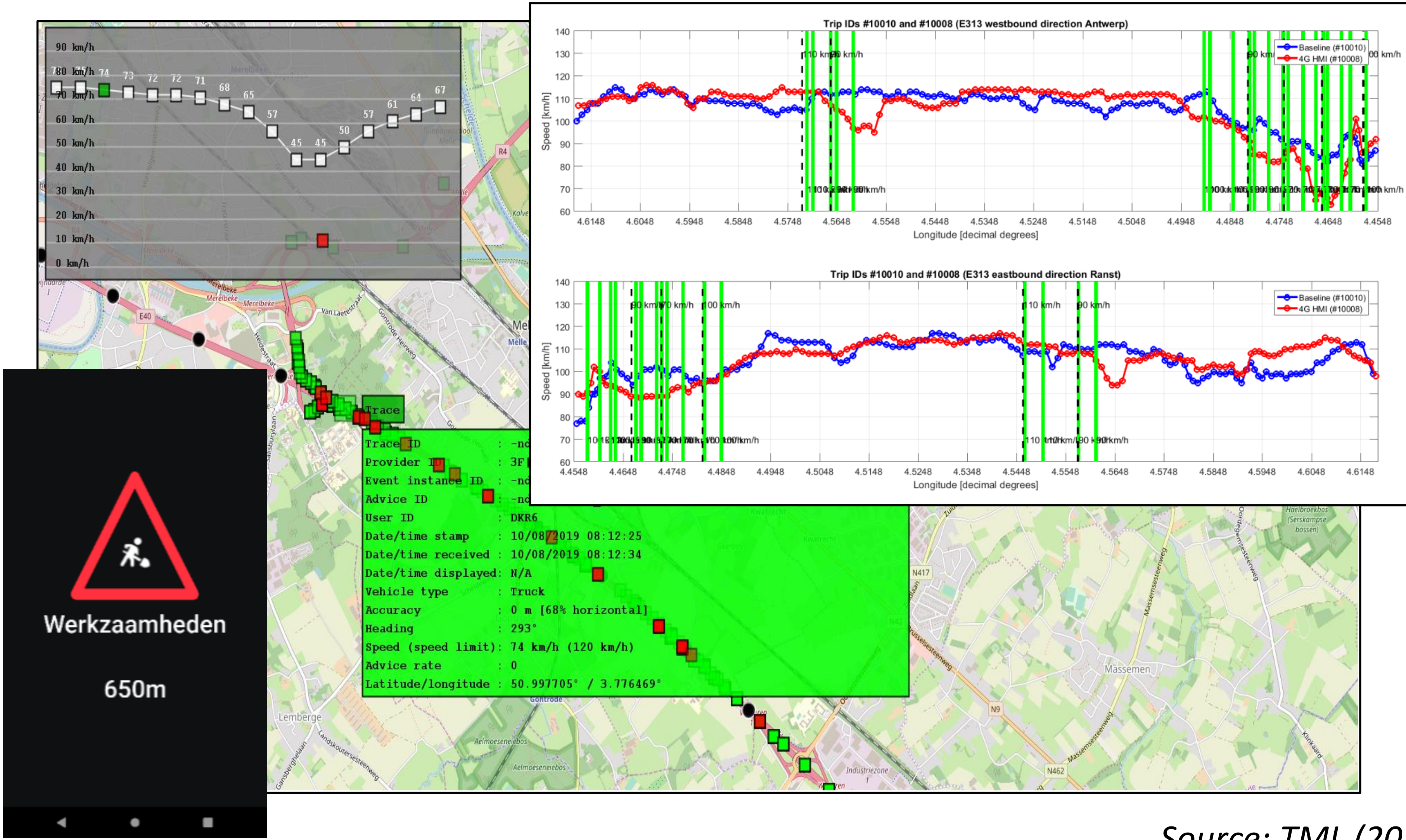
Cooperative ITS testbeds

citrus CONCORDA C-ROADS 4 TRAFFIC MANAGEMENT CAD InterCor



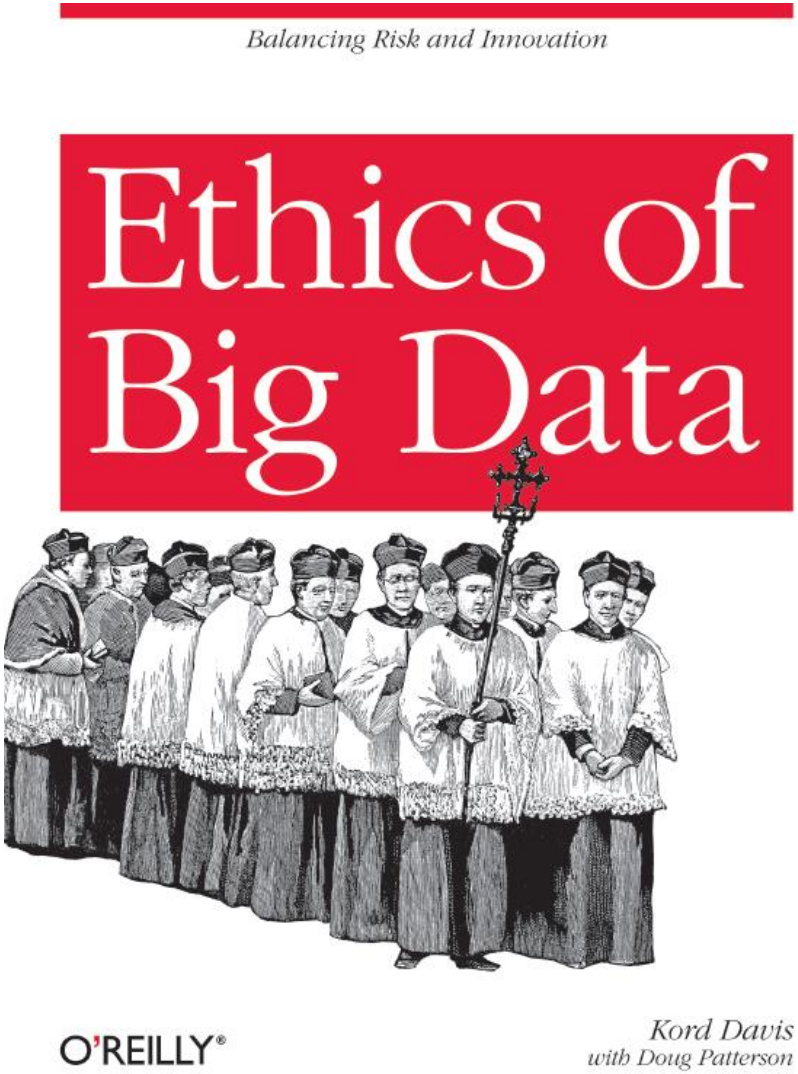
Source: TML (2019)

