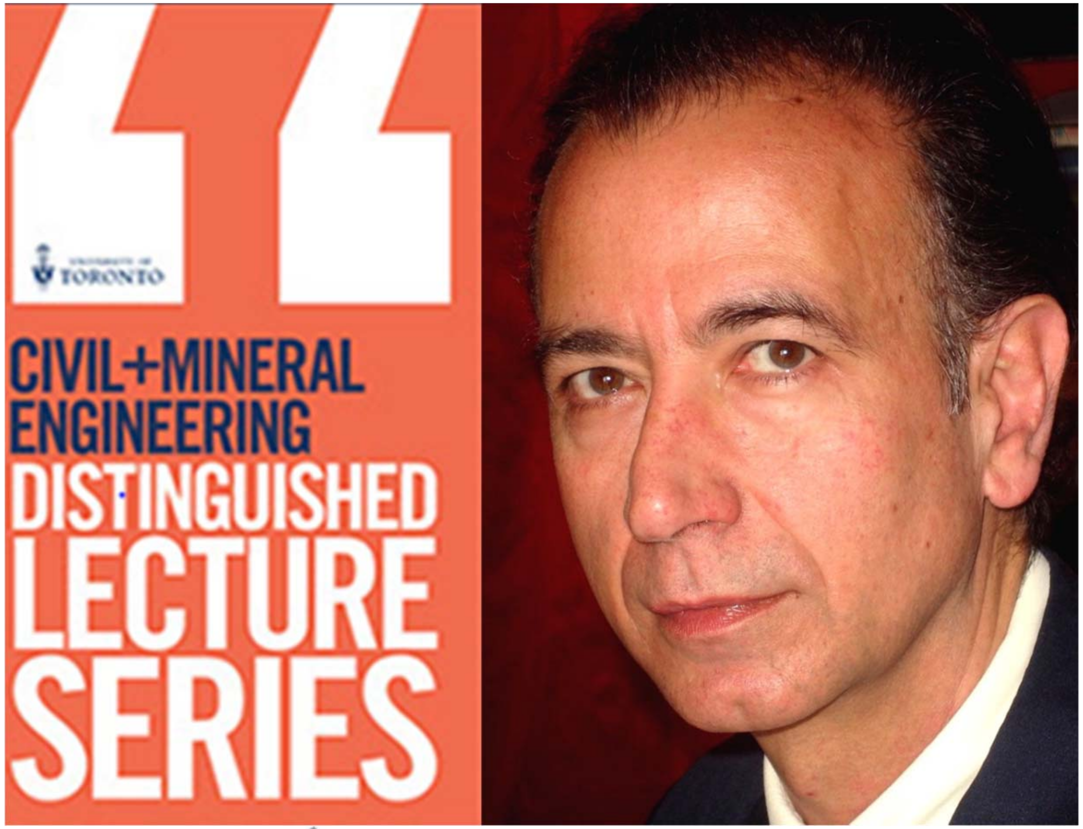

Traffic Management for the 21st Century

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#TrafficSolutions

Traffic Management for the 21st Century

Prof. Markos Papageorgiou
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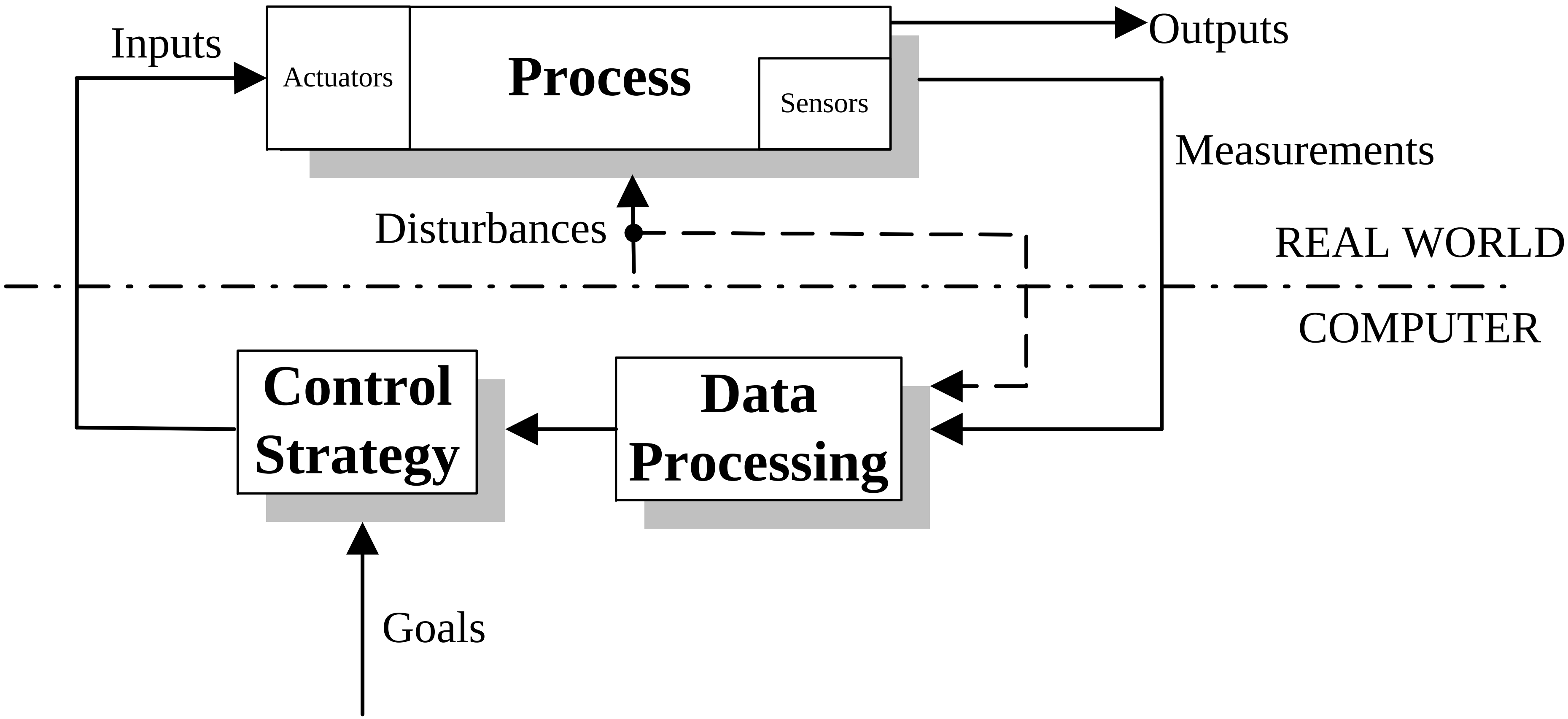
1. WHY TRAFFIC MANAGEMENT (TM)?

