The Smart Highway – Modern Traffic Control

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DCSC & Siemens

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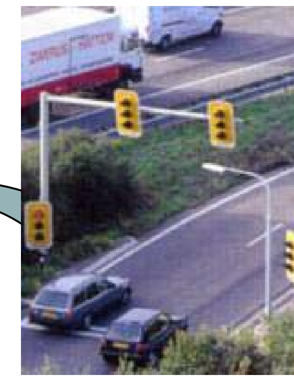
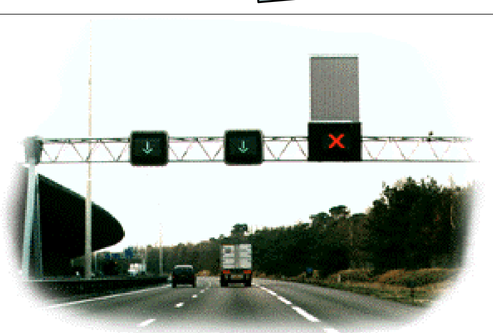
Traffic measures





Traffic measures

- Lights
  - Traffic lights
  - Ramp metering
- Information
  - Dynamic Route Information Panels
  - Dynamic speed limits
  - RDS-TMC
  - Travel information
- Dedicated lanes
  - Dynamic left lane
  - Emergency hard shoulder, peak lane
  - Dynamic lane marking (light emitting road marking)
- Road pricing

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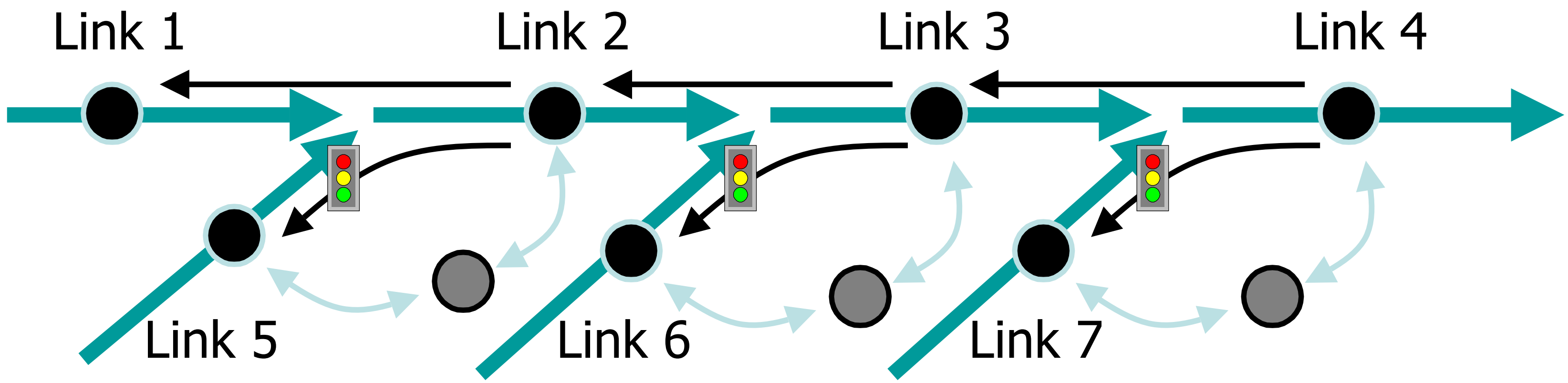
Traffic control – remarks

- Control loop – extremely large loop with many uncertainties
- Disturbances – have a very high impact on the traffic system (accidents, road work, bomb alarm)
- Hybrid control – combines discrete and continuous control in one scheme
- Model predictive control – takes into account multiple constraints and uses models of the system

Examples of projects

- Multi agent control
- Freeway and urban traffic control
- Traffic information and traffic control
- Shock waves
- Autonomous vehicles

Coordinated ramp metering



- Links, services, measures
- Length of the onramp
- Coordination stream up
- Hierarchical solution is limited