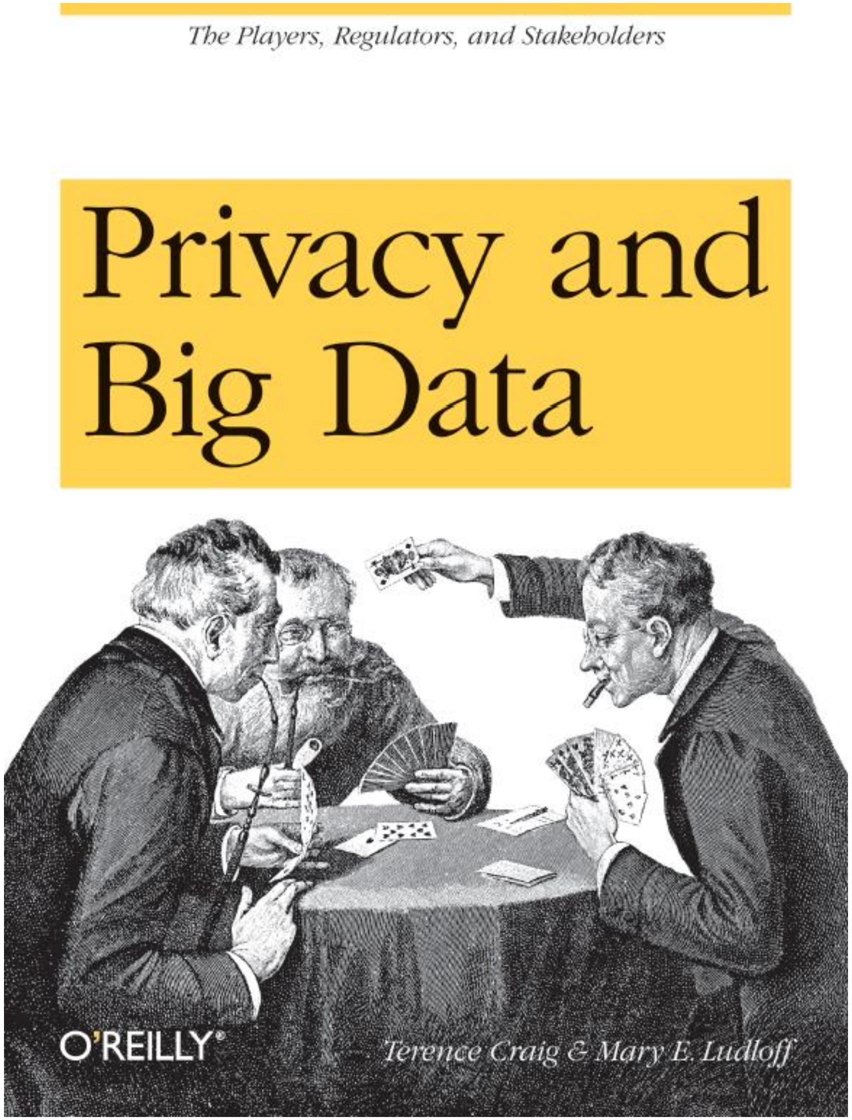
Impacting driver behaviour



Source: TML (2020)

Protecting identities (and EU's GDPR)



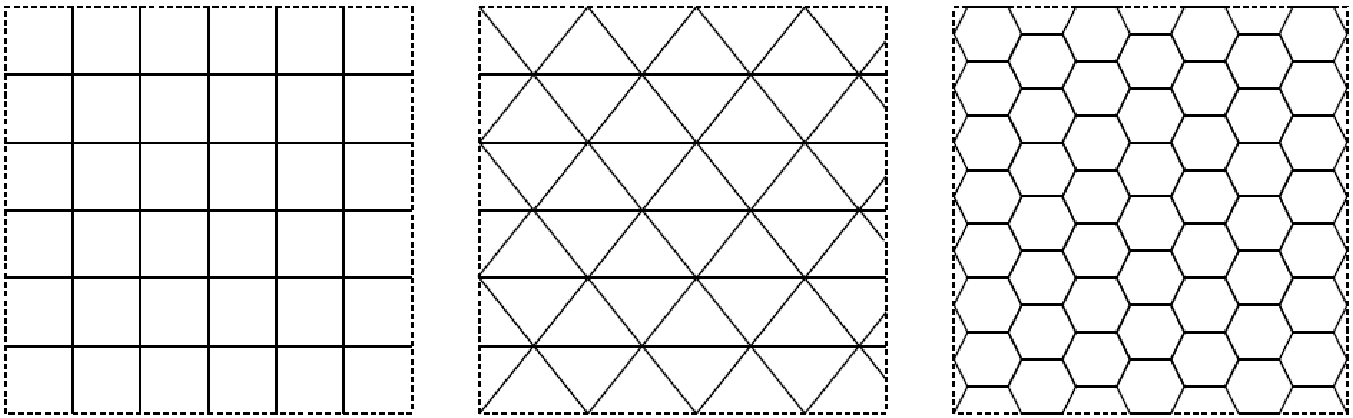


Overview

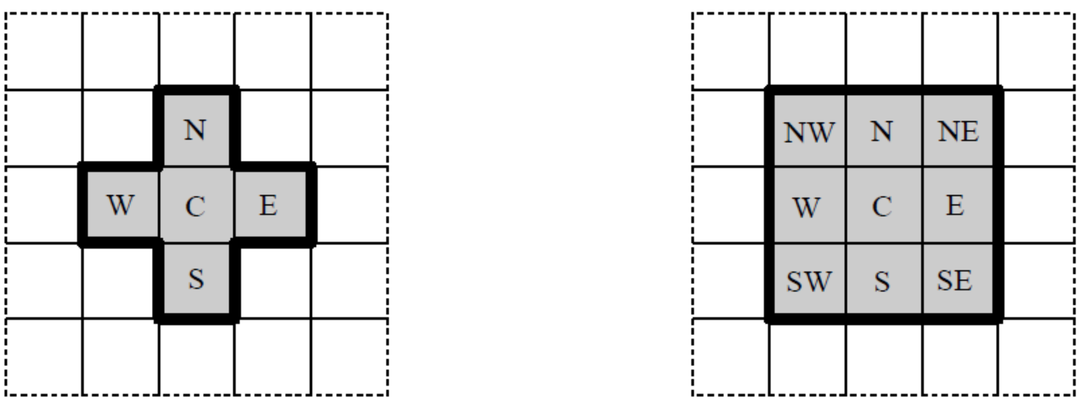
- Introducing Transport & Mobility Leuven (TML)
- Traffic Flow Theory
- Traffic Management
- Traffic Data and TML Case Studies
- **Extra: Traffic Cellular Automata**

Theory of cellular automata

- Cells in a **discrete space** (e.g., 2D plane):