- Motorised road vehicle: A highly influential invention ➡ Vehicular traffic
- Vehicles share the road infrastructure among them, as well as with other (vulnerable) users: TM needed
- Few vehicles: Static TM for safety
- Many vehicles: Dynamic TM for efficiency

Basic elements of an automatic control system



Technology (Sensors, communications, computing, actuators): **Skeleton**

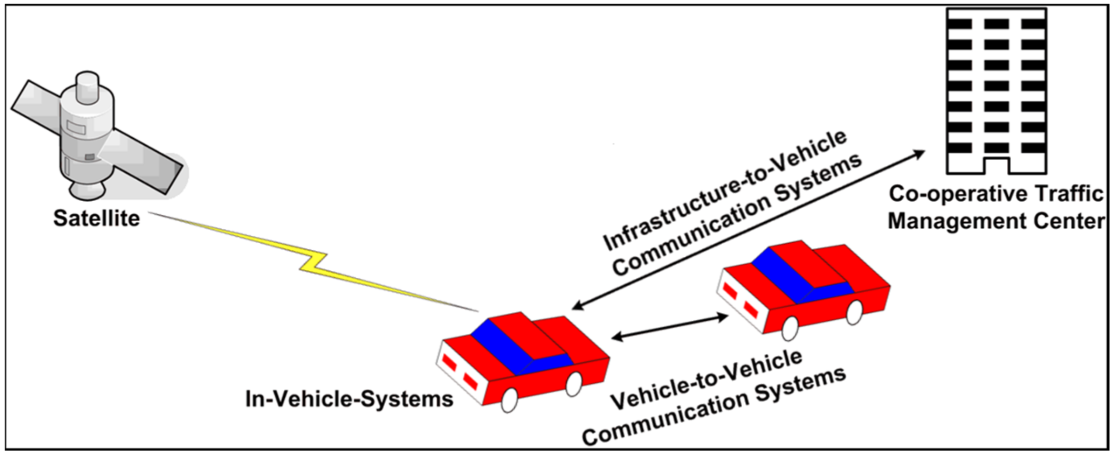
Methodology (Data processing, control strategy): **Intelligence**

Current TM Systems (ITS)

- **Process**: conventional vehicle flow
- **Sensors**: spot sensors (loops, vision, magnetometers, radar, ...)
- **Communications**: wired
- **Computing**: distributed/hierarchical
- **Actuators**: road-side (TS, RM, VSL, VMS, ...)

2. EMERGING VACS (Vehicle Automation and Communication Systems)

- Significant efforts: Automotive industry, Research community, Government agencies
- Mostly vehicle-centric: safety, convenience
- In-vehicle systems (automated vehicles), e.g. ACC
- VII or cooperative systems (connected vehicles), e.g. CACC



Future TM Systems (C-ITS)

- **Process**: enhanced-capability vehicle flow
- **Sensors**: vehicle-based
- **Communications**: wireless, V2V, V2I, I2V
- **Computing**: massively distributed
- **Actuators**: in-vehicle, individual commands

Implications/Exploitation for traffic flow efficiency?

- TRAMAN21: TRAffic MANagement for the 21st Century (ERC Advanced Investigator Grant) http://www.traman21.tuc.gr/

- Intelligent vehicles may lead to dumb traffic flow (efficiency decrease ⇒ congestion increase)
- Why?
  - ACC with long gap (→ capacity)...
  - ... or sluggish acceleration (→ capacity drop)
  - Conservative lane-change or merge assistants
  - Underutilized dedicated lanes
  - Inefficient lane assignment
  - Uncoordinated route advice
  - ...
- What needs to be done in advance/parallel to VACS developments?

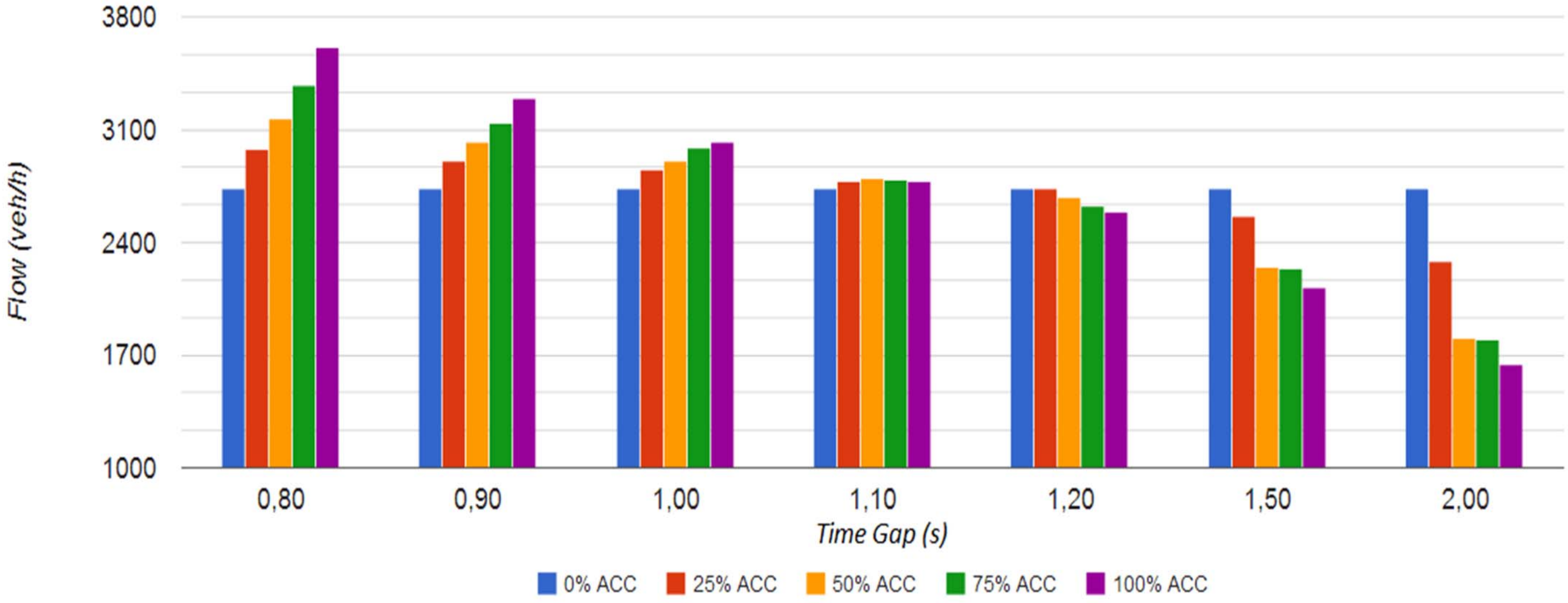
3. MODELLING

- Currently not sufficient traffic-level penetration of VACS → no real data available
- Analysis of implications of VACS for traffic flow behaviour
- Also needed for design and testing of traffic control strategies
- Microscopic/Macroscopic traffic flow modelling

Microscopic Modelling

- No ready available tools
- Research (open-source) tools: documentation, GUI, ...
  - e.g. SUMO: an expanding open-source tool (DLR, Germany)
- Commercial tools: closed; or elementary coding of VACS functions

ACC traffic efficiency



From: Ntousakis, I.A., Nikolos, I.K., Papageorgiou, M.: On microscopic modelling of adaptive cruise control systems. *4th Intern. Symposium of Transport Simulation (ISTS'14)*, 1-4 June 2014, Corsica, France. Published in *Transportation Research Procedia* 6 (2015), pp. 111-127.