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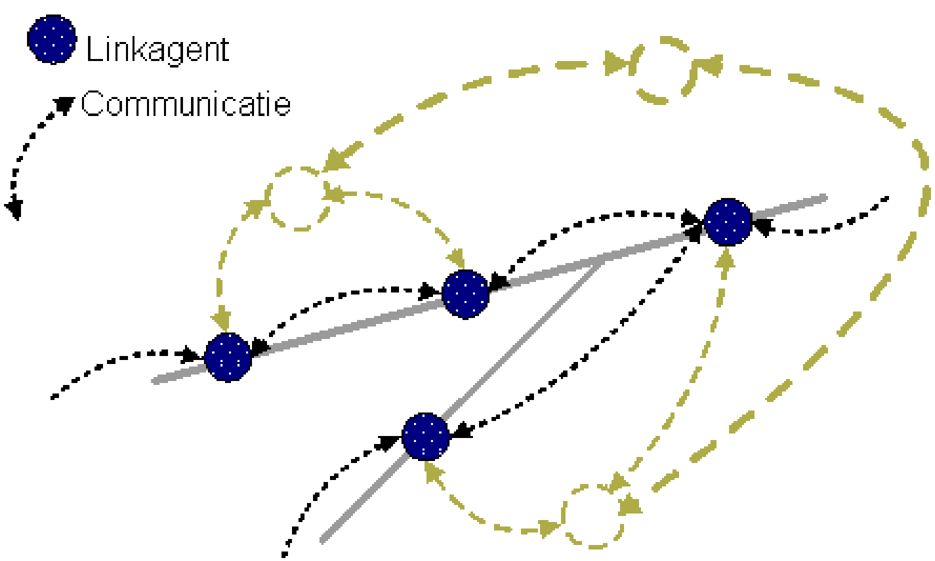
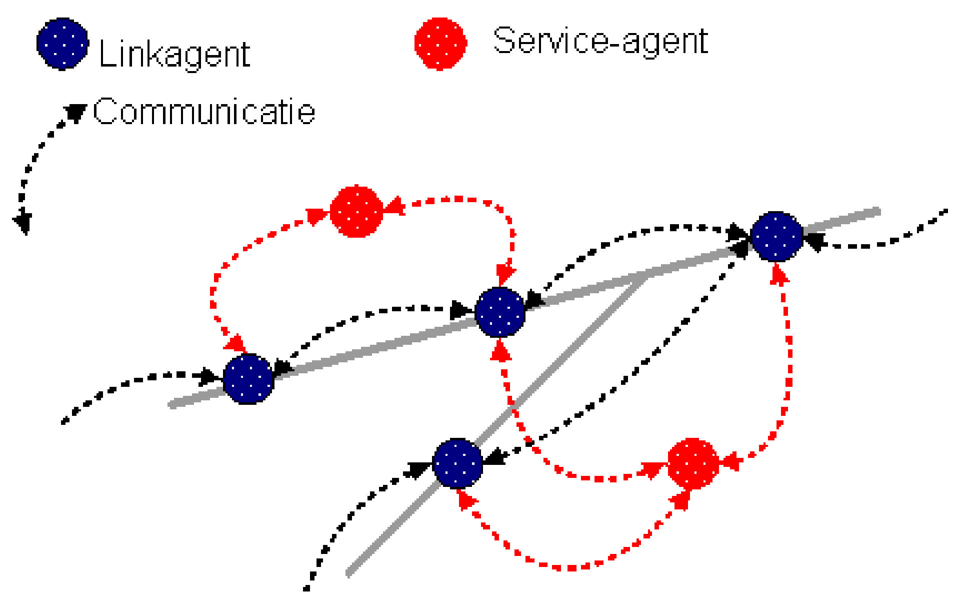
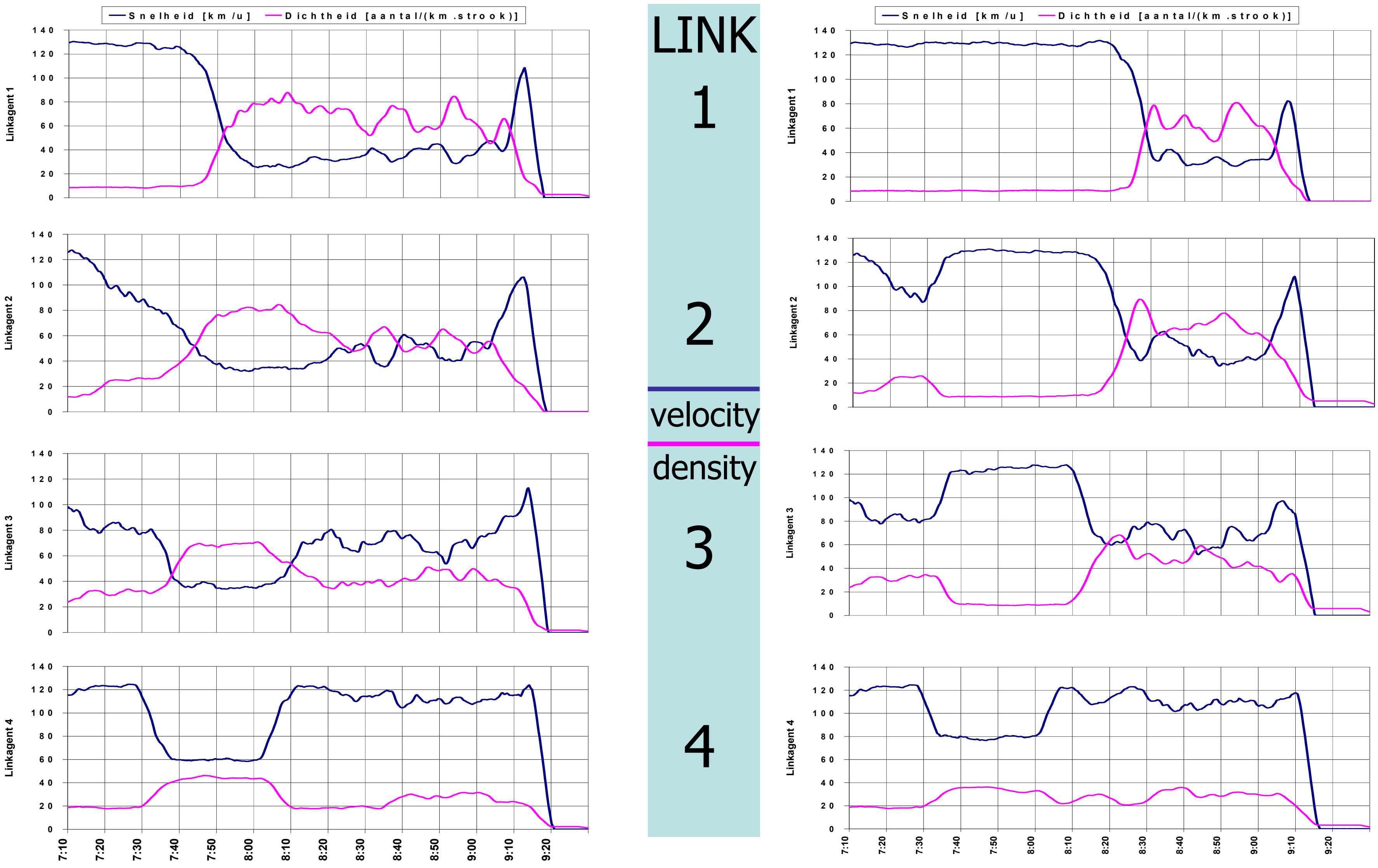
Link and services agents

- Link agents observe the local traffic situation and determine local actions, they can discuss local actions with other link agents
- Service-agents collect the demands of link agents, they decide a tactical solution for the link agents