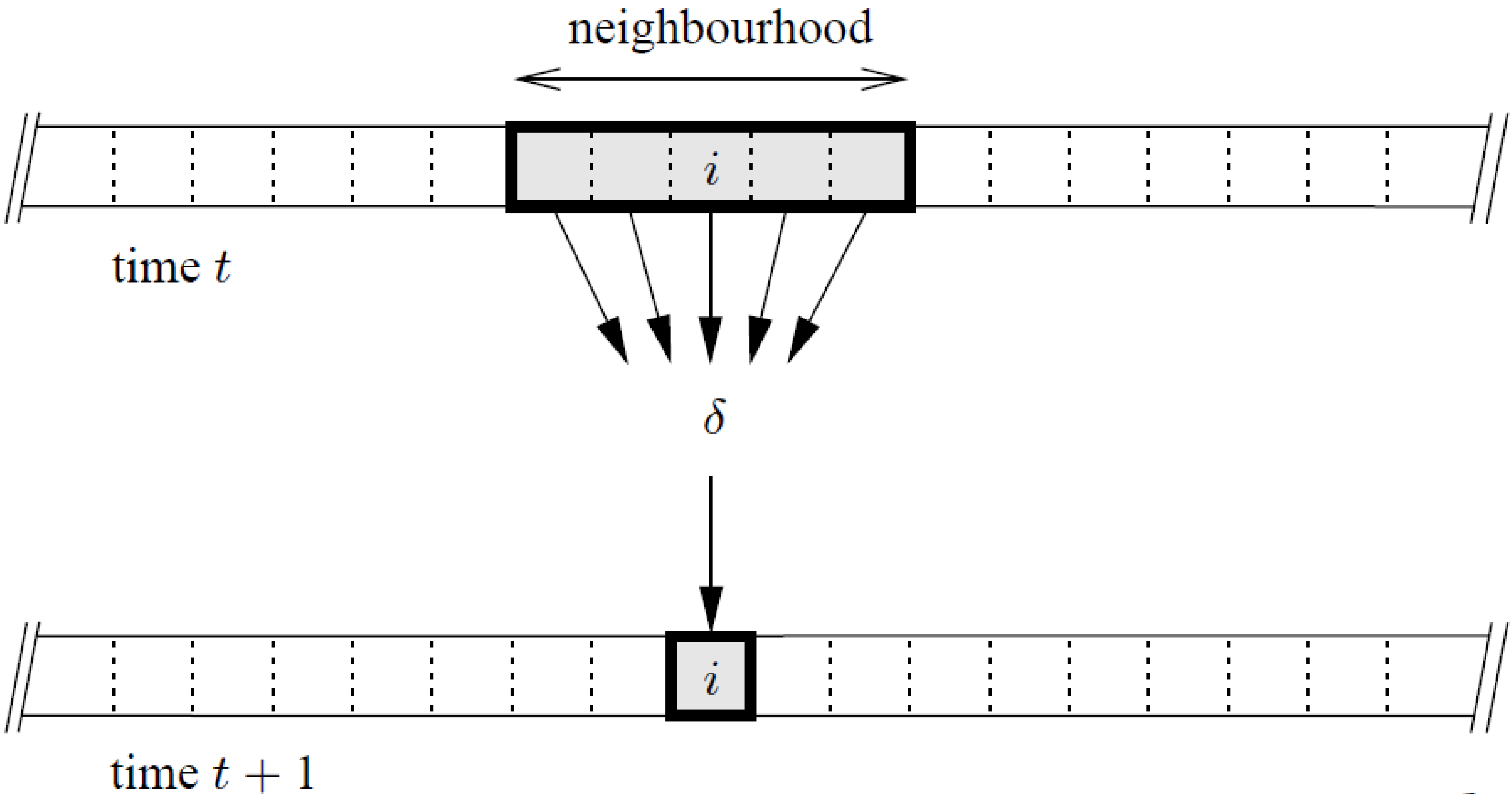


- The **neighbours** of cells (von Neumann vs. Moore):



Theory of cellular automata

- The local **transition rule**:

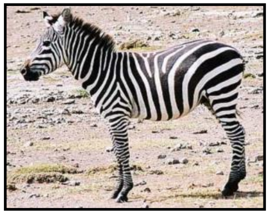
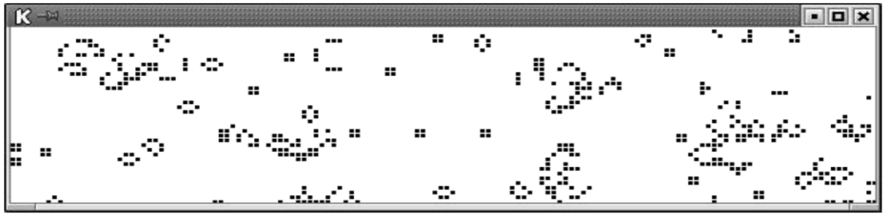
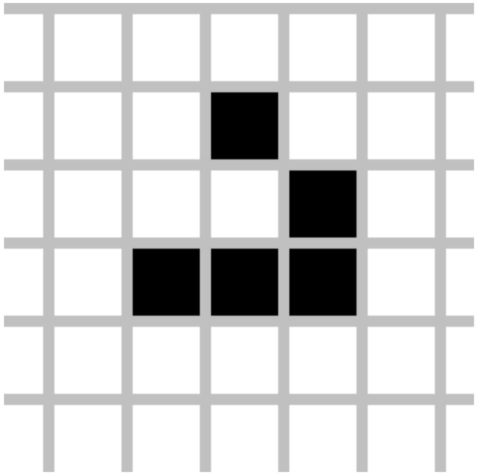


$$\mathrm{CA} = (\mathcal{L}, \Sigma, \mathcal{N}, \delta)$$

The history of cellular automata

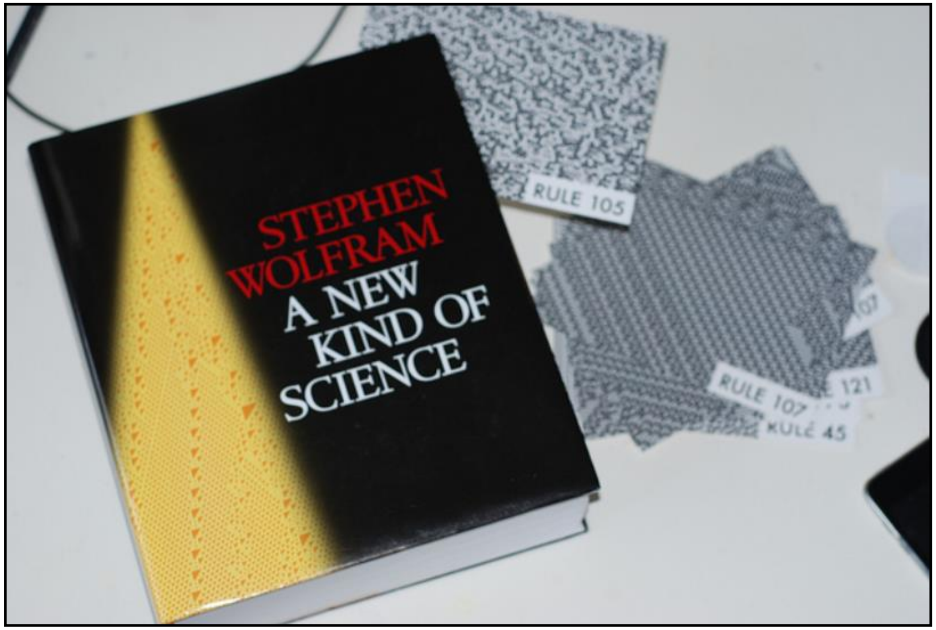
- 1948:
  - von Neumann on self-reproduction
  - Ulam introduces "cellular spaces"
- 1952:
  - Turing talks about morphogenesis
- 1970:
  - John Conway's "*Game of Life*"



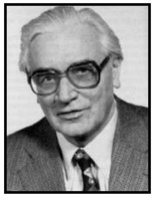





The history of cellular automata

- 1983:
  - Wolfram's "*A New Kind of Science*"