Macroscopic Modelling

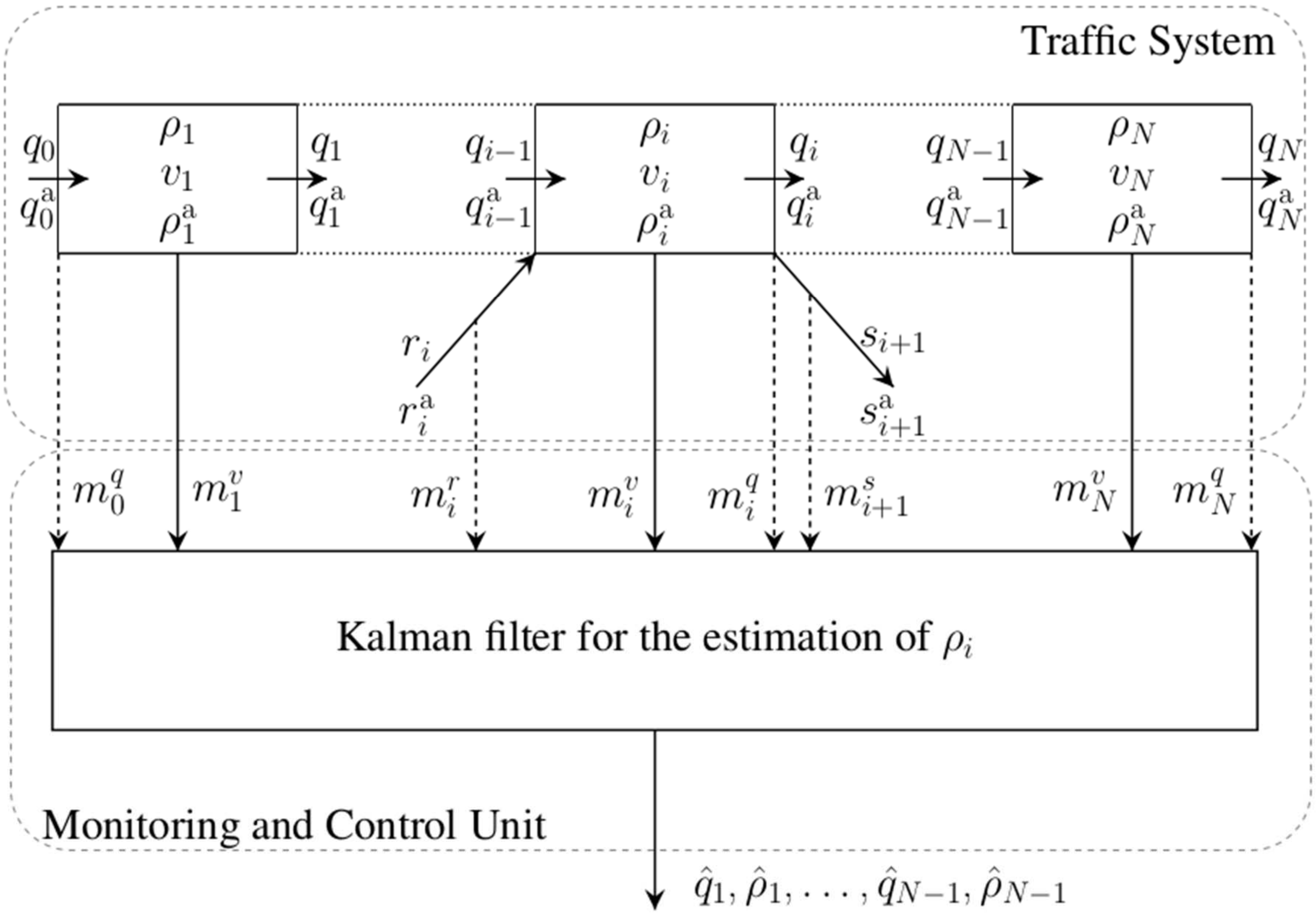
- Few research works
- Different penetration rates
- Macroscopic lane-based models
- Validation based on microscopic simulation data

4. MONITORING/ESTIMATION

- Prerequisite for real-time traffic control
- Conventional detectors are:
  - spot sensors (local information)
  - costly (to acquire, install, maintain)
- Exploitation of new real-time information from connected vehicles:
  - abundant in space
  - “cost-free” → ask TomTom, Google, Gaode, ...
  - suffices for speed and travel time
  - not for total flow or density

- Mixed traffic, various penetration levels
- Fusion with conventional detector data
- Reduction (...replacement) of infrastructure-based sensors
- OD estimation
- Incident detection

Freeway traffic estimation scheme



From: Bekiaris-Liberis, N., Roncoli, C., Papageorgiou, M.: Use of speed measurements for highway traffic state estimation - Case studies on NGSIM data and Highway A20, Netherlands. *Transportation Research Record* No. 2559 (2016), pp. 90-100.

Urban road/network traffic estimation
(with new data)

- Road queue length estimation
- Total flow estimation
  - Data fusion with conventional detectors
- Paradigm shift in signal control:
  - Strongly reduced (or no) detector hardware, cost for real-time signal control
  - Performance evaluation for fixed signals update

5. TRAFFIC CONTROL

- Which conventional traffic control measures can be taken over? – In what form?
- Which new opportunities arise for more efficient traffic control?
  - Increased control granularity (e.g. by lane, by destination, flow splitting)
  - Arbitrary space-time resolution
  - Efficient lane assignment
- Various control levels: vehicle, local, link, network

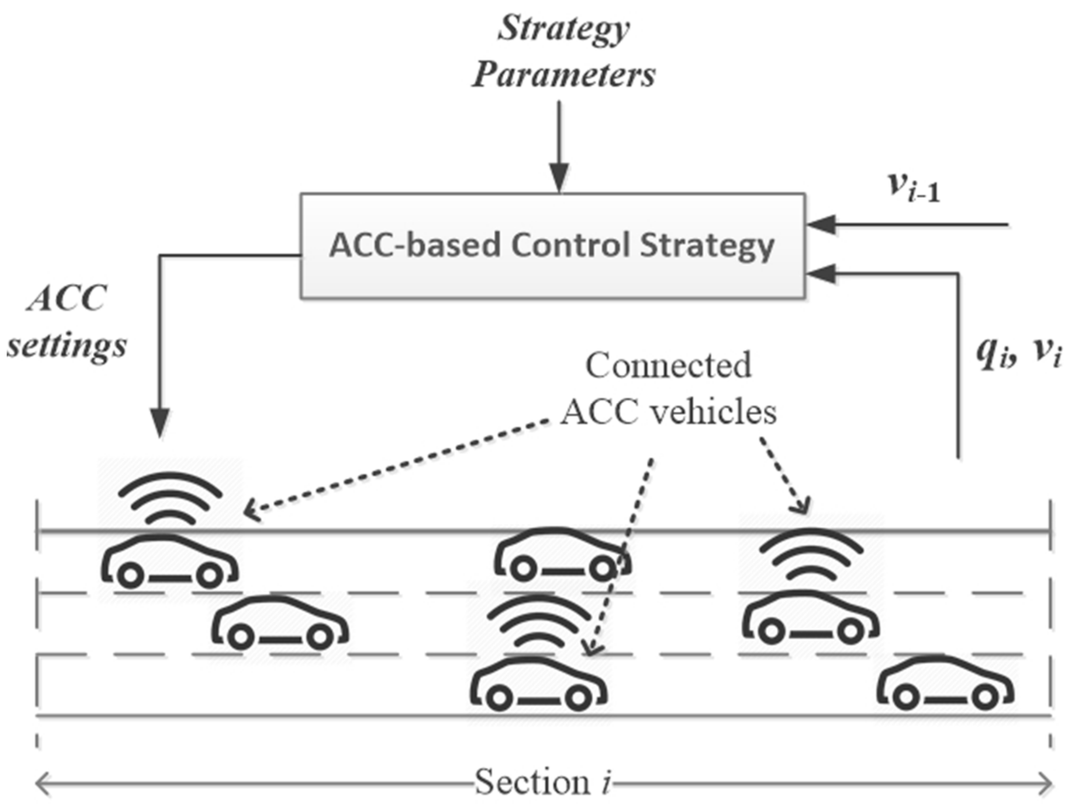
Vehicle-level tasks

- What is the movement strategy of automated cars? (in a manually driven world)
- How would traffic look like if all vehicles were automated?
- Can automated cars be exploited as actuators to improve the traffic flow?
- Space-time dependent change (control) of vehicle behaviour?
  - ACC gap and acceleration
  - Lane-changing behaviour
- Vehicle trajectory control