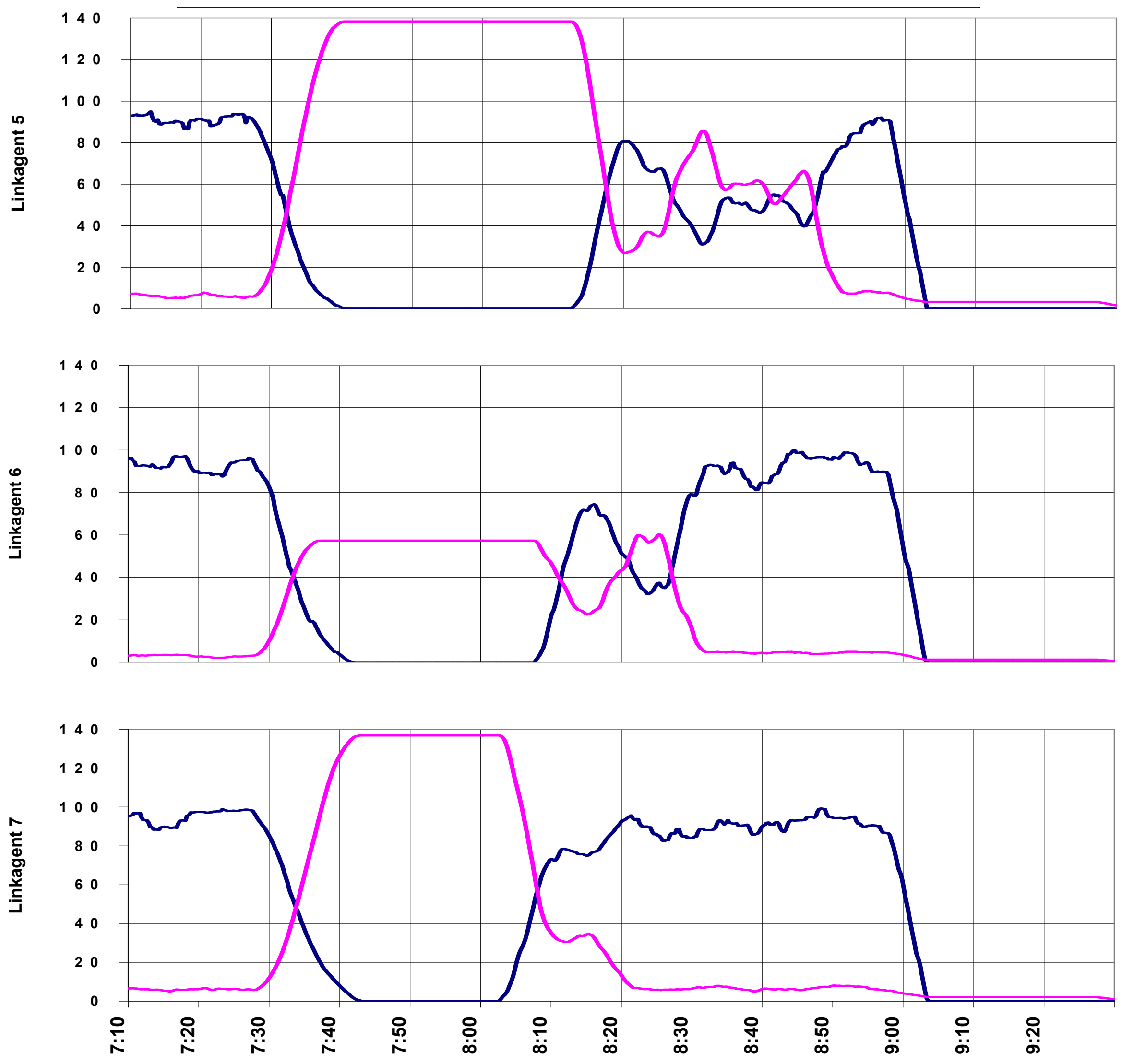
Four link agents without (left) and with (right) control



The onramps

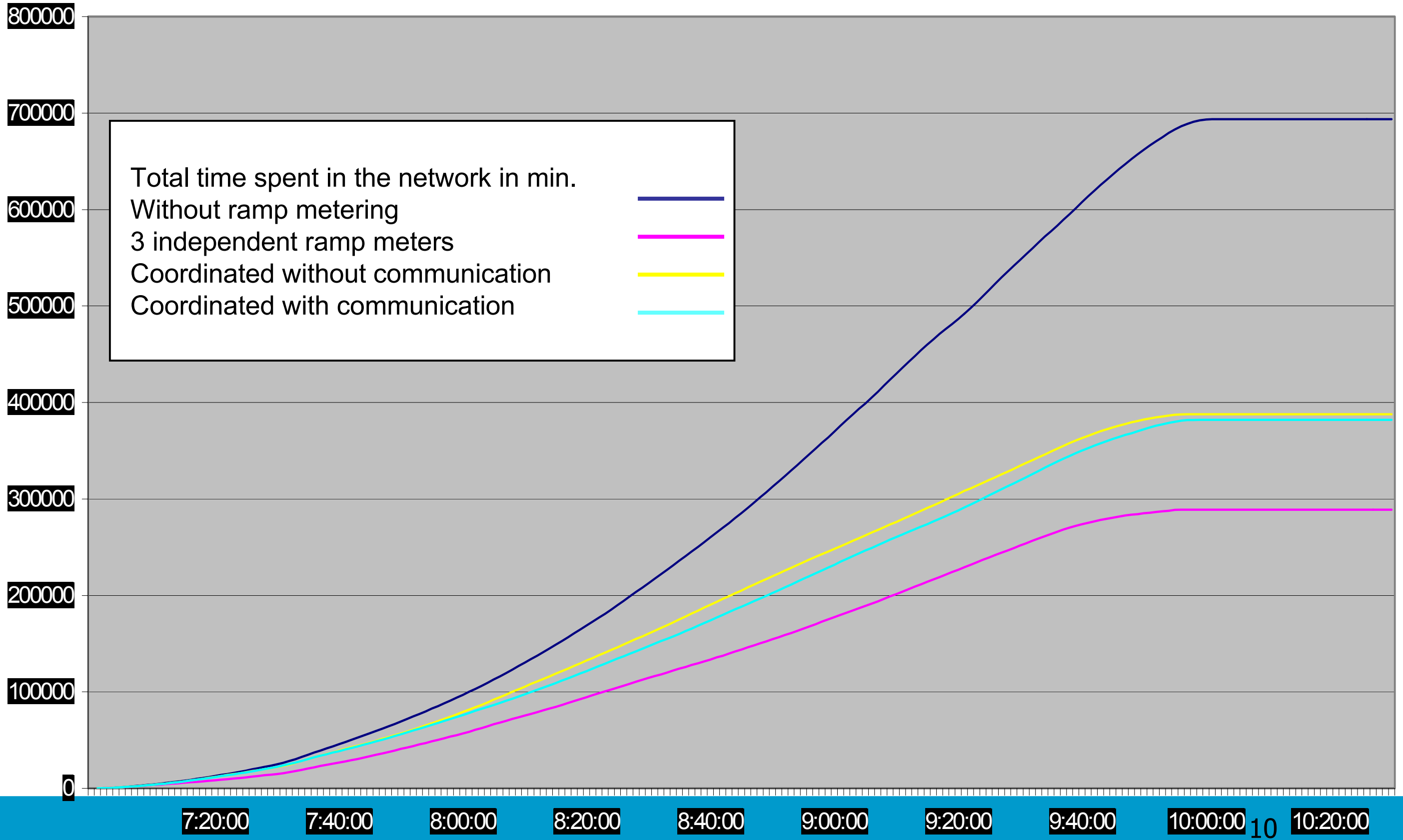
velocity

density



Problems

- Long term – short term behavior with ramp metering
- Coordination of more or less independent units
- Stability



