Traffic Management in the Era of VACS (Vehicle Automation and Communication Systems)

Prof. Markos Papageorgiou
Dynamic Systems and Simulation Laboratory,
Technical University of Crete, Chania, Greece

traman21

erc

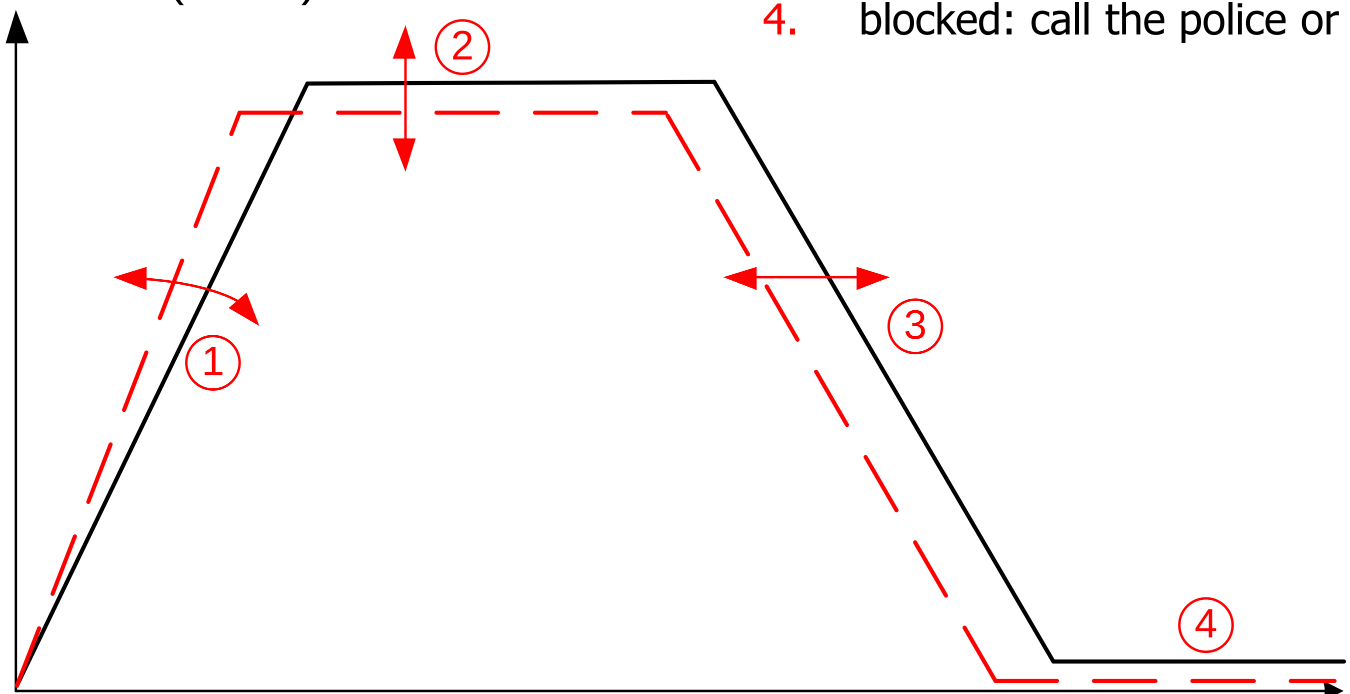
1. WHY TRAFFIC MANAGEMENT (TM)?

- 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
- Too many vehicles (congestion): Dynamic TM for protection from degradation

Network Fundamental Diagram (NFD)

(Fahri, 2008; Geroliminis & Daganzo, 2008; Helbing 2009)

total network flow or flow of exiting vehicles (veh/h)



veh in network

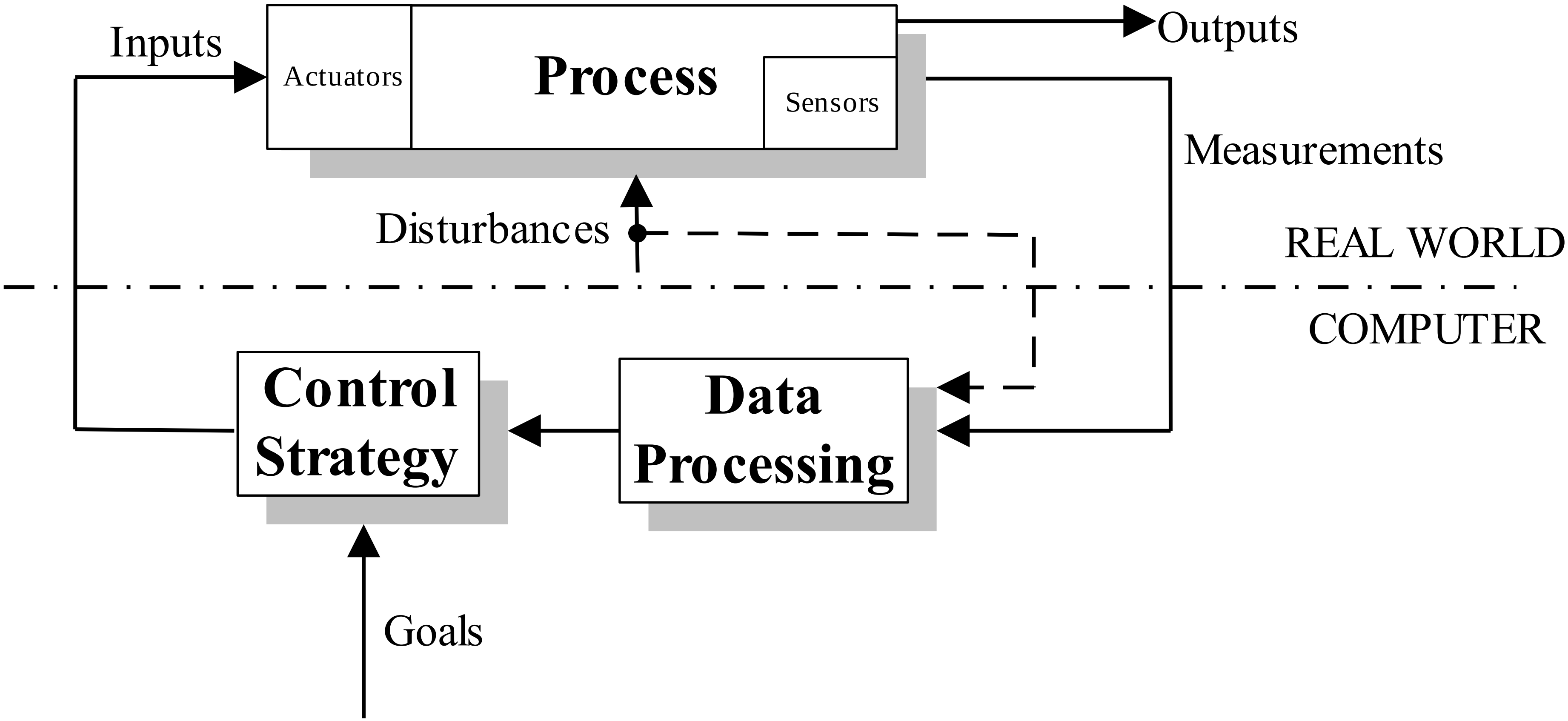
1. undersaturated; maximise speeds!
2. saturated: maximise capacity!
3. oversaturated: queue management, metering!
4. blocked: call the police or walk home!