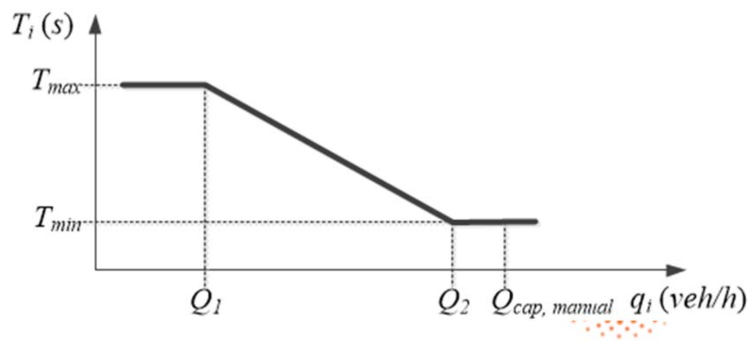
Vehicle-optimal advancement
versus
Traffic-optimising vehicle behaviour

Real-time ACC Time-Gap Control

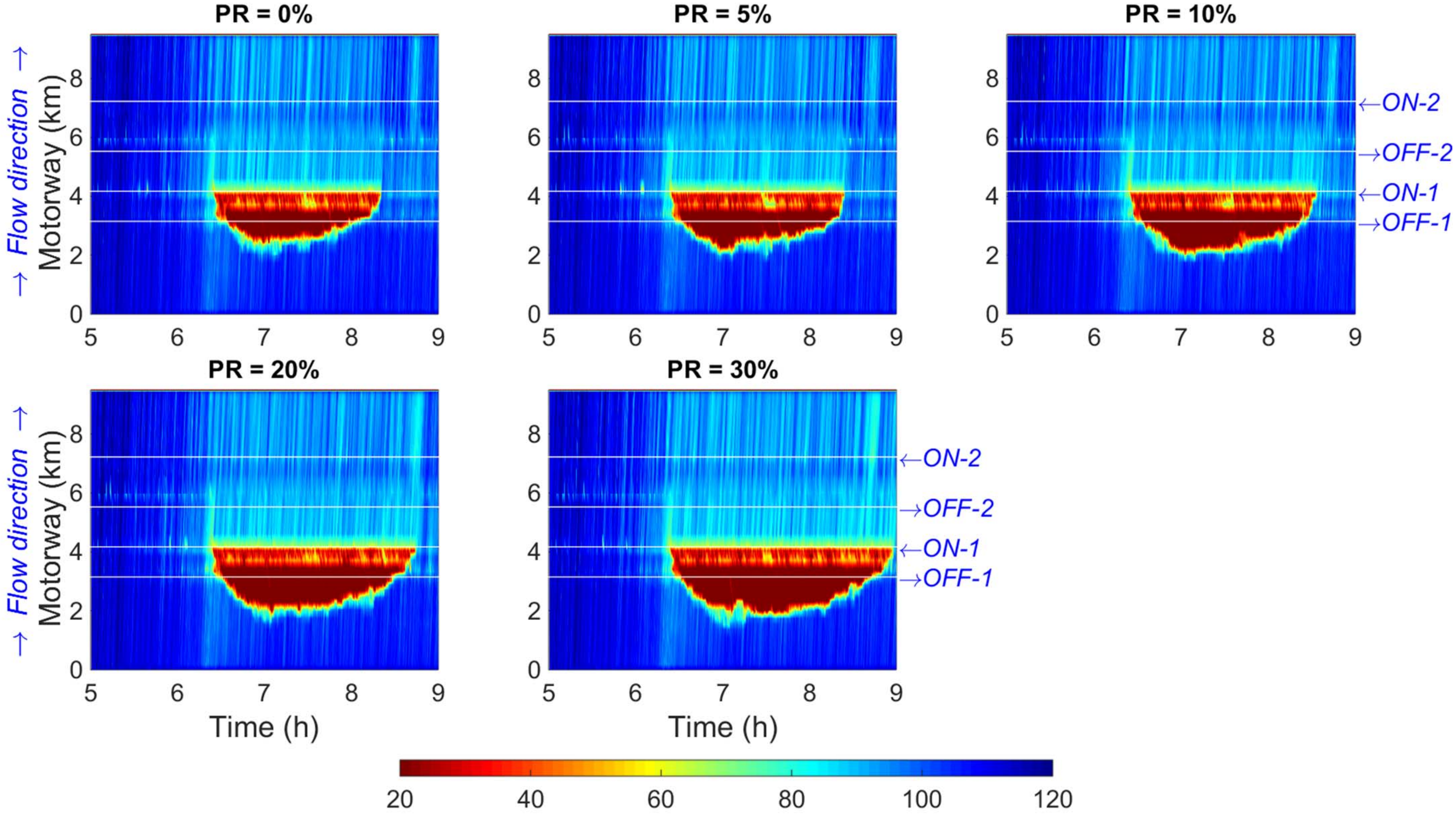
(section-based)



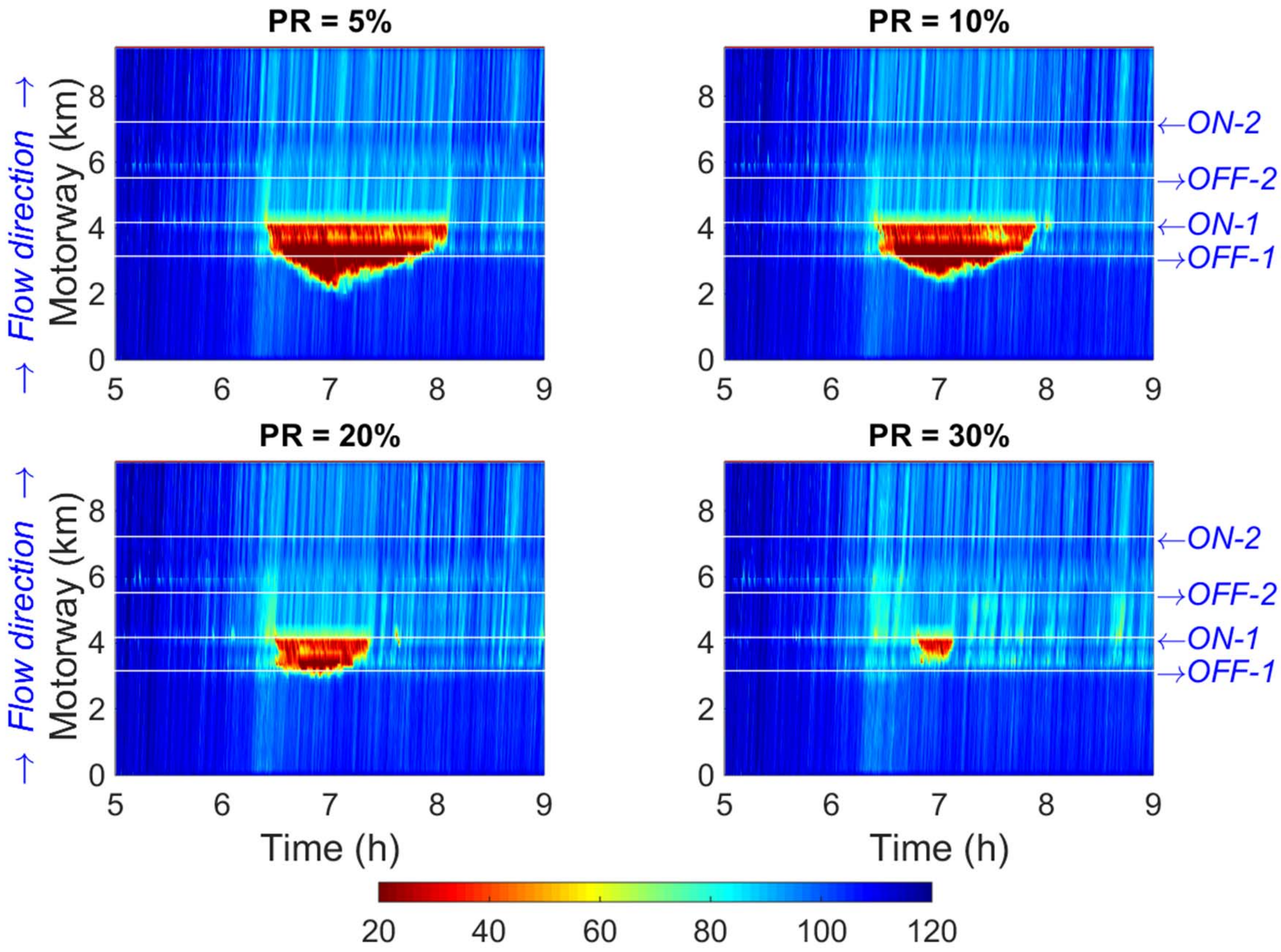
$$T_{stg,i}(k) = \begin{cases} T_i[q_i(k)] & \text{if } v_i(k) > v_{cong} \\ T_{\min} & \text{at active bottlenecks} \\ T_{\max} & \text{else} \end{cases}$$