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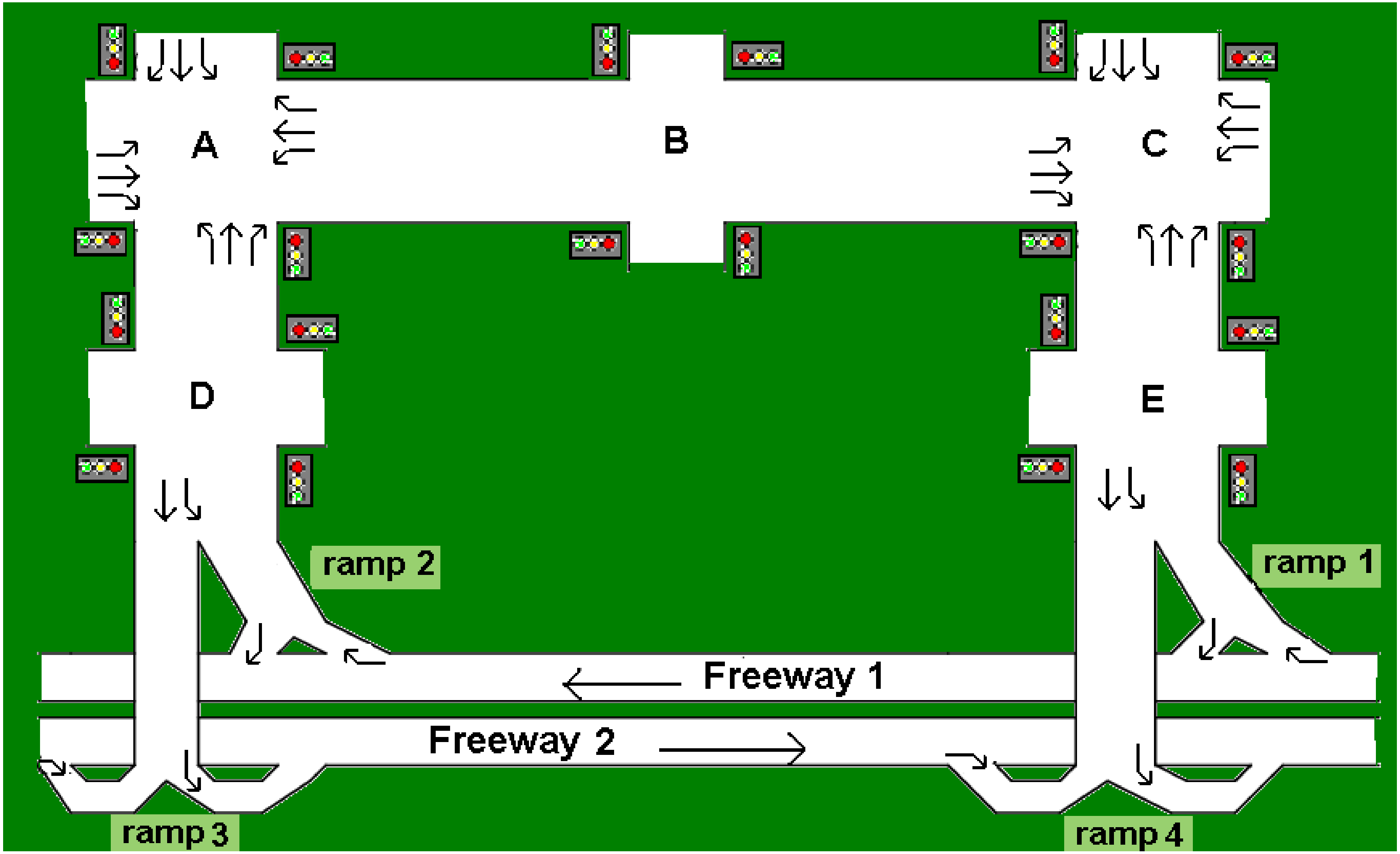
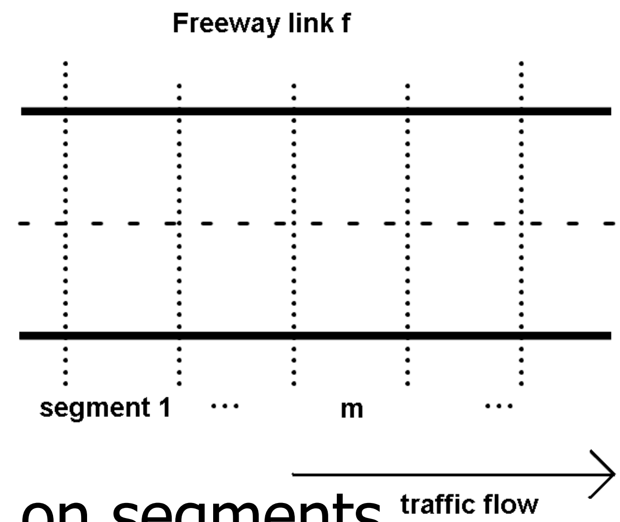
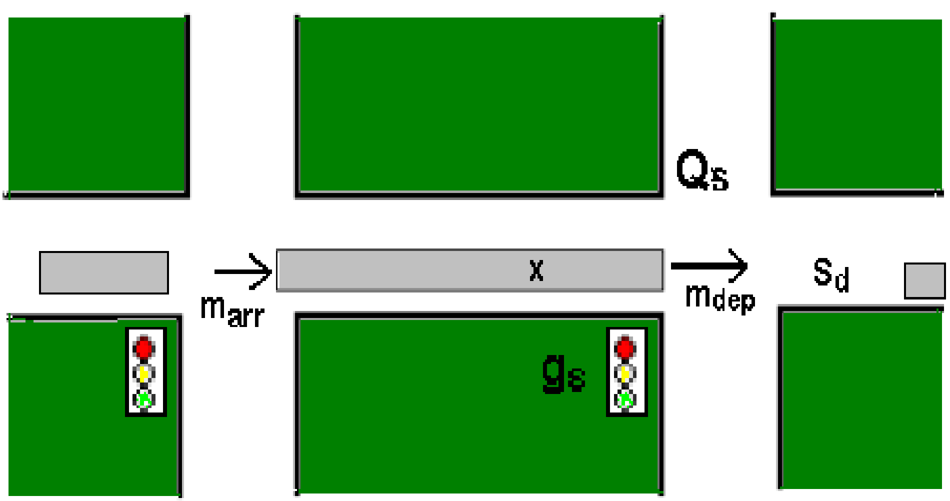
A network of freeway and urban traffic