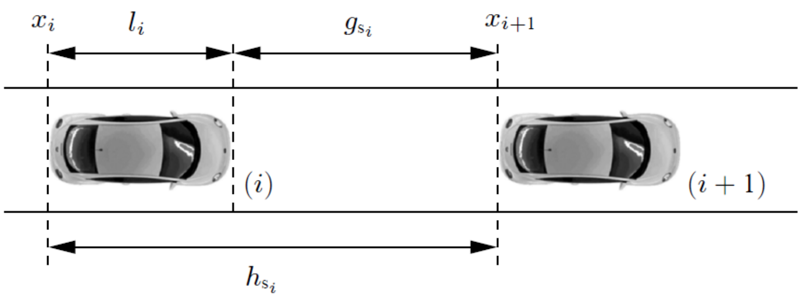


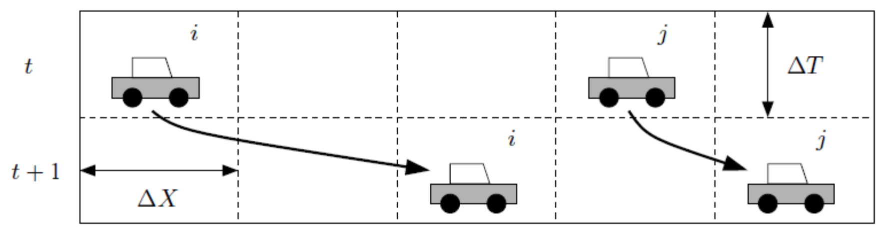
- 1967-1990:
  - Zuse and Fredkin state that the **universe** is a CA

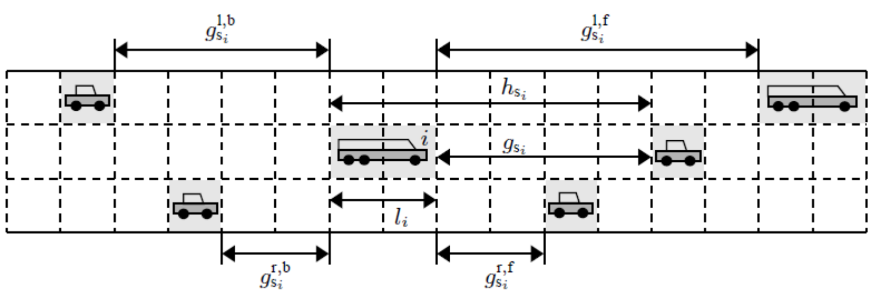



Modelling traffic cellular automata (TCA)

- Conversion of continuous to discrete time/space:

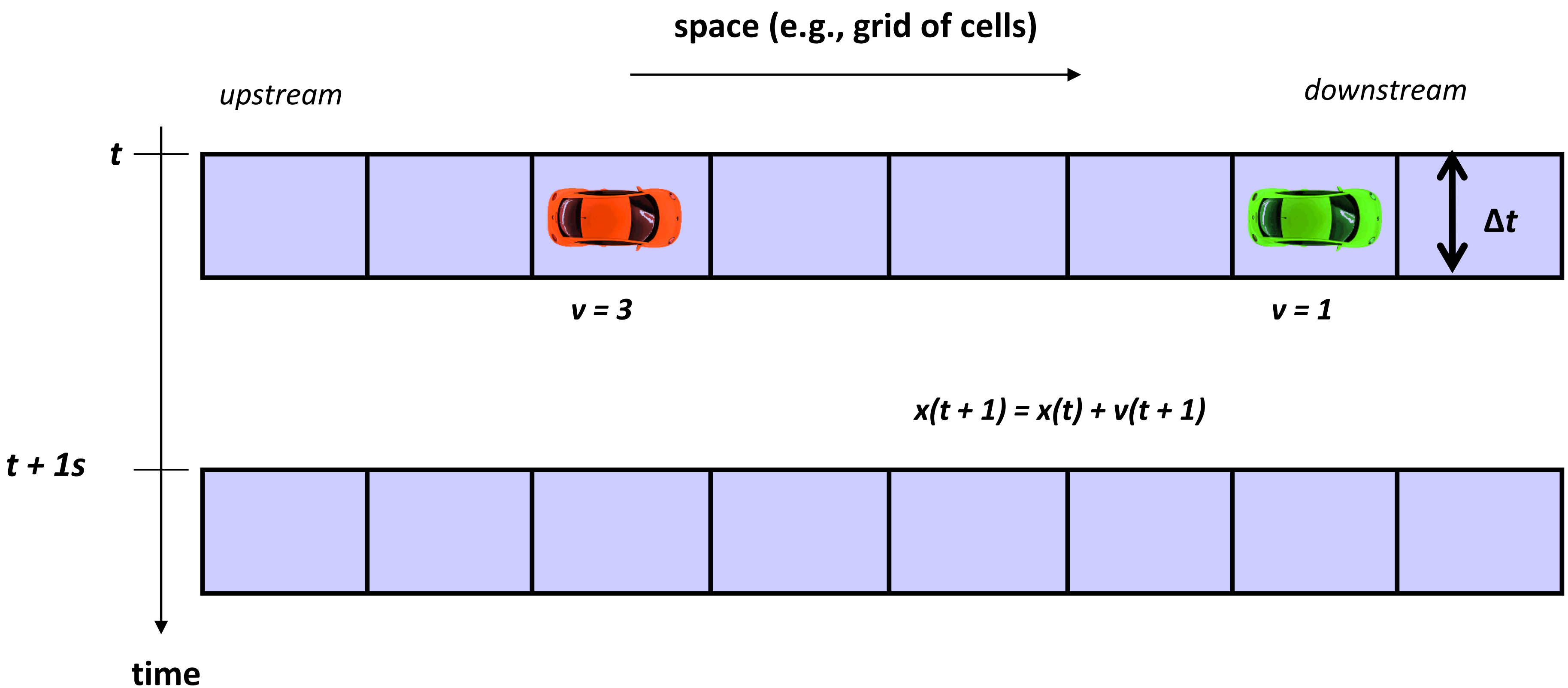






Modelling traffic cellular automata (TCA)