- Freeway traffic: strongly degraded daily

12 January 2011, 8:14 am

16 December 2010, 17:55 pm

Basic elements of an automatic control system



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

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

Current TM Systems (ITS)

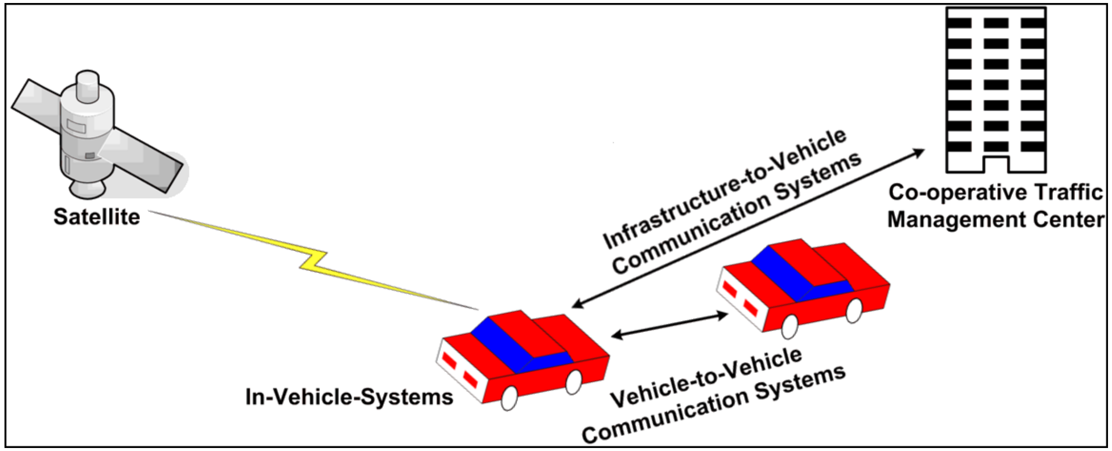
- **Process**: conventional vehicle flow
- **Sensors**: spot sensors (loops, vision, magnetometers, radar, …)
- **Communications**: wired
- **Computing**: central, decentralised, hierarchical
- **Actuators**: road-side (TS, RM, VSL, VMS, …)

2. EMERGING VACS (Vehicle Automation and Communication Systems)

- Significant efforts: Automotive industry, Research community, Government agencies
- Mostly vehicle-centric
- Implications/Exploitation for traffic flow efficiency?
- TRAMAN21: TRAffic MANagement for the 21st Century (ERC Advanced Investigator Grant) http://www.traman21.tuc.gr/
- Review identified 88 different VACS
  - 46 safety/convenience related
  - 12 urban traffic
  - 30 freeway traffic

- **In-vehicle systems (automated vehicles)**
  - Collision warning; automated queue, congestion, and road works assistance; active green driving; obstacle avoidance; lane keeping; ACC; active lane-changing or merging system; fully automated vehicles (Google car); driver supervision; …
  - Mainly for safety and convenience: ADAS
  - Some (few) VACS have direct traffic flow implications

- **VII or cooperative systems (connected vehicles)**



  - Several of the previous functions, but better (e.g. CACC, cooperative lane-changing, …)
  - Vehicles = mobile sensors
  - What applications for V2V?
  - Direct link TCC --> vehicle (e.g. route advise, VSL, lane change, …)
- **Platooning**
  - Various suggestions
  - Dedicated lanes?

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?

- 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?

VACS classification by **impact** on traffic flow:

- Level 0: convenience VACS – no impact
- Level 1: safety VACS – indirect impact (less incidents)
- Level 2: modified vehicle behavior, but no real-time TM "button"
- Level 3: TM "button" available in real time

Related Challenges:

- Very large-scale system: Design, actors, reliability, vulnerability, security
- Driver involvement: What role? Acceptance?
- Penetration level: Moving target
- Infrastructure investment: Chicken or egg?
- New operators role/generation?
- Long, evolutionary and uncertain process; contradictory development scenarios
- Legal aspects, liability, privacy, standardisation, …