Simulation results: without ACC exploitation



Simulation results: with ACC exploitation



Local-level tasks:

- Urban intersection
  - Speed control (reduction of stops)
  - Eco-driving
  - Platoon-forming while crossing urban intersections → increased saturation flow
  - Dual vehicle ←→ traffic signal communication
  - No/virtual traffic signals
    - Crossing sequence
    - Safe and convenient vehicle trajectories
    - Vulnerable road users
    - Mixed traffic?

Rush Hour by Fernando Livschitz
https://www.youtube.com/watch?v=MRPK1rBl_rI

Too difficult?

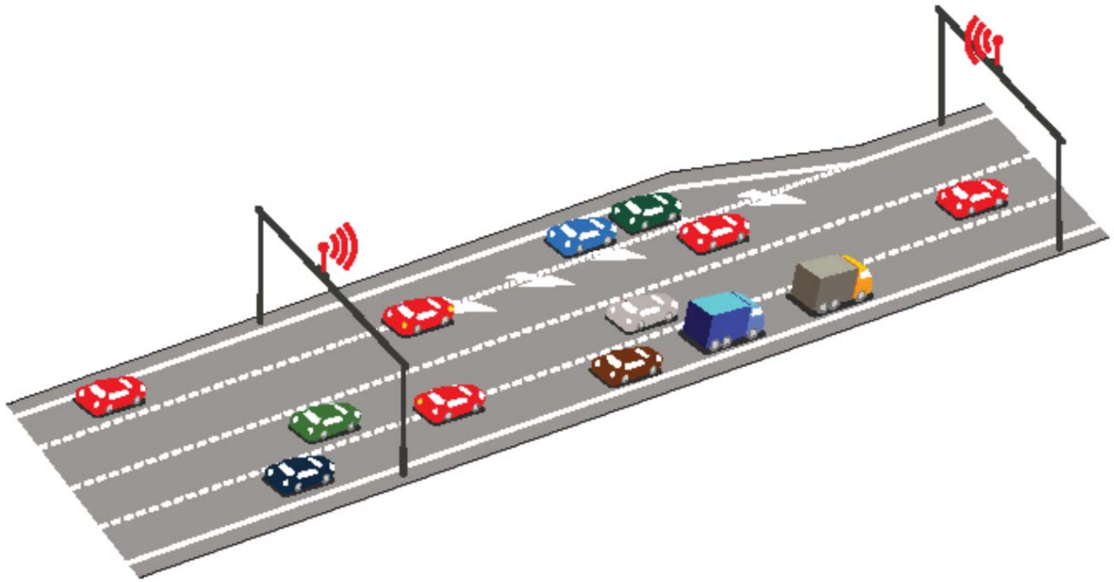
- Individual drivers act autonomously
  - Monitor: other arriving vehicles on higher-priority approaches
  - Communicate: turn blinker
  - Predict: ego and other vehicles trajectories; potential conflicts
  - Decide: go or non-go
  - Repeat: whole loop, if non-go decision
  - Emergency reaction: in real time, if go decision

  - Video in lapse time

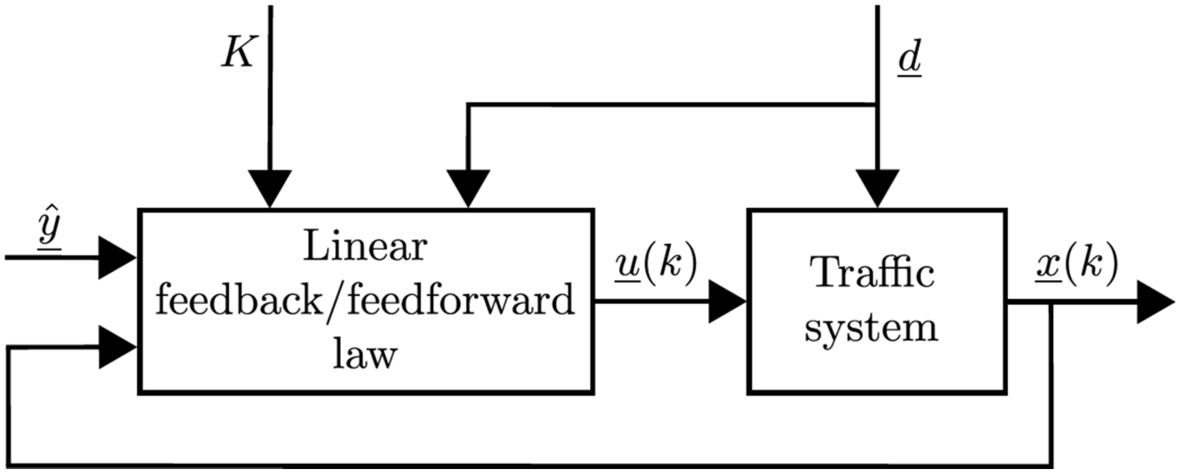
- Automated/Connected vehicles?
  - Monitor: with sensors → all around, simultaneously, fast
  - Communicate: V2V, V2I → comprehensive, fast
  - Predict: computation based on assumptions → fast
  - Decide: go or non-go
  - Repeat: whole loop, if non-go decision → high frequency (real-time MPC)
  - Emergency reaction: in real time, if go decision
  - Overall fast, reliable
  - Weak point: Prediction uncertainty (disturbances)
    - Stochasticity margins
    - Physical inertia