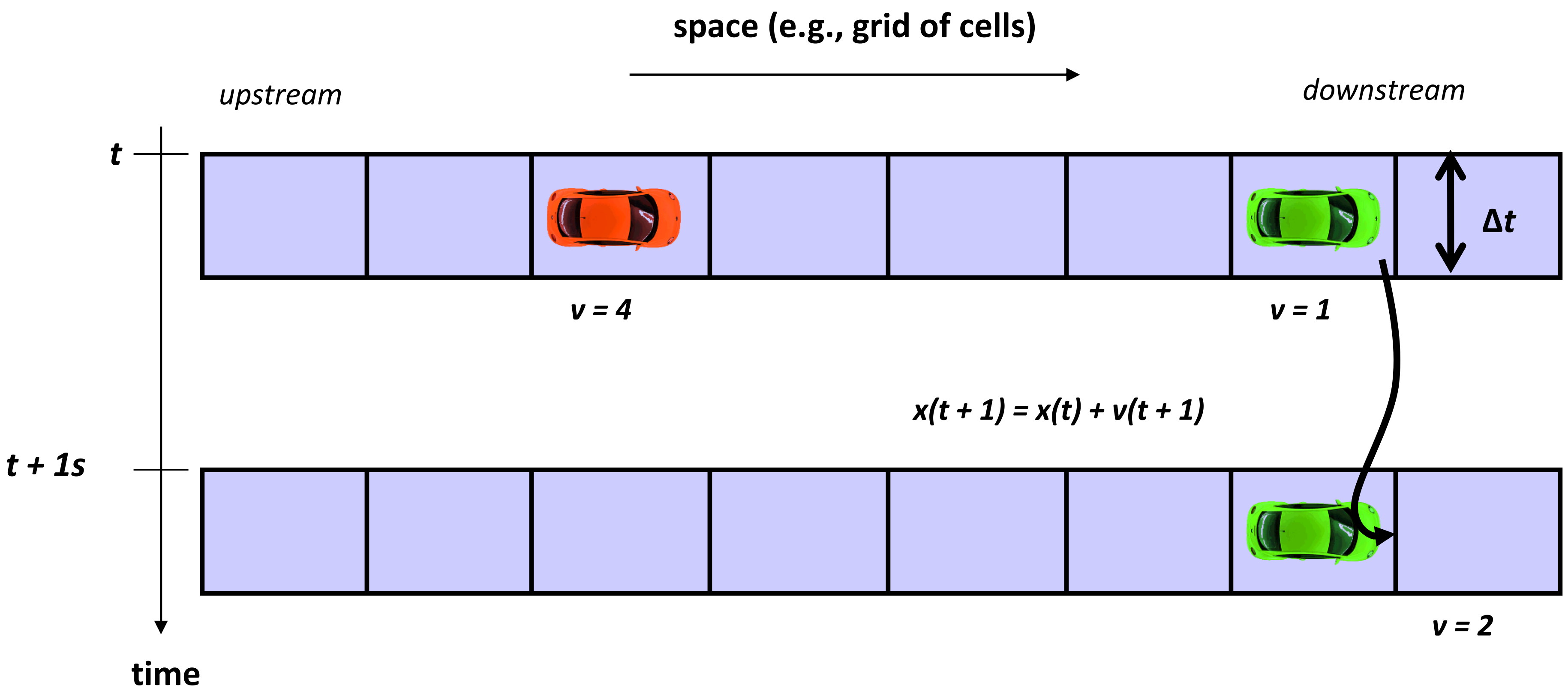
- Faster (but coarser) version of microscopic models



Car-following submodel = set of local transition rules

Modelling traffic cellular automata (TCA)

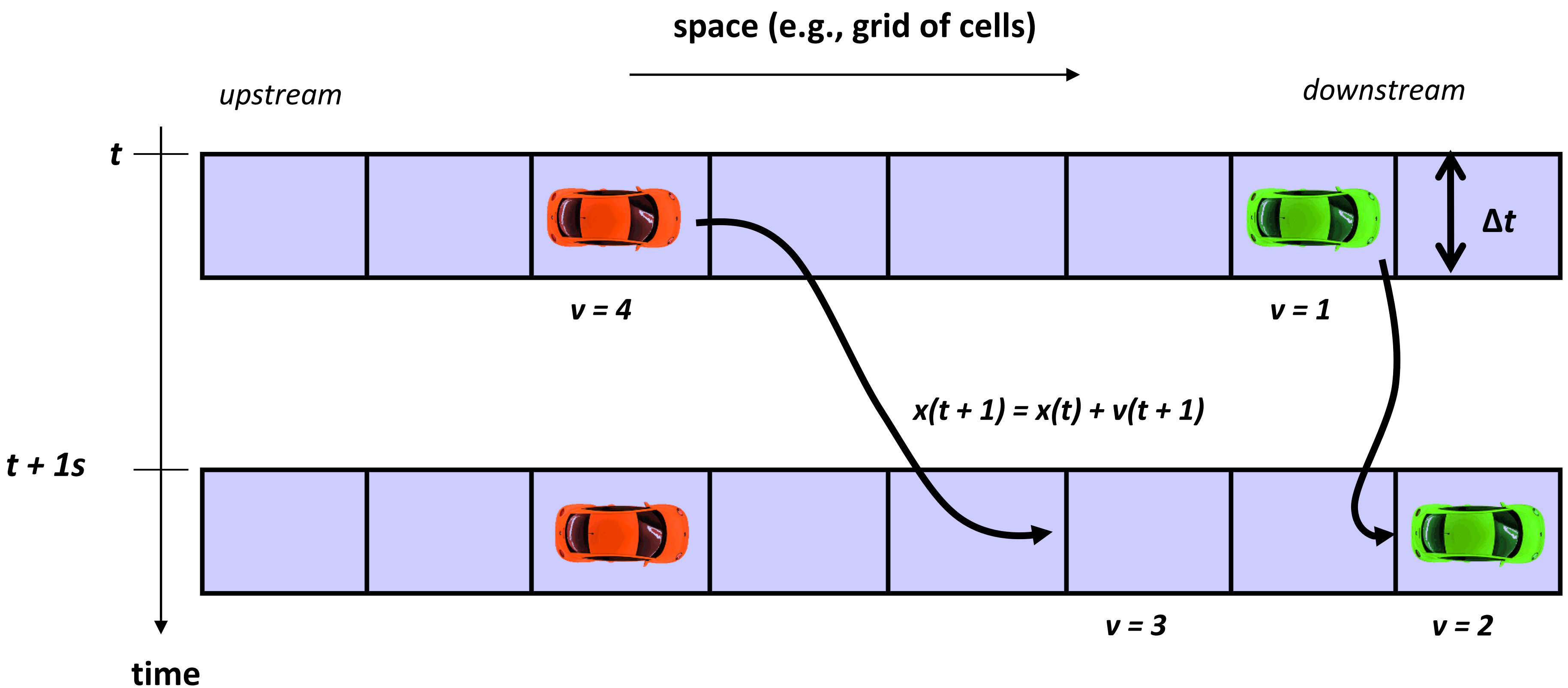
- Faster (but coarser) version of microscopic models



Car-following submodel = set of local transition rules

Modelling traffic cellular automata (TCA)

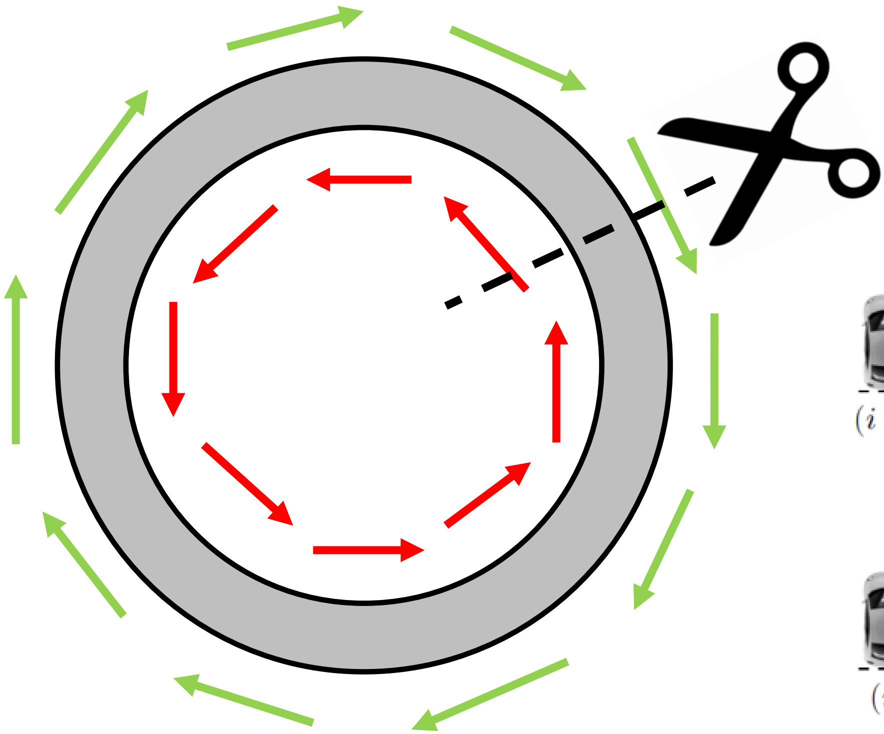
- Faster (but coarser) version of microscopic models