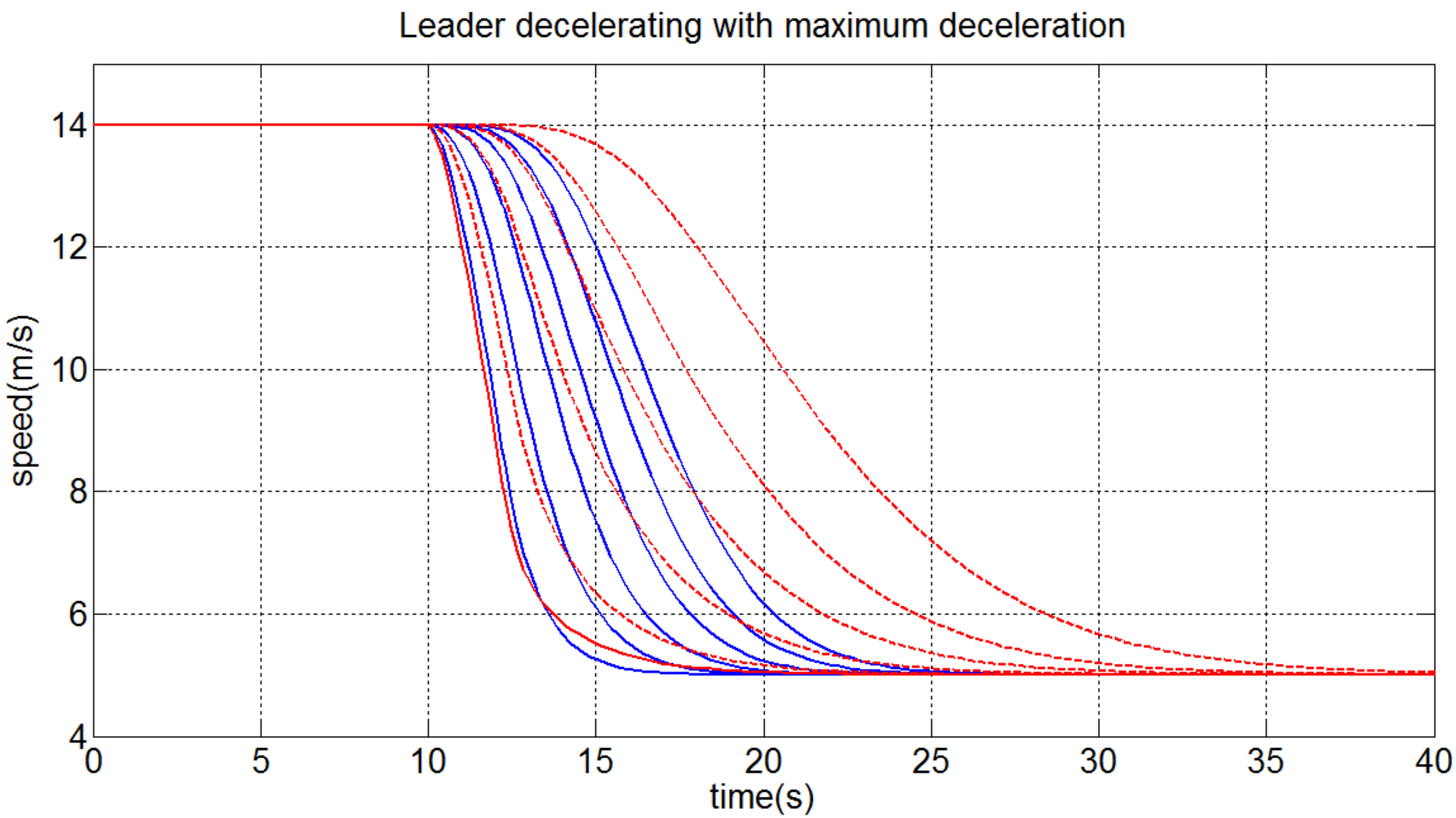
3. MODELLING

- 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

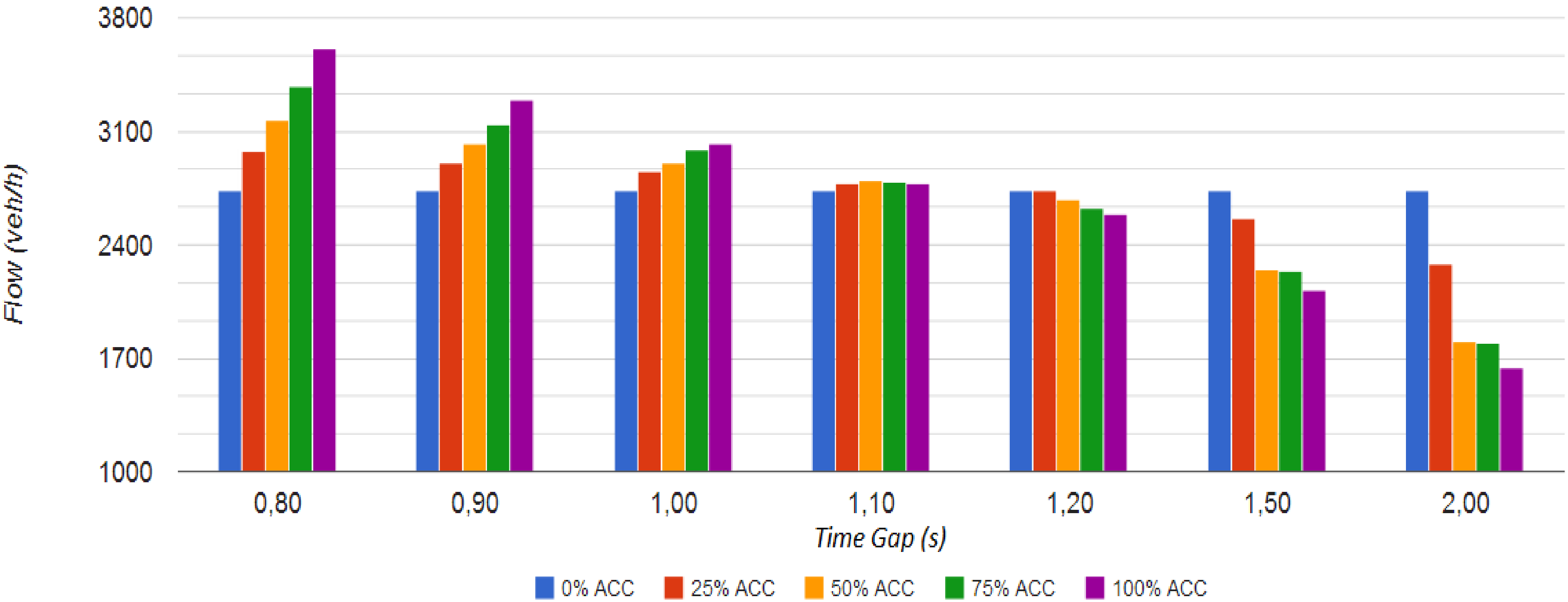
Microscopic Modelling

- 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
- AIMSUN commercial simulator: MicroSDK

ACC string-stability



ACC traffic efficiency

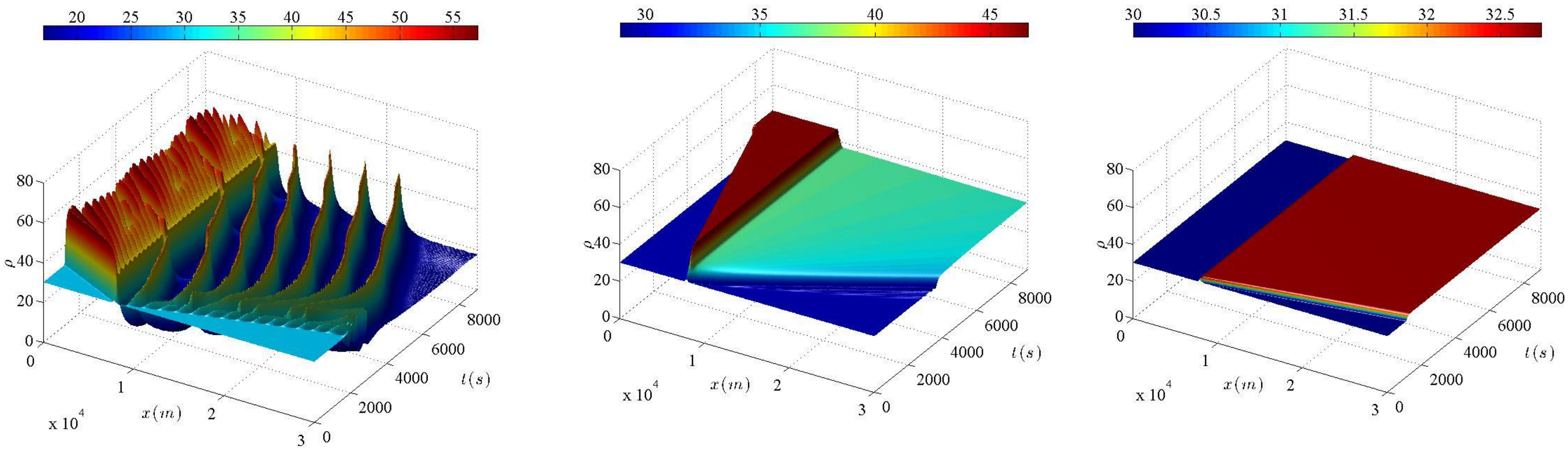


From: Ntousakis, I.A., Nikolos, I.K., Papageorgiou, M.: On microscopic modelling of adaptive cruise control systems. *4th Intern. Symposium of Transport Simulation (ISTS'14)*, 1-4 June 2014, Corsica, France. Published in *Transportation Research Procedia* 6 (2015), pp. 111-127.