    → reduced efficiency for higher reliability

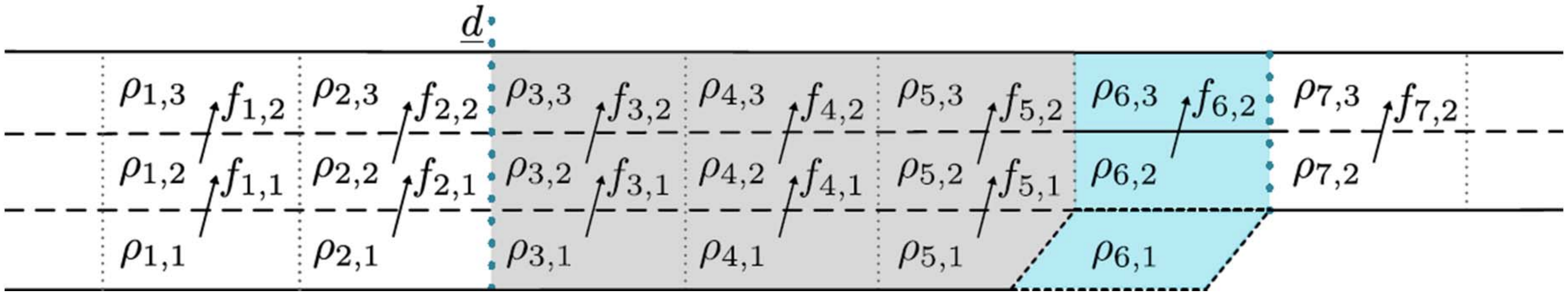
Local task example: bottleneck control
(for throughput maximisation)



Feedback-based

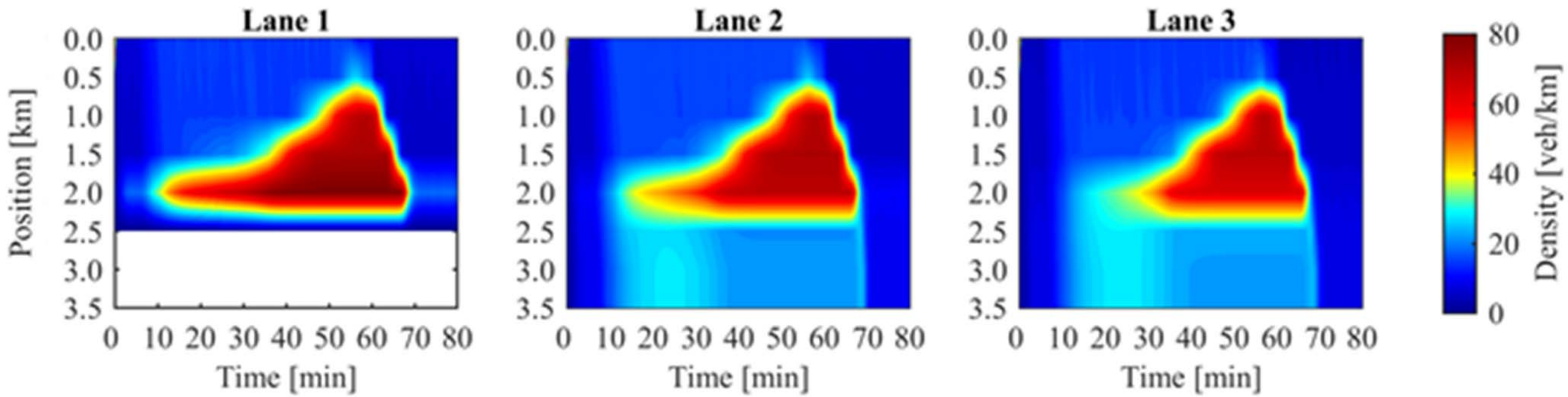


Application Example (lane changing only)

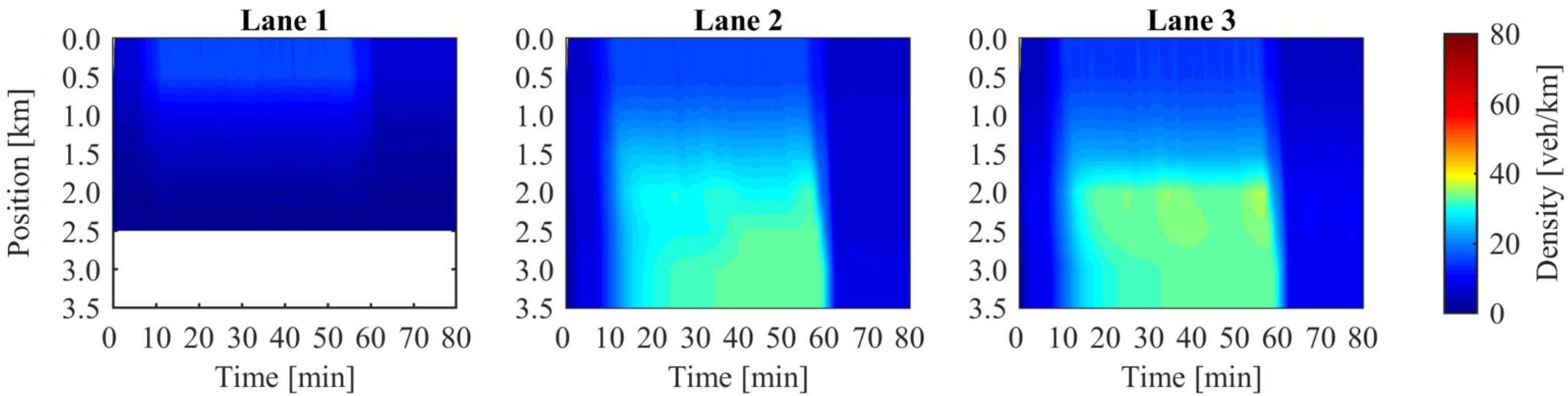


From: Roncoli, C., Bekiaris-Liberis, N., Papageorgiou, M.: Optimal lane-changing control at motorway bottlenecks. *IEEE 19th Intern. Conference on Intelligent Transportation Systems (ITSC)*, Rio de Janeiro, Brazil, November 1-4, 2016, pp. 1785-1791.

Without Control



With Control



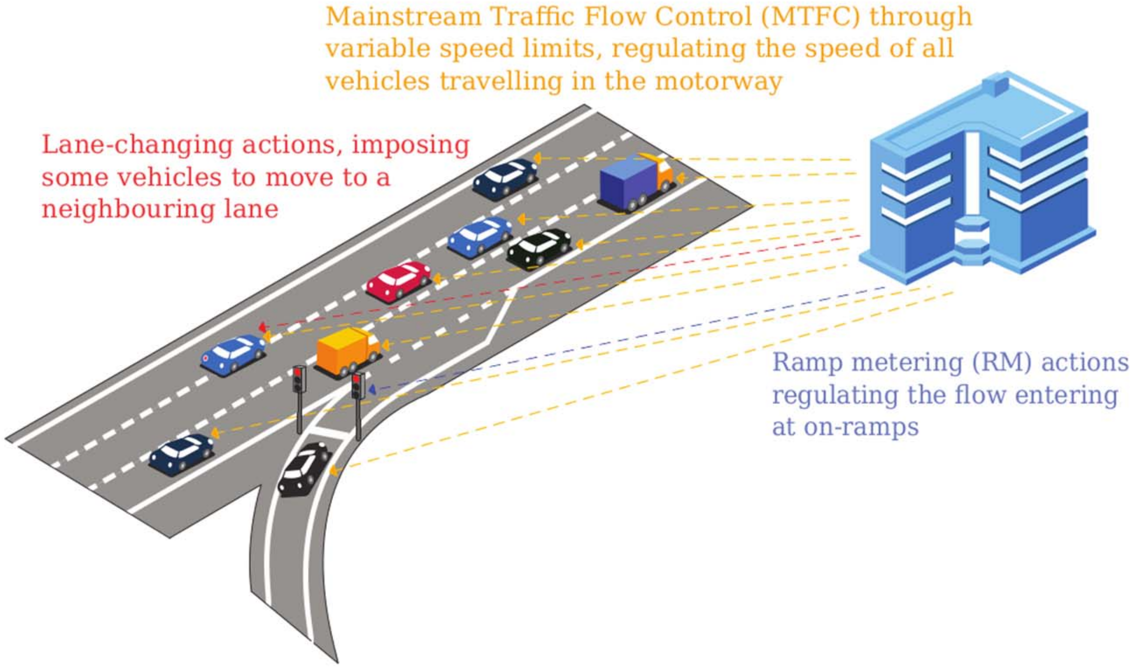
Link/Network-level tasks:

- Route guidance

- Urban road networks
  - Offset control (reduction of stops)
  - Platoon-forming: Stronger intersection interconnections (increased saturation flow, queues)
  - Saturated traffic conditions?
    - Handling?
    - Storage space? Where?