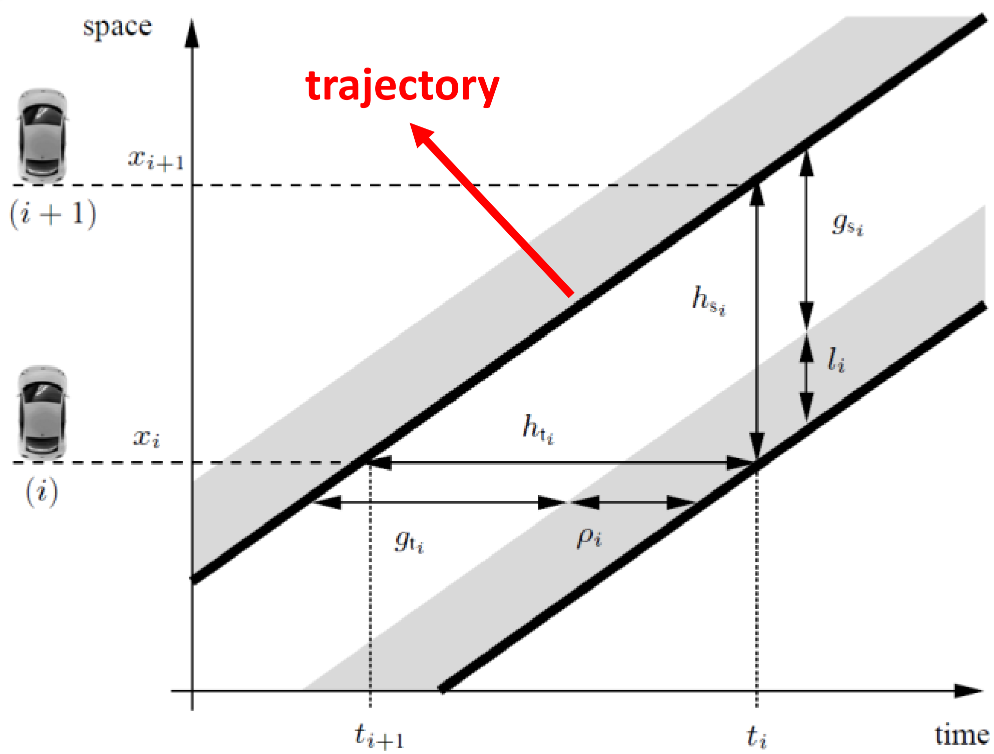
Car-following submodel = set of local transition rules

Visualising congestion in a cellular automaton

- E.g., vehicles are driving round a circle:



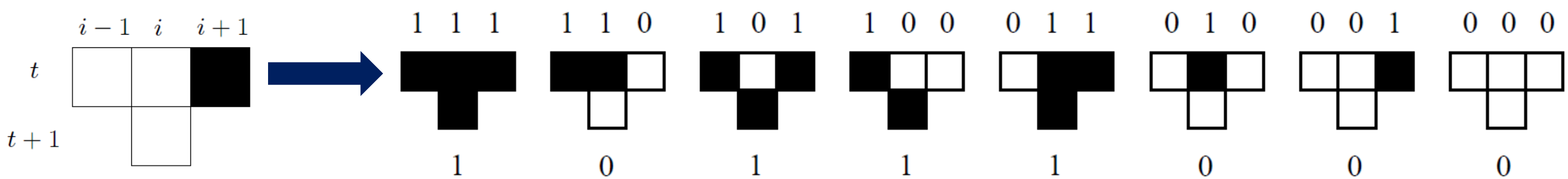
time-space diagram!



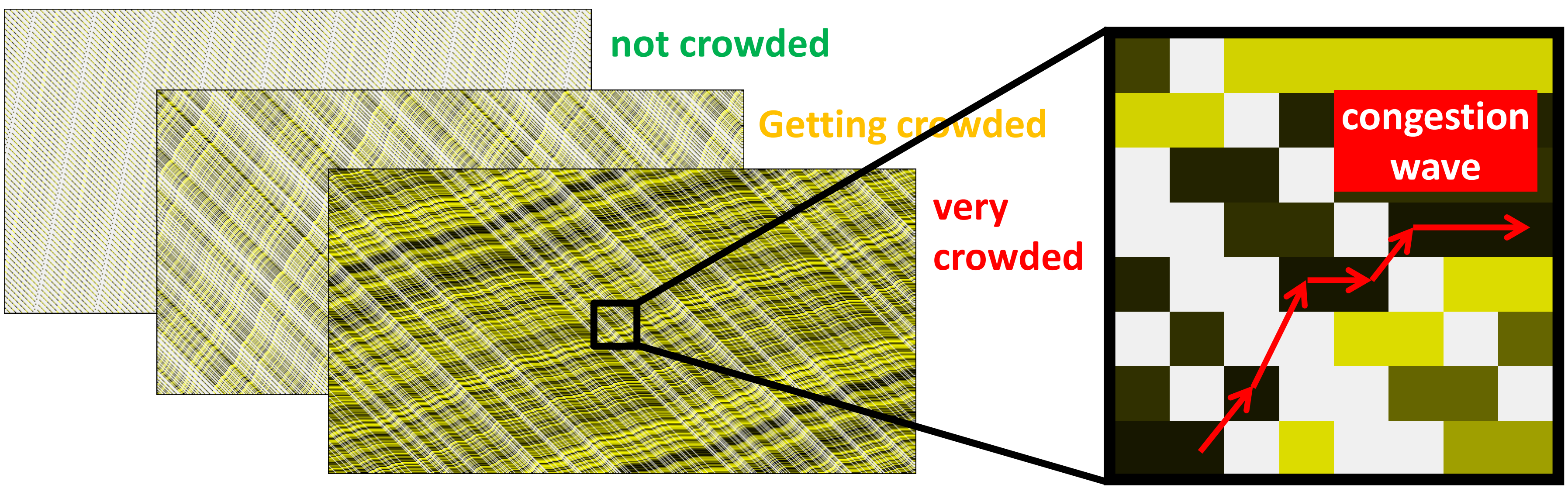
Wolfram’s regel CA-184

$$
\begin{aligned}
\mathcal{L} &= \mathbb{Z}^d \quad (\text{with } d = 1)\\
\Sigma &= \mathbb{Z}_2 = \{0, 1\}\\
\mathcal{N}_i &= \{i-1, i, i+1\}\\
\delta(i,t) &: \mathbb{Z}_2^3 \longrightarrow \mathbb{Z}_2\\
&: \{\sigma_{i-1}(t), \sigma_i(t), \sigma_{i+1}(t)\} \longmapsto \sigma_i(t+1)
\end{aligned}
$$