Macroscopic Modelling

- Very few research works
- Gas-kinetic developments
- Validation based on microscopic simulation
- Different penetration rates
- Macroscopic lane-changing

ACC/CACC: stability/efficiency



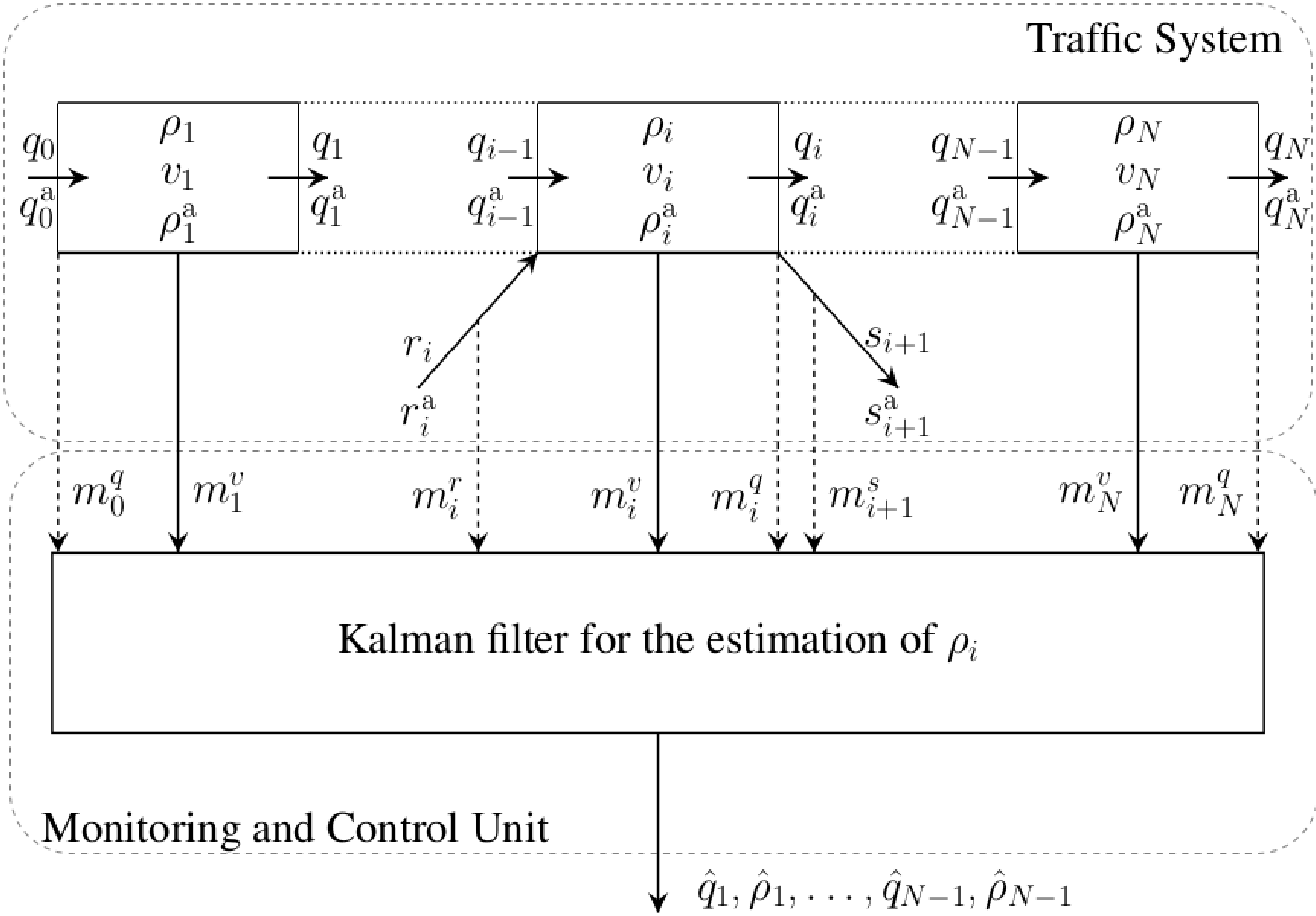
Macroscopic simulation of traffic flow (spatio-temporal evolution of traffic density) close to an on-ramp using the GKT model, combined with a novel ACC/CACC modeling approach. Left: manual cars; Middle: ACC-equipped cars; Right: CACC-equipped cars.

From: Delis, A.I., Nikolos, I.K., Papageorgiou, M.: Macroscopic traffic flow modeling with adaptive cruise control: Development and numerical solution. *Computers & Mathematics with Applications*, 2015, in press.

4. MONITORING/ESTIMATION

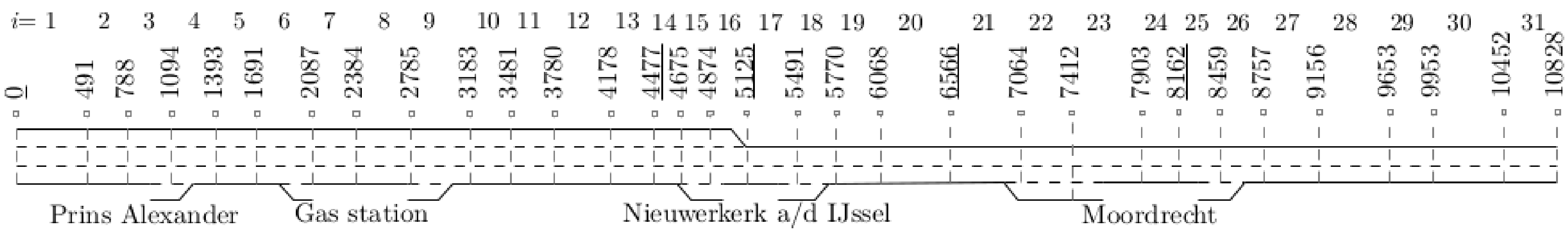
- Traffic density/queue estimation for traffic control
- Exploitation of abundant new real-time information from connected vehicles
- Mixed traffic, various penetration levels
- Fusion with conventional detector data
- Reduction (…replacement) of infrastructure-based sensors

Freeway traffic estimation scheme



From: Bekiaris-Liberis, N., Roncoli, C., Papageorgiou, M.: Highway traffic state estimation with mixed connected and conventional vehicles. 2015, submitted.