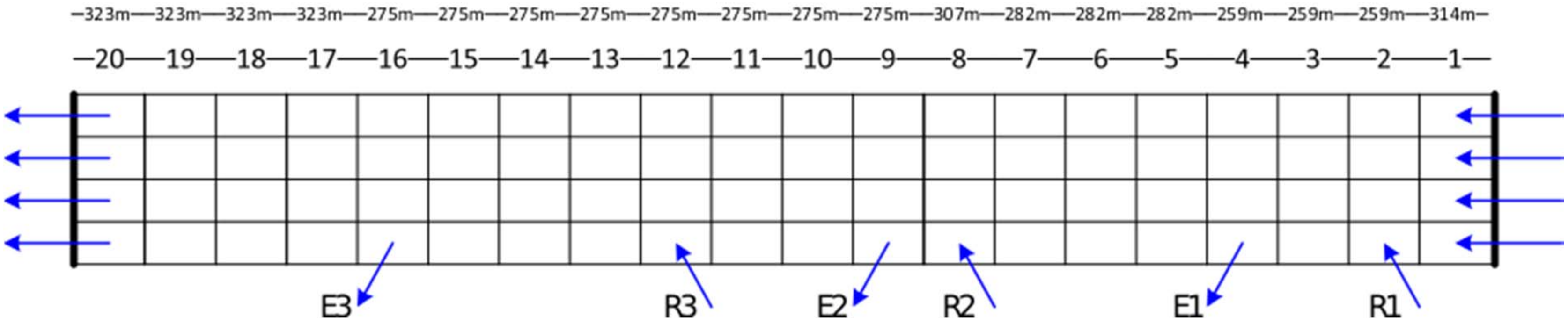
Motorway Link-level control

- Control actuators



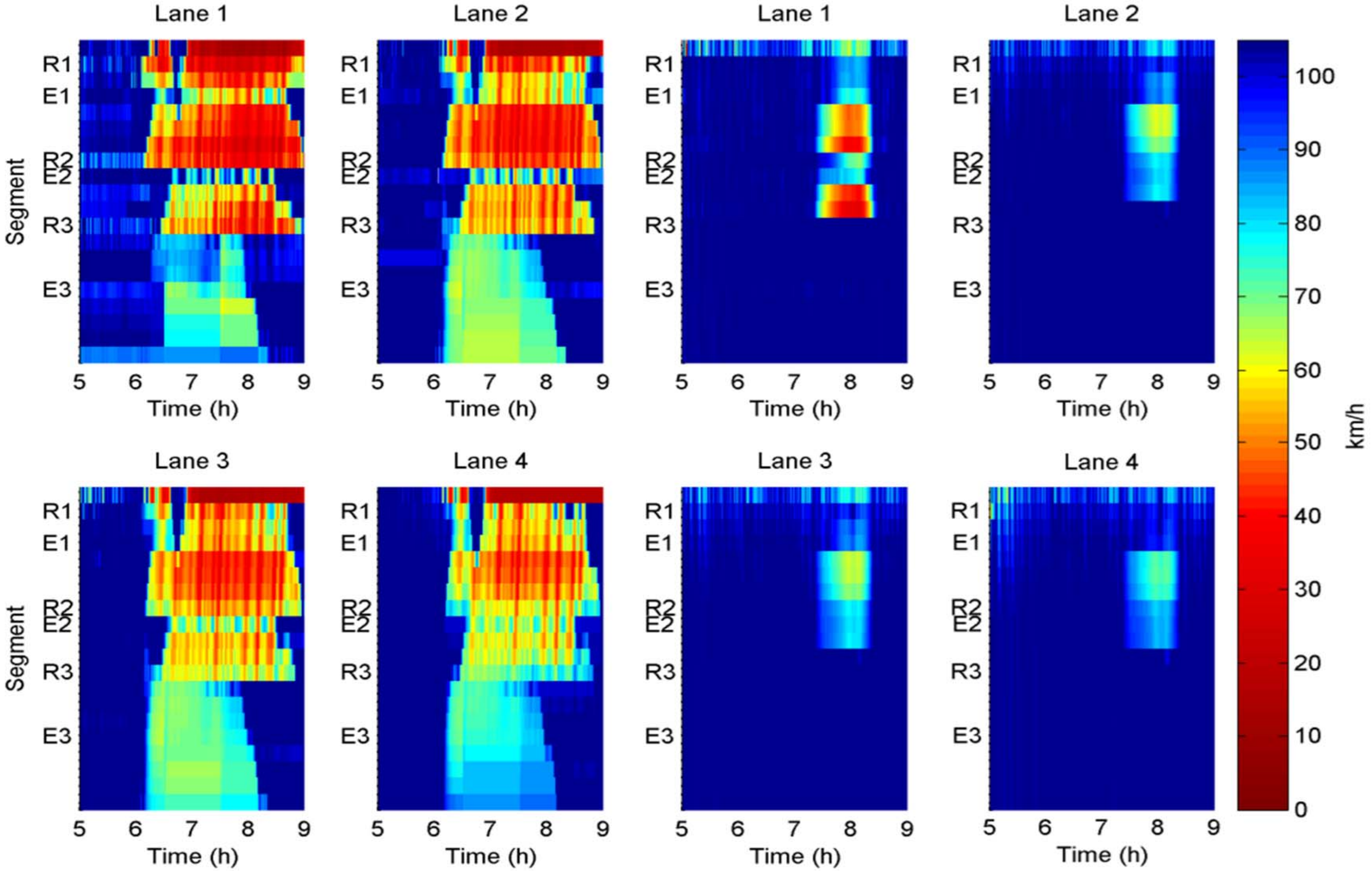
From: Roncoli, C., Papageorgiou, M., Papamichail, I.: Traffic flow optimisation in presence of vehicle automation and communication systems – Part II: Optimal control for multi-lane motorways. *Transportation Research Part C* 57 (2015), pp. 260-275.