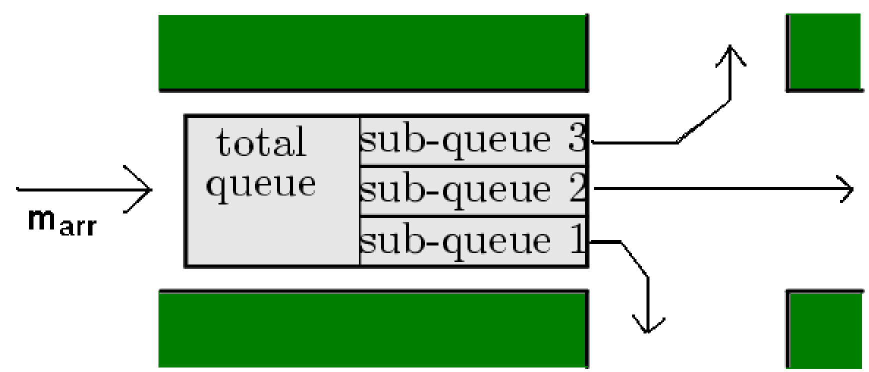


Modeling



- Freeway: macroscopic model, based on segments
- Computes flow, density and velocity
- Urban: short time steps, queuing

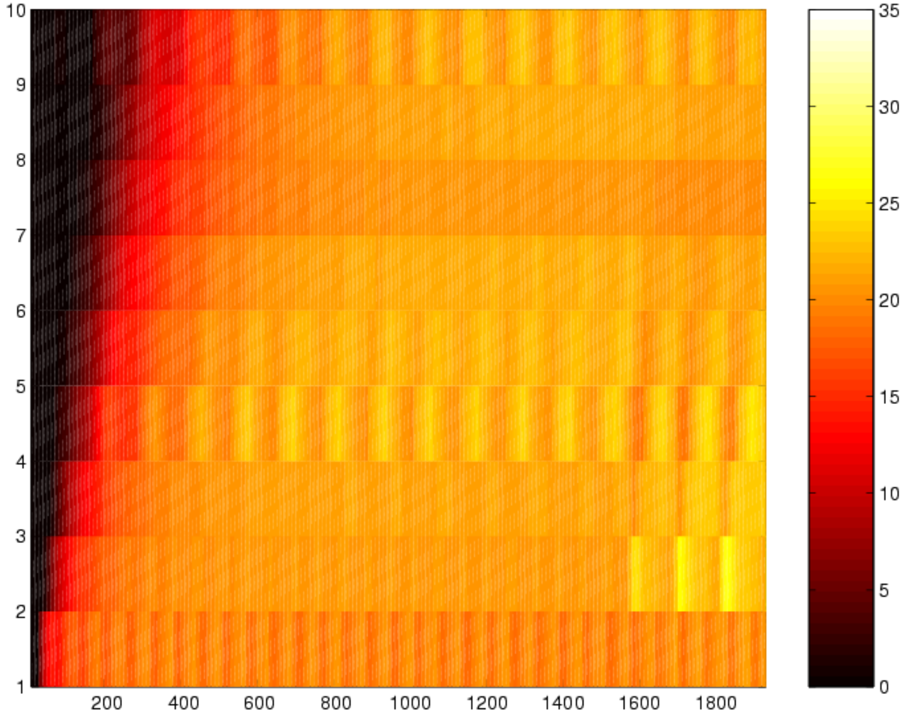




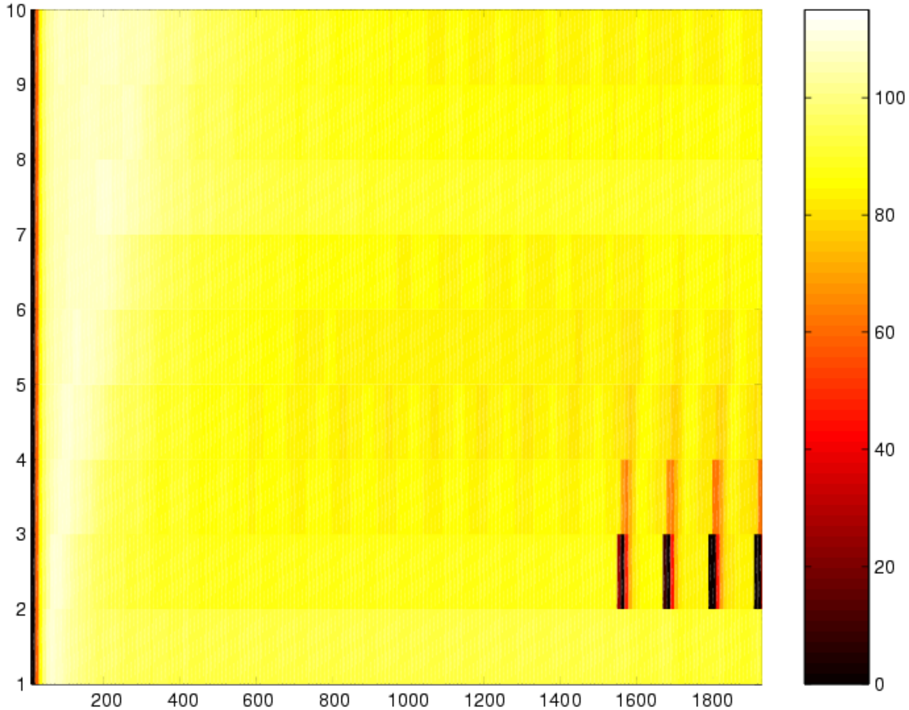
Five simulation scenario's

- Marginally saturated intersections
- Morning rush, traffic traveling into the city
- Evening rush, traffic leaving the city
- Congestion at one of the urban intersections
- Congestion on the freeway