Estimation case-study

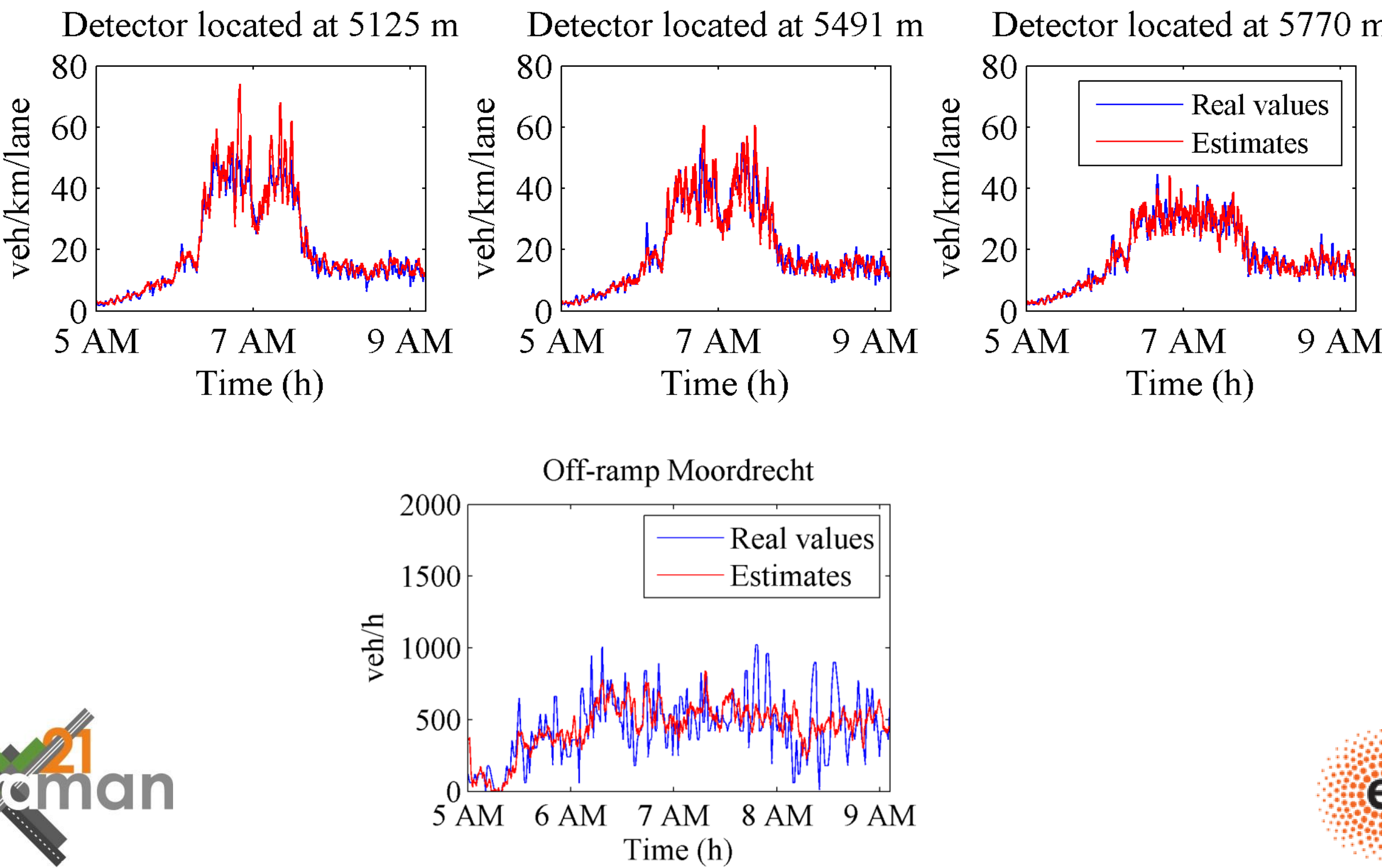


Highway A20 from Rotterdam to Gouda, the Netherlands

(data: courtesy Prof. B. van Arem)

Estimation results

From: Bekiaris-Liberis, N., Roncoli, C., Papageorgiou, M.: Highway traffic state estimation with mixed connected and conventional vehicles. 2015, submitted.



Urban road/network traffic estimation
(with new data)

- OD estimation
- Road queue length estimation
- Link spillback detection
- Incident detection

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)
- Vehicle speed control
- Efficient lane assignment
- Improved incident detection and management

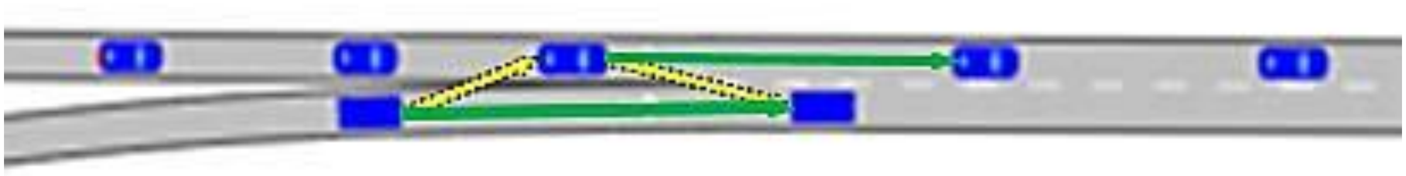
Vehicle-level tasks:

- How would traffic look like if all vehicles were automated?
- Space-time dependent change (control) of vehicle behaviour?
- ACC gap and acceleration
- Eco-driving
- Vehicle trajectory control

Local-level tasks:

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

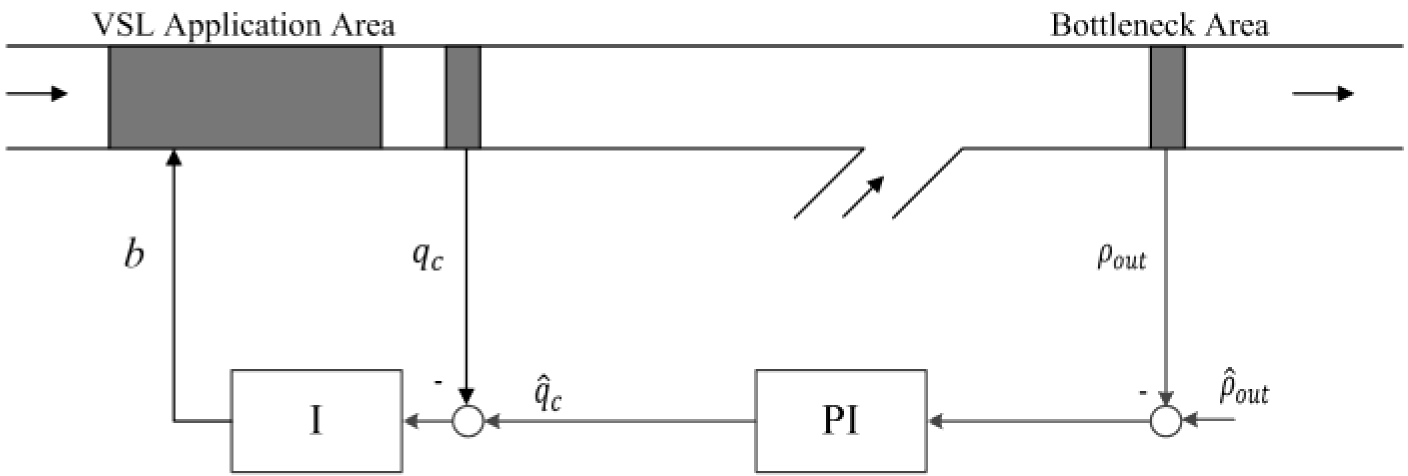
Local task example: merging vehicles



- Safety, convenience, maximum throughput
- Merging sequence, vehicle trajectories
- Vehicle cooperation?
- Mixed traffic?