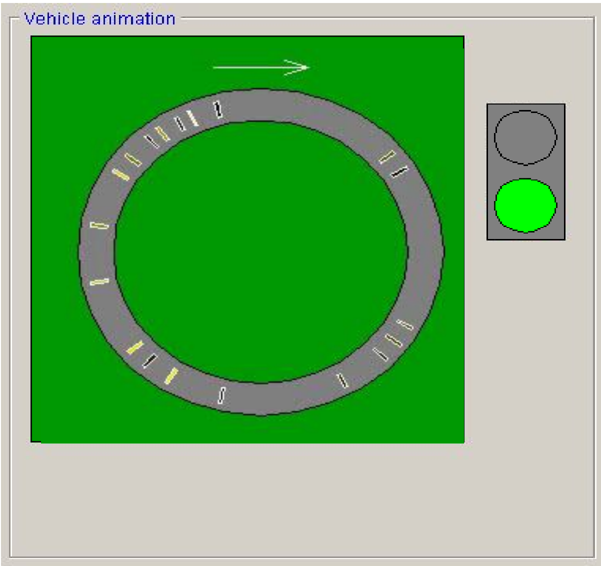
- Simple, 8 possible transitions:



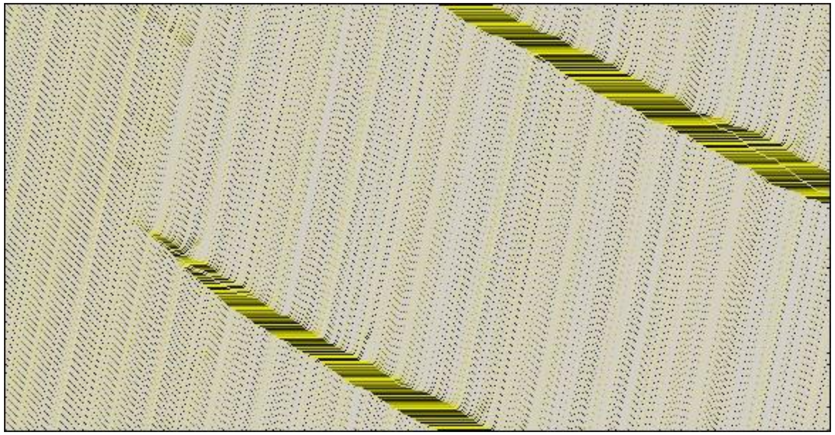
- Time-space diagrams:



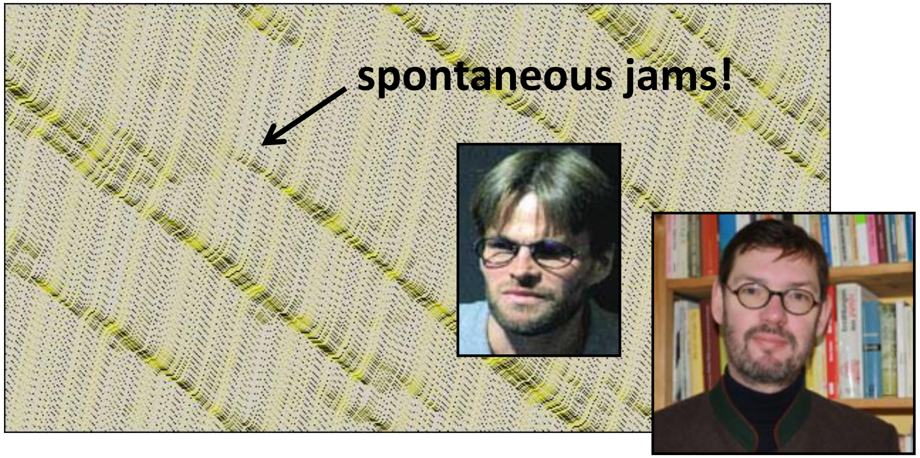
Variations of cellular automata



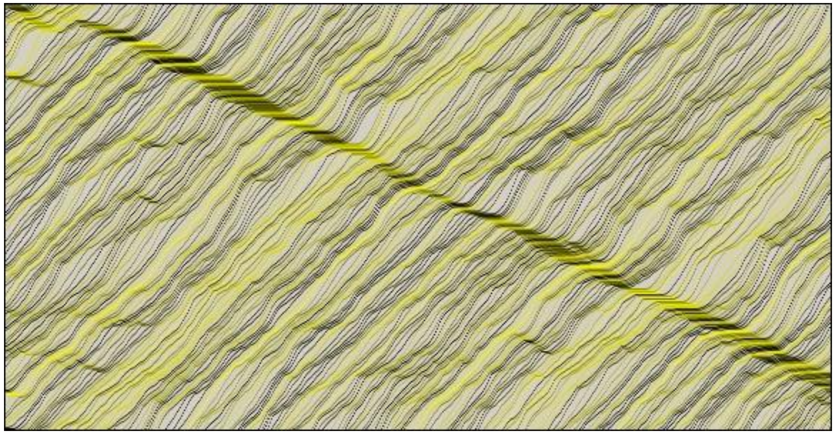
Velocity-dependent randomisation model



Nagel-Schreckenberg model



Knospe's model with brake lights



Complexity of the rules: a TCA with brake lights

- Random slowing down: randomisation
- '*Slow-to-start*' behaviour: capacity drop
- Anticipation effects: stabilisation of free-flowing traffic

R0: *determine stochastic noise*

$$\begin{cases} b_{i+1}(t-1) = 1 \quad \wedge \quad g_{t_i}(t-1) < t_{s_i}(t-1) & \Longrightarrow \quad p(t) \leftarrow p_b, \\ v_i(t-1) = 0 & \Longrightarrow \quad p(t) \leftarrow p_0, \\ \text{else} & \Longrightarrow \quad p(t) \leftarrow p_d, \\ b_i(t) \leftarrow 0 & \end{cases}$$

R1: *acceleration*

$$(b_i(t-1) = 0 \quad \wedge \quad b_{i+1}(t-1) = 0) \quad \vee \quad g_{t_i}(t) \geq t_{s_i}(t)$$
$$\Longrightarrow v_i(t) \leftarrow \min\{v_i(t+1), v_{\max}\}$$

R2a: *determine effective space gap*

$$g^*_{s_i}(t) \leftarrow g_{s_i}(t-1) + \max\{\underbrace{\min\{v_{i+1}(t-1), g_{s_{i+1}}(t-1)\}}_{\text{anticipated speed of leading vehicle}} - g_{s_{\text{security}}}, 0\}$$

R2b: *braking*

$$v_i(t) \leftarrow \min\{v_i(t), g^*_{s_i}(t)\}$$
$$v_i(t) < v_i(t-1) \Longrightarrow b_i(t) \leftarrow 1$$