Simulation results: Freeway I



Density



Velocity

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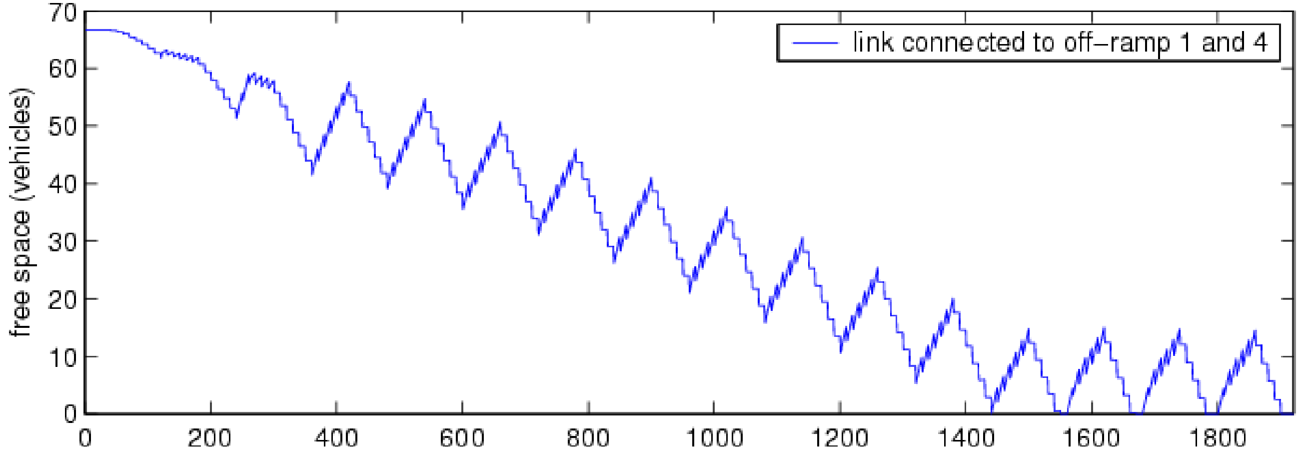
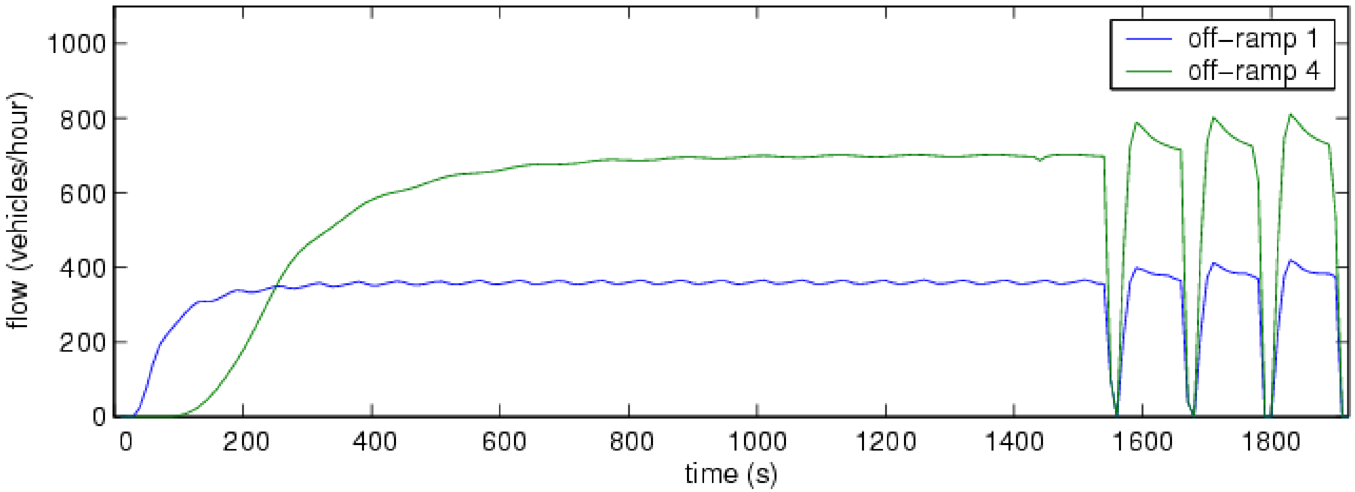
Simulation results: Off-ramp

Free space



Flow



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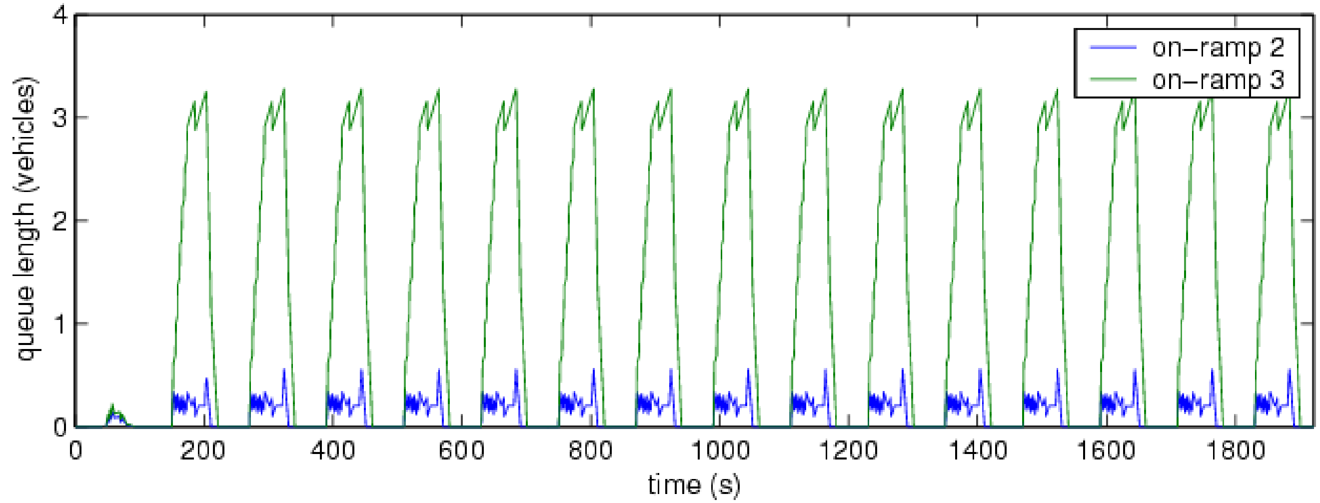
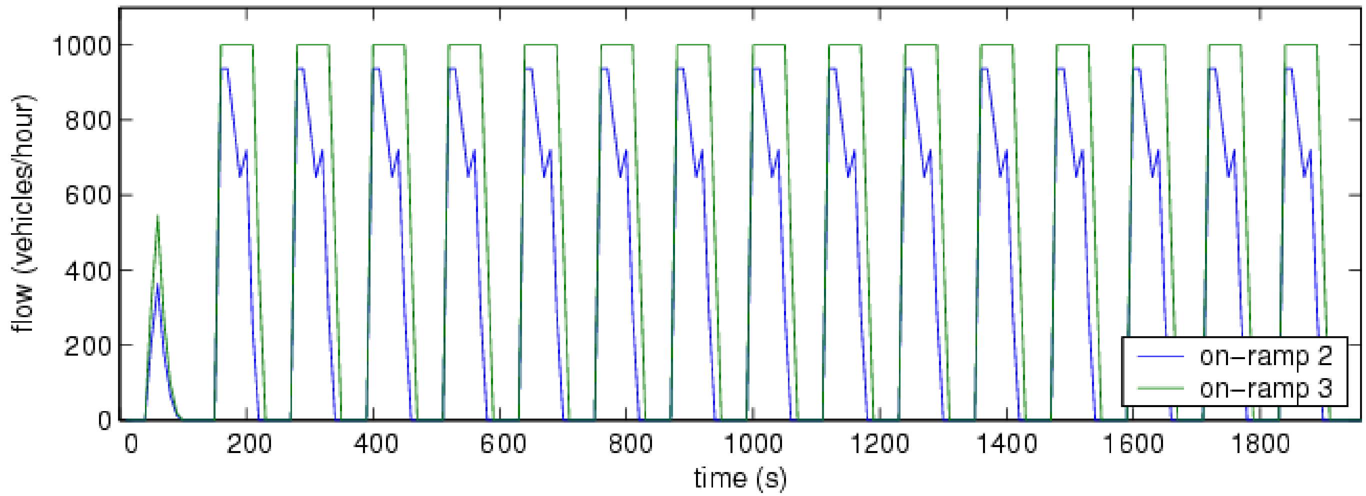
Simulation results: On-ramp