From: Ntousakis, I.A., Porfyri, K., Nikolos, I.K., Papageorgiou, M.: Assessing the impact of a cooperative merging system on highway traffic using a microscopic flow simulator. *Proc. ASME 2014 Intern. Mechanical Engineering Congress and Exposition (IMECE2014)*, Montreal, Quebec, Canada, November 14-20, 2014, Paper No. IMECE2014-39850.

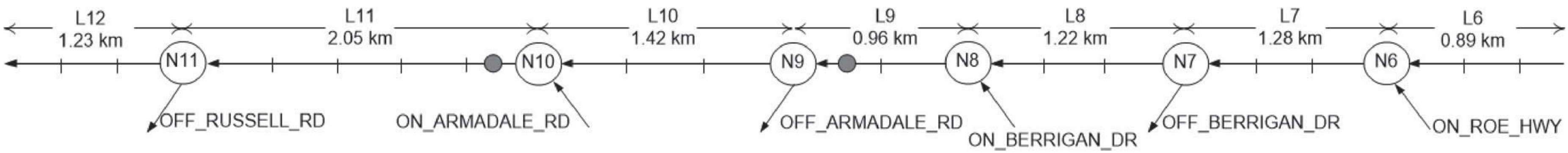
Local task example: bottleneck control

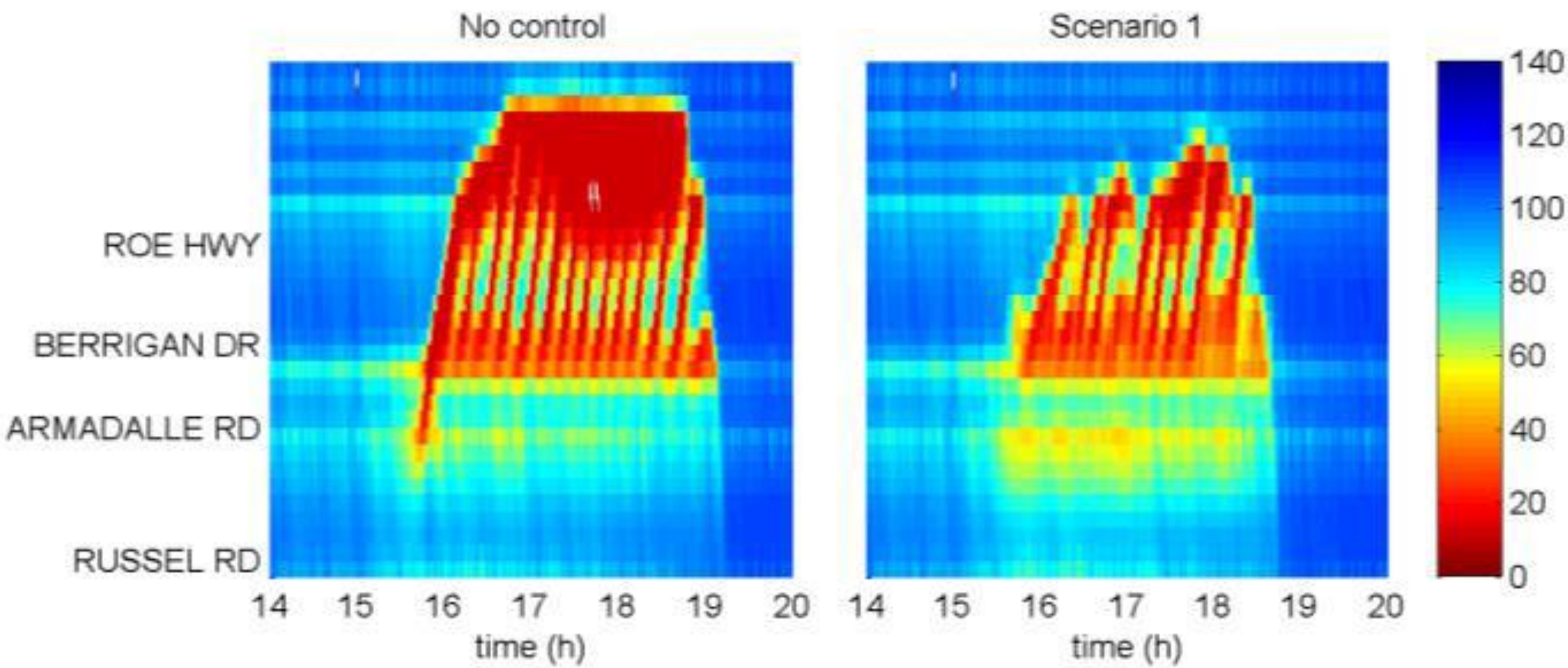


- Vehicle speed control ➡ mainstream metering
- Mitigation of capacity drop
- Conventional VSL or equipped vehicles

From: Iordanidou, G.-R., Roncoli, C., Papamichail, I., Papageorgiou, M.: Feedback-based mainstream traffic flow control for multiple bottlenecks on motorways. *IEEE Trans. on Intelligent Transportation Systems* 16 (2015), pp. 610-621.

Bottleneck control: Simulation results





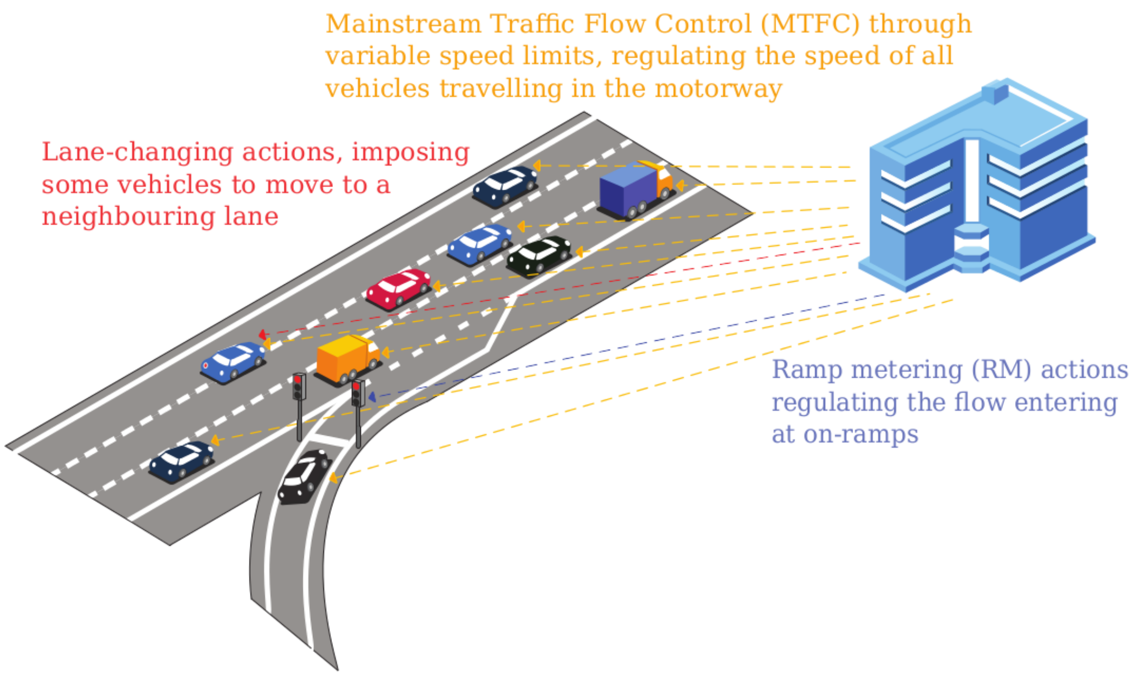
Link/Network-level tasks:

