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

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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**: 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: safety, convenience
- In-vehicle systems (automated vehicles), e.g. ACC
- V2I 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)
Intelligent vehicles may lead to dumb traffic flow (efficiency decrease $\Rightarrow$ congestion increase)

Why?
- ACC with long gap ($\Rightarrow$ capacity)…
- …or sluggish acceleration ($\Rightarrow$ 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, ...
- Commercial tools: closed; or elementary coding of VACS functions
ACC traffic efficiency

Macroscopic Modelling

- Very few research works
- Different penetration rates
- Macroscopic lane-changing
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.

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

Estimation case-study

Highway A20 from Rotterdam to Gouda, the Netherlands
(data: courtesy Prof. B. van Arem)
Estimation results

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) $\rightarrow$ longer queues
  - Dual vehicle $\leftrightarrow$ 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: **bottleneck control**

- Vehicle speed control \(\rightarrow\) mainstream metering
- Mitigation of capacity drop
- Conventional VSL or equipped vehicles

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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

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?
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?
- How to deal with mixed traffic?
- 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
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