Queue length



Flow



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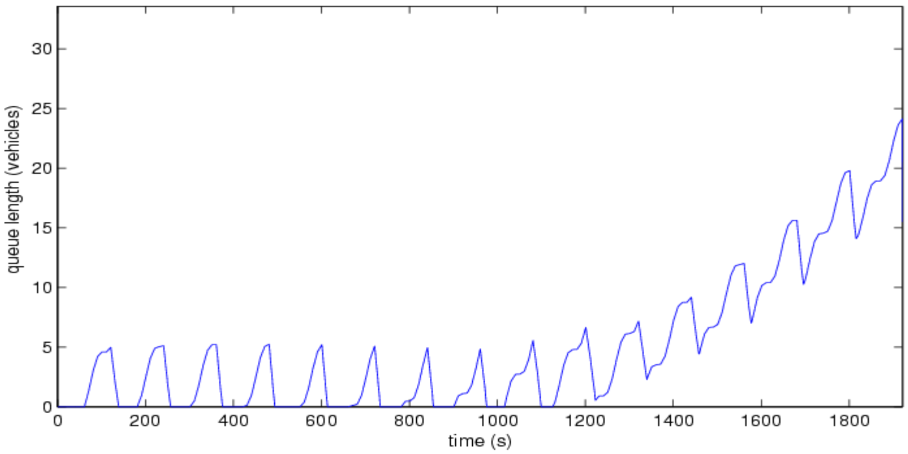
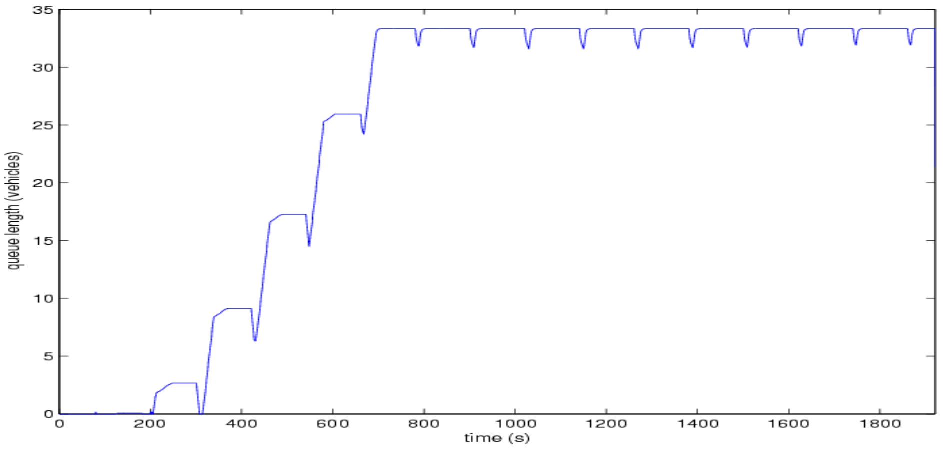
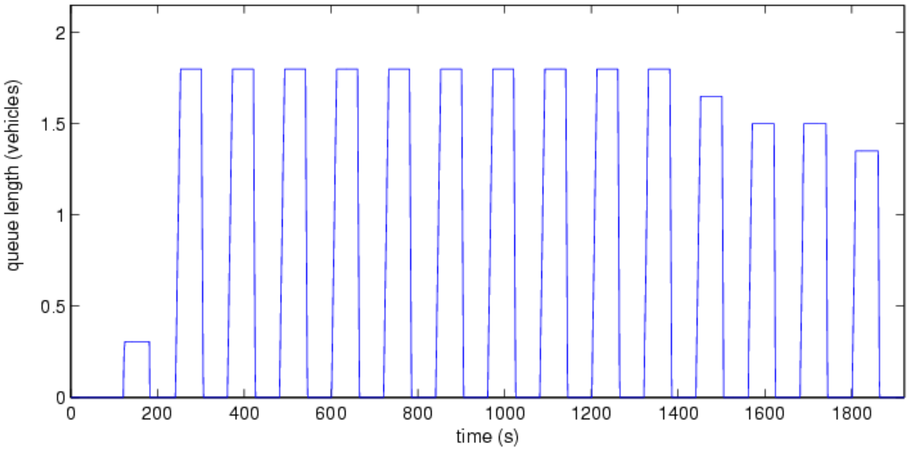
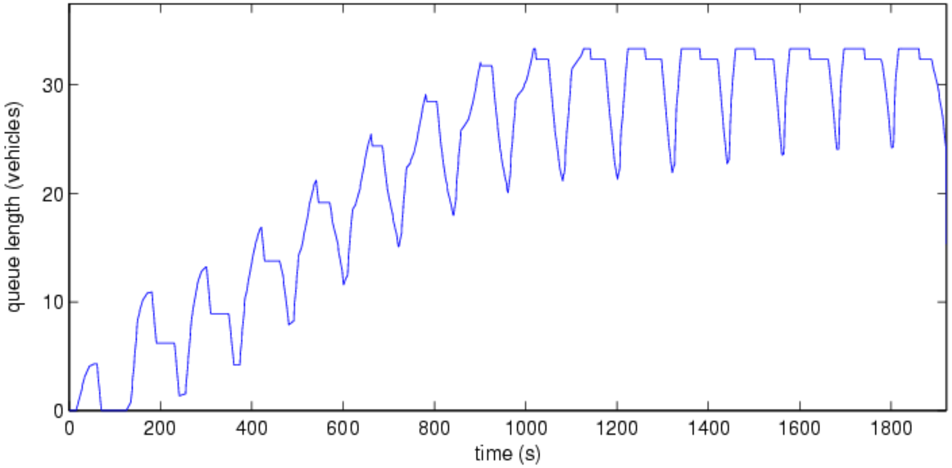
Simulation results: Urban queue lengths