- 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?
    - Detrimental impact?

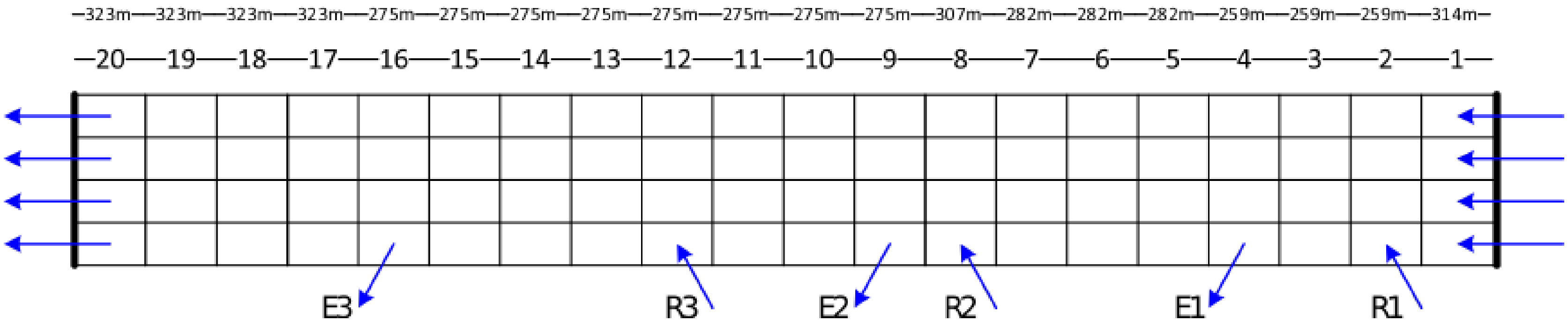
Link-level control

- Control actuators



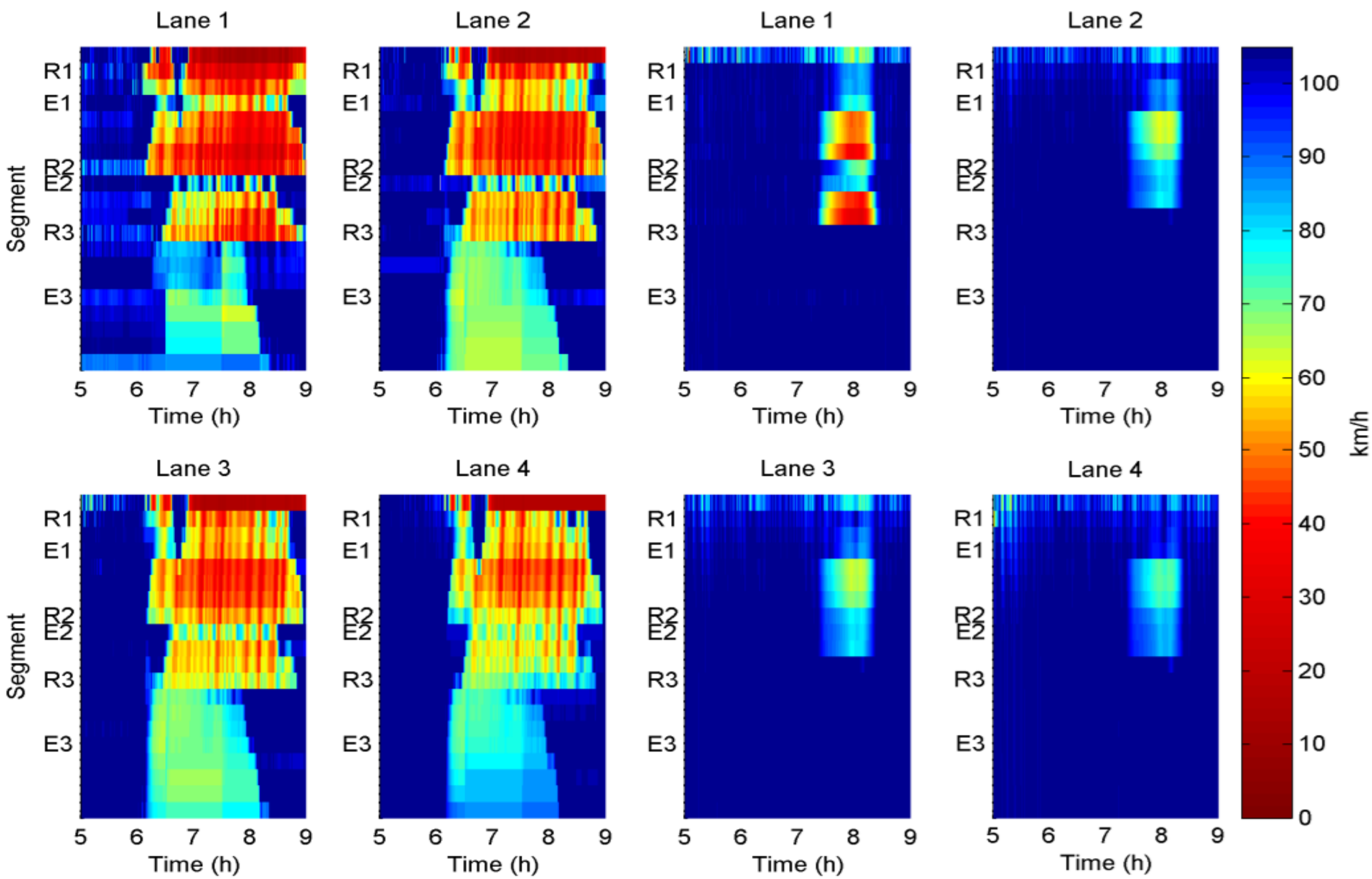
From: Roncoli, C., Papageorgiou, M., Papamichail, I.: Traffic flow optimisation in presence of vehicle automation and communication systems – Part II: Optimal control for multi-lane motorways. *Transportation Research Part C* 57 (2015), pp. 260-275.