Link control: Model-based Optimisation
(case study)



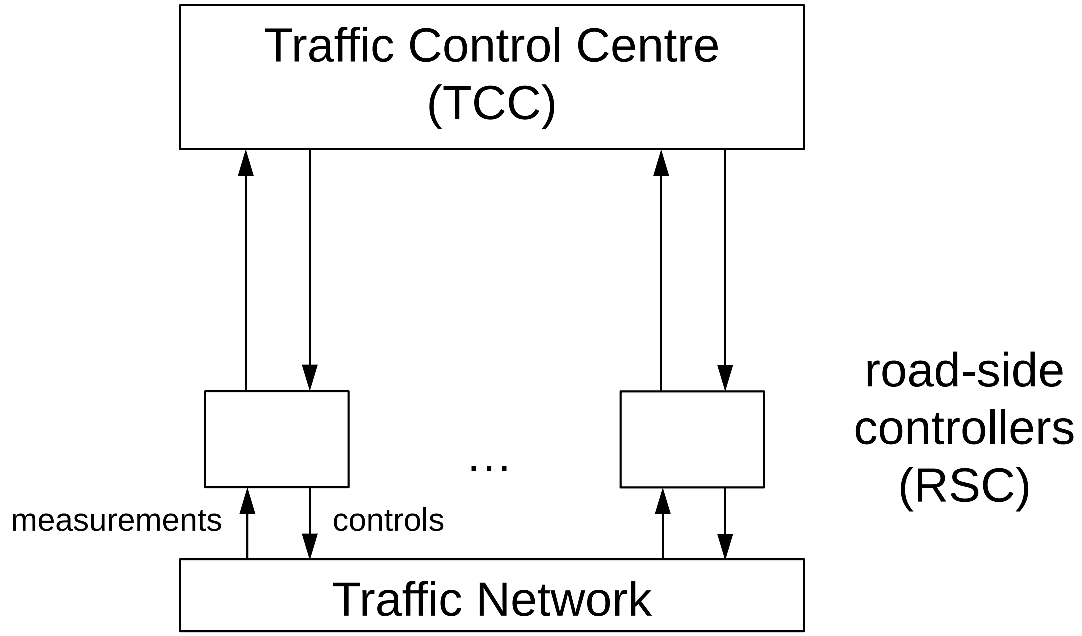
Monash Freeway (M1), Melbourne, Australia
(data: courtesy VicRoads)

Link control results



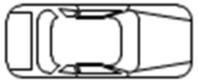
6. FUNCTIONAL/PHYSICAL ARCHITECTURE

Conventional TM Architecture

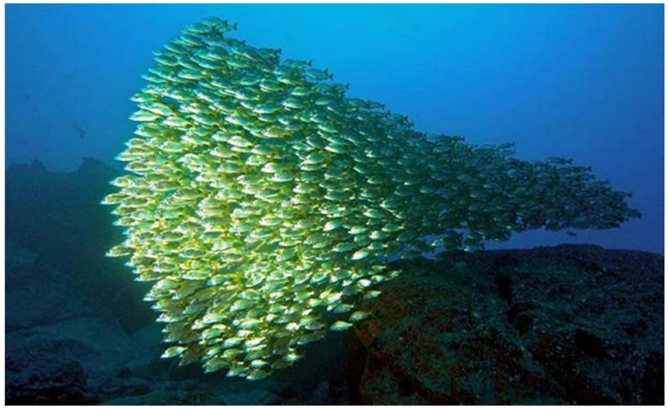


Various options for task share among RSC and TCC

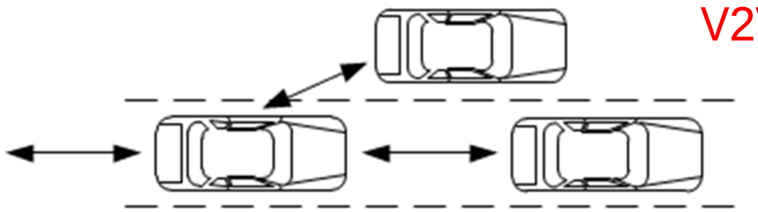
Decentralised Vehicle-Embedded TM



- Self-organisation (e.g. bird flock or fish school)
- Single vehicle sensors: Is this sufficient information for sensible TM actions?

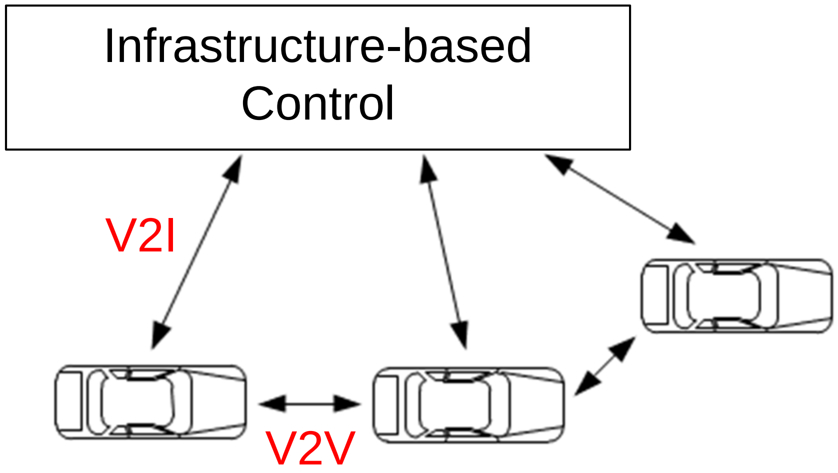


Decentralised Vehicle-Embedded TM



- V2V Communication: Extended traffic flow information
- How far ahead/behind should a vehicle be able to "see" for sensible TM?
- Where is data aggregation taking place?
- What about network-level TM? (ramp metering, route guidance)

Hierarchical TM

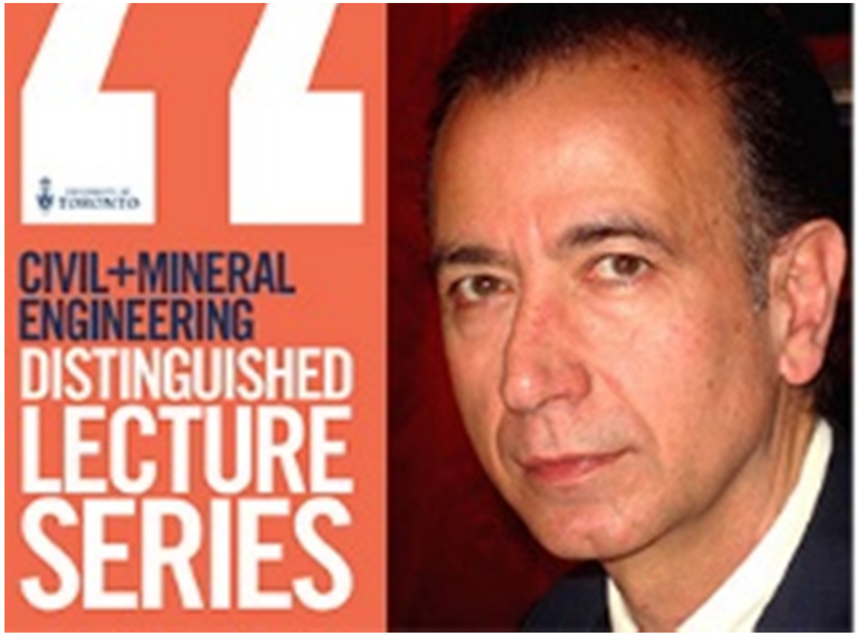


- Vehicle level: ACC, obstacle avoidance, lane keeping, ...
- V2V level: CACC, cooperative lane-changing, cooperative merging, warning/alarms, platoon operations
- Infrastructure level: speed, lane changing, time-gaps, platoon size, ramp metering, route guidance

7. CONCLUSIONS

- Intelligent vehicles may lead to dumb traffic flow – if not managed appropriately
- Connect VACS and TM communities for maximum synergy
- TM remains vital while VACS are emerging

See also: Papageorgiou, M., Diakaki, C., Nikolos, I., Ntousakis, I., Papamichail, I., Roncoli, C. : Freeway traffic management in presence of vehicle automation and communication systems (VACS). In *Road Vehicle Automation 2*, G. Meyer and S. Belker, Editors, Springer International Publishing, Switzerland, 2015, pp. 205-214.



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