R3: *randomisation*

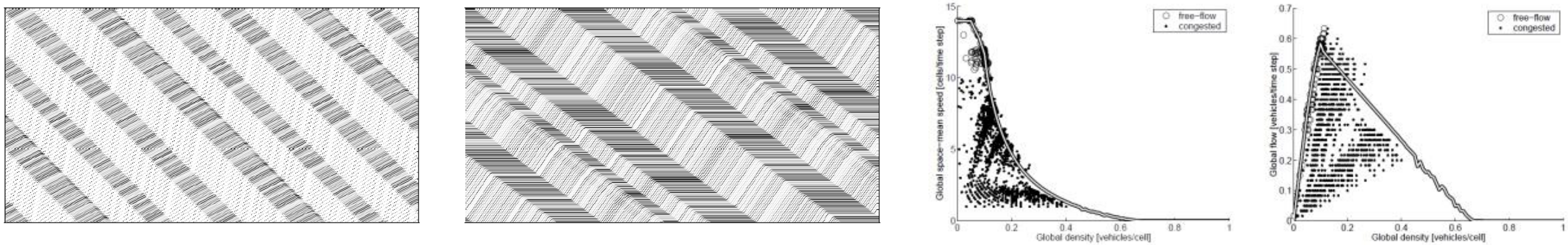
$$\xi(t) < p(t) \Longrightarrow$$
$$p(t) = p_b \quad \wedge \quad v_i(t) = v_i(t-1) + 1 \Longrightarrow b_i(t) \leftarrow 1$$
$$v_i(t) \leftarrow \max\{0, v_i(t) - 1\}$$

R4: *vehicle movement*

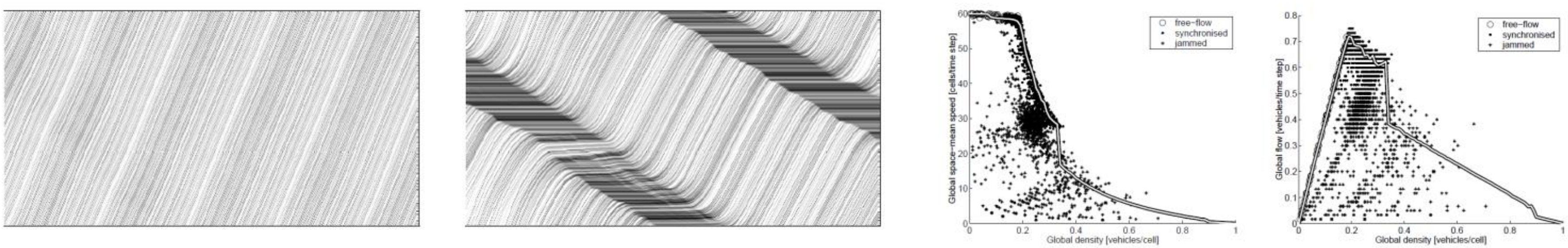
$$x_i(t) \leftarrow x_i(t-1) + v_i(t)$$

→ **human behaviour**

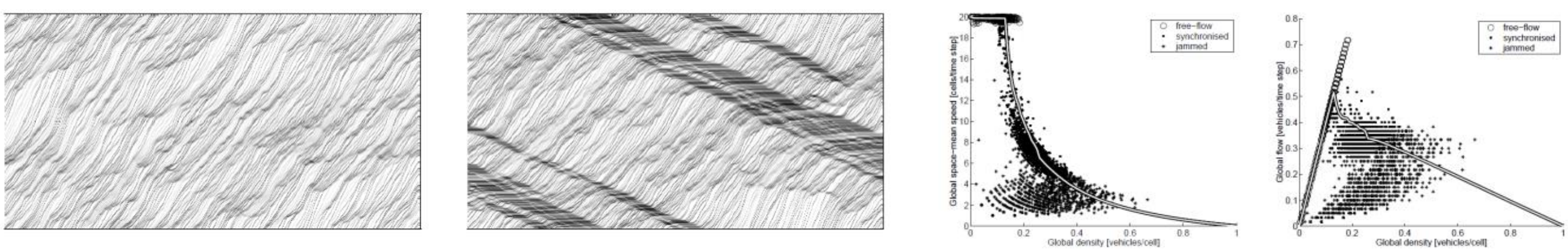
A look on the fundamental diagram in a TCA



Helbing-Schreckenberg



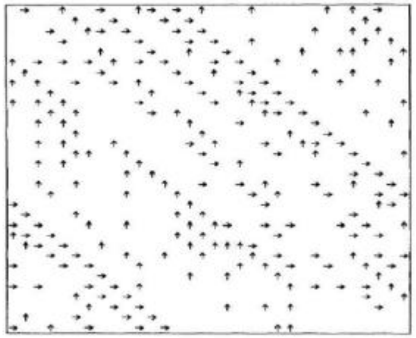
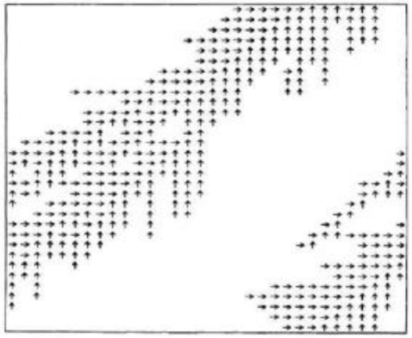
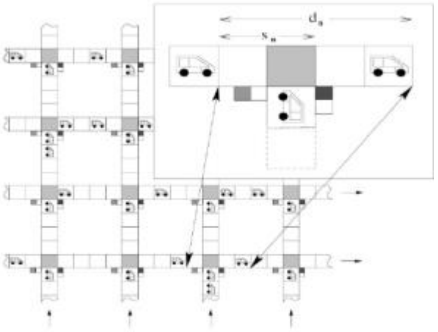
Kerner-Klenov-Wolf



Knospe et al. ('brake-lights')

More lanes and city traffic

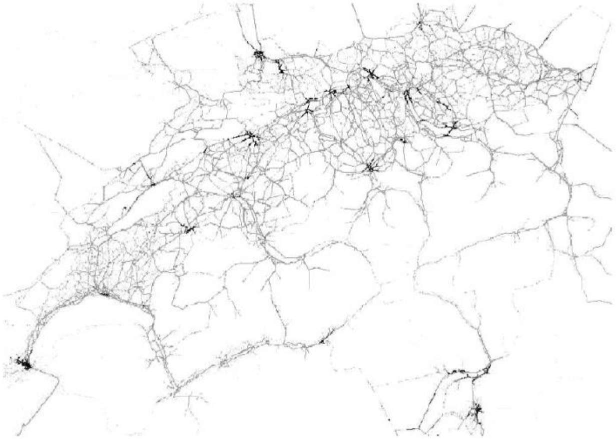
- ‘*Multi-lane traffic*’:
  - Mandatory versus discretionary lane change
  - Culture: ‘*keep-your-lane*’ vs. mandatory driving on the right
  - Phenomena: speed differences, density inversions, …
  - Same driving directions versus bidirectional traffic
  - Watch out for “*ping-pong traffic*”!
- City traffic:
  - Classic Biham, Middleton, and Levine (BML) model

  - Explicit intersections, roundabouts, …

Transportplanning with TCA models

- TRANSIMS:
  - TRansportation ANalysis SIMulation System
  - Activity- and agent-based



- MATSim:
  - Multi-Agent Traffic Simulation
  - Activity- and agent-based
  - Even faster: queueing models
  - Finite buffers!

More information?

www.tmleuven.be | www.telraam.net

sven.maerivoet@tmleuven.be

+32 (16) 31.77.33

twitter.com/tmleuven | twitter.com/telraamtelraam

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