Link control case study



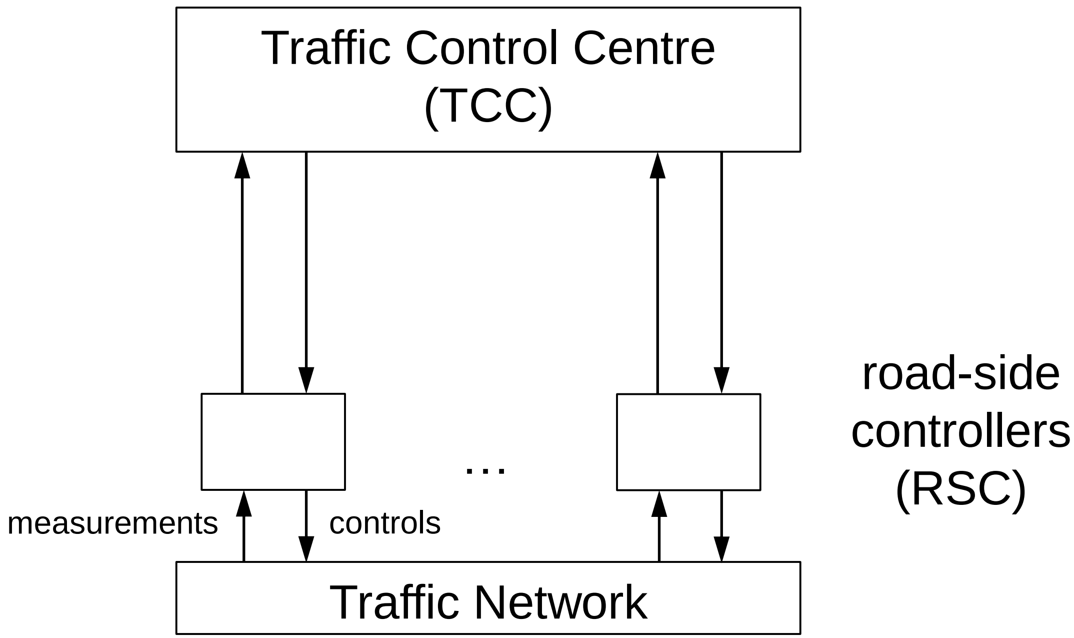
Monash Freeway (M1), Melbourne, Australia
(data: courtesy VicRoads)

Link control results



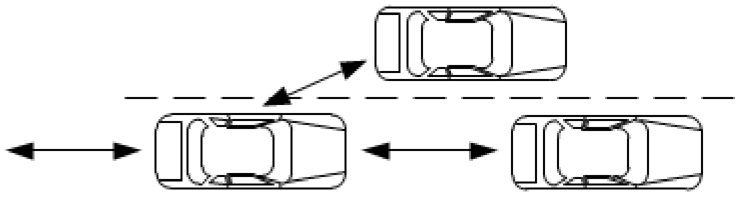
6. FUNCTIONAL/PHYSICAL ARCHITECTURE

Conventional TM Architecture



Various options for task share among RSC and TCC

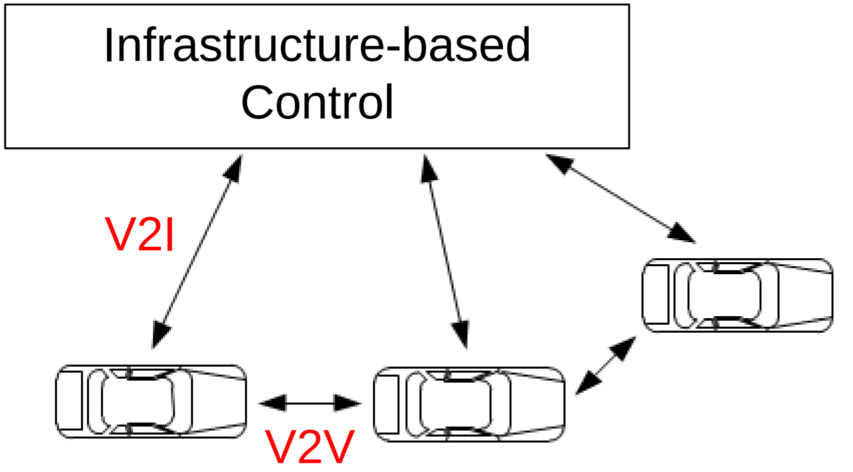
Decentralised Vehicle-Embedded TM



- Self-organisation (e.g. bird flock or fish school)
- Single vehicle sensors: Is this sufficient information for sensible TM actions?
- V2V Communication: Extended traffic flow information
- How far ahead/behind should a vehicle be able to "see" for sensible TM?

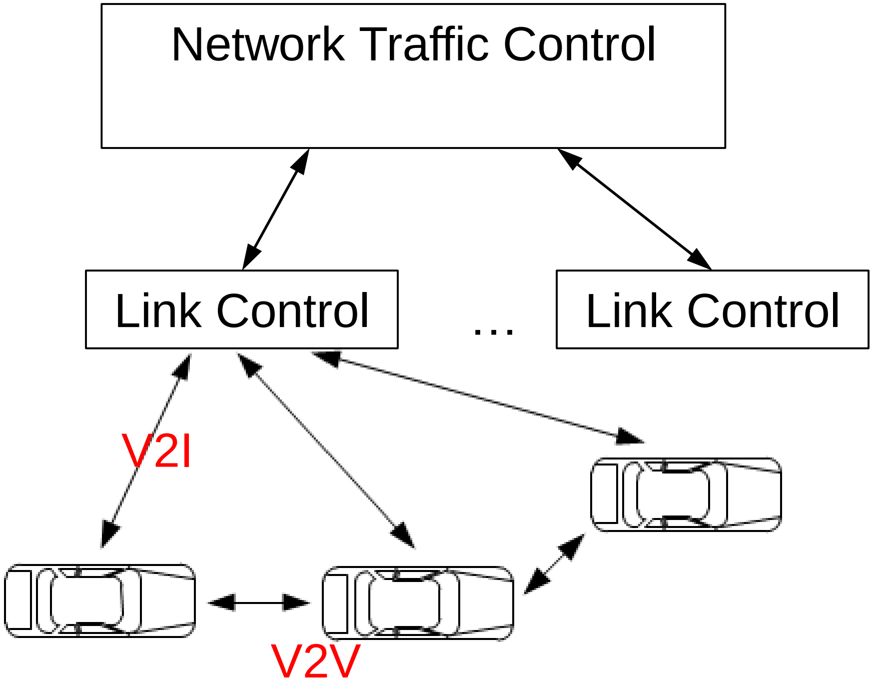
- Where is data aggregation taking place?
- How to deal with mixed traffic?
- Should road-side actuators remain?
- What about network-level TM? (ramp metering, route guidance)

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, headways, platoon size, ramp metering, route guidance

Hierarchical+ TM



- Link length?
- Overlapping link controllers?
- Share of control tasks?

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.