Model Predictive Control

- Control signal: offsets, green times
- Cost function: Total time spent

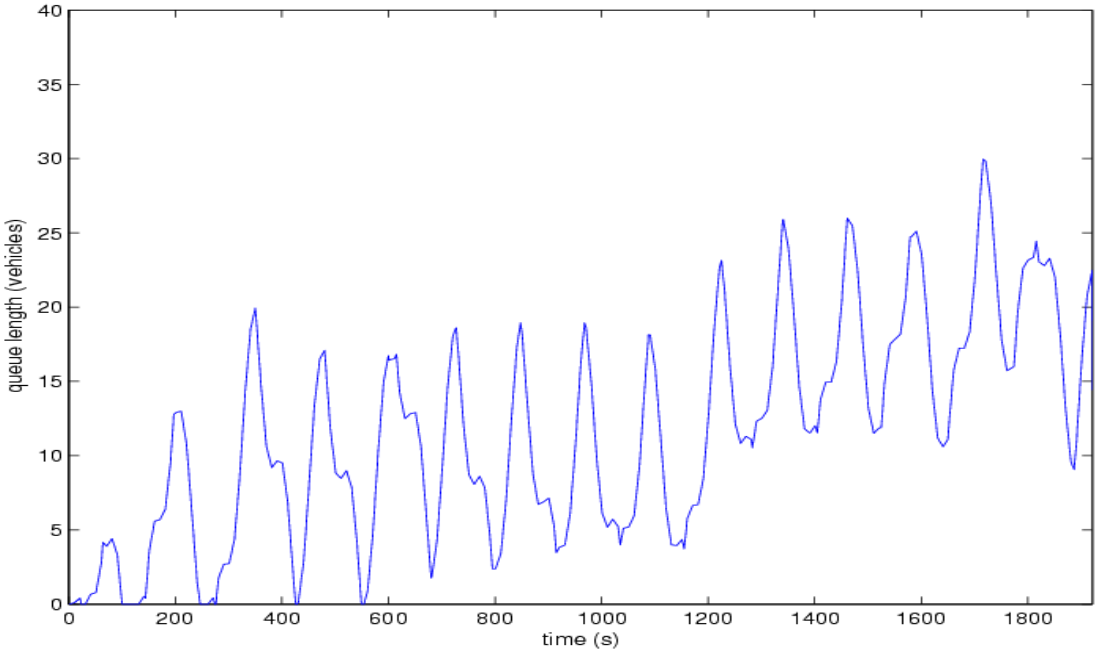
$$TTS = T_u * \sum vehicles(urban) + T_f * \sum vehicles(freeway)$$

Scenario	Improvement
Normal traffic	7.6%
Morning rush hour	6.2%
Evening rush hour	8.2%
Urban congestion	3.9%
Freeway congestion	6.4%

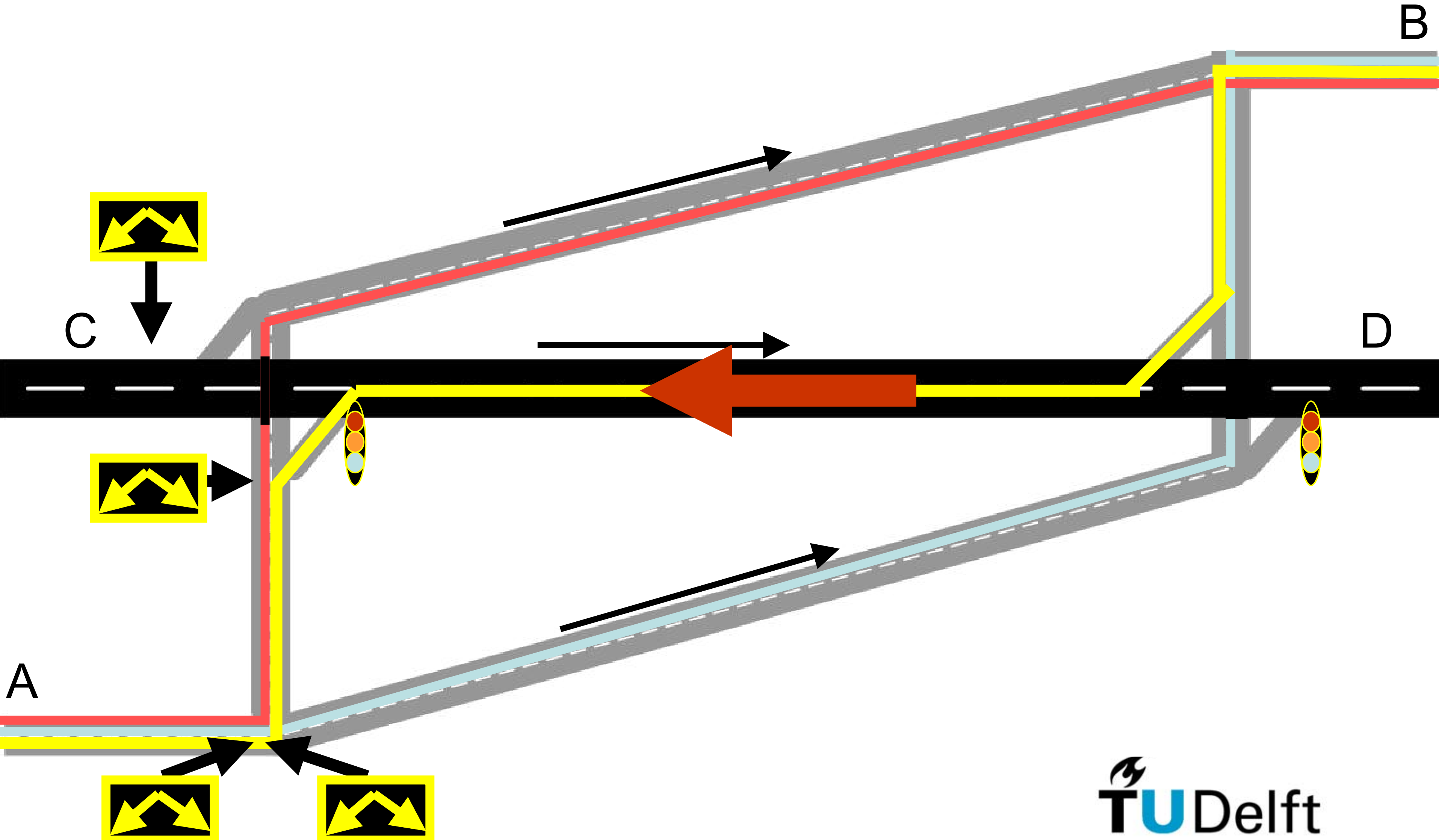
Model Predictive Control

- Keep traffic waiting at origins
- More green for crossing traffic
- Improve flow towards the freeways

Queue length



Traffic information and traffic control



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Control strategy

Minimize simultaneously:

- total time spent
- jam building at onramp
- difference between displayed and realized travel times
- variation in control signal

using

- travel time information and ramp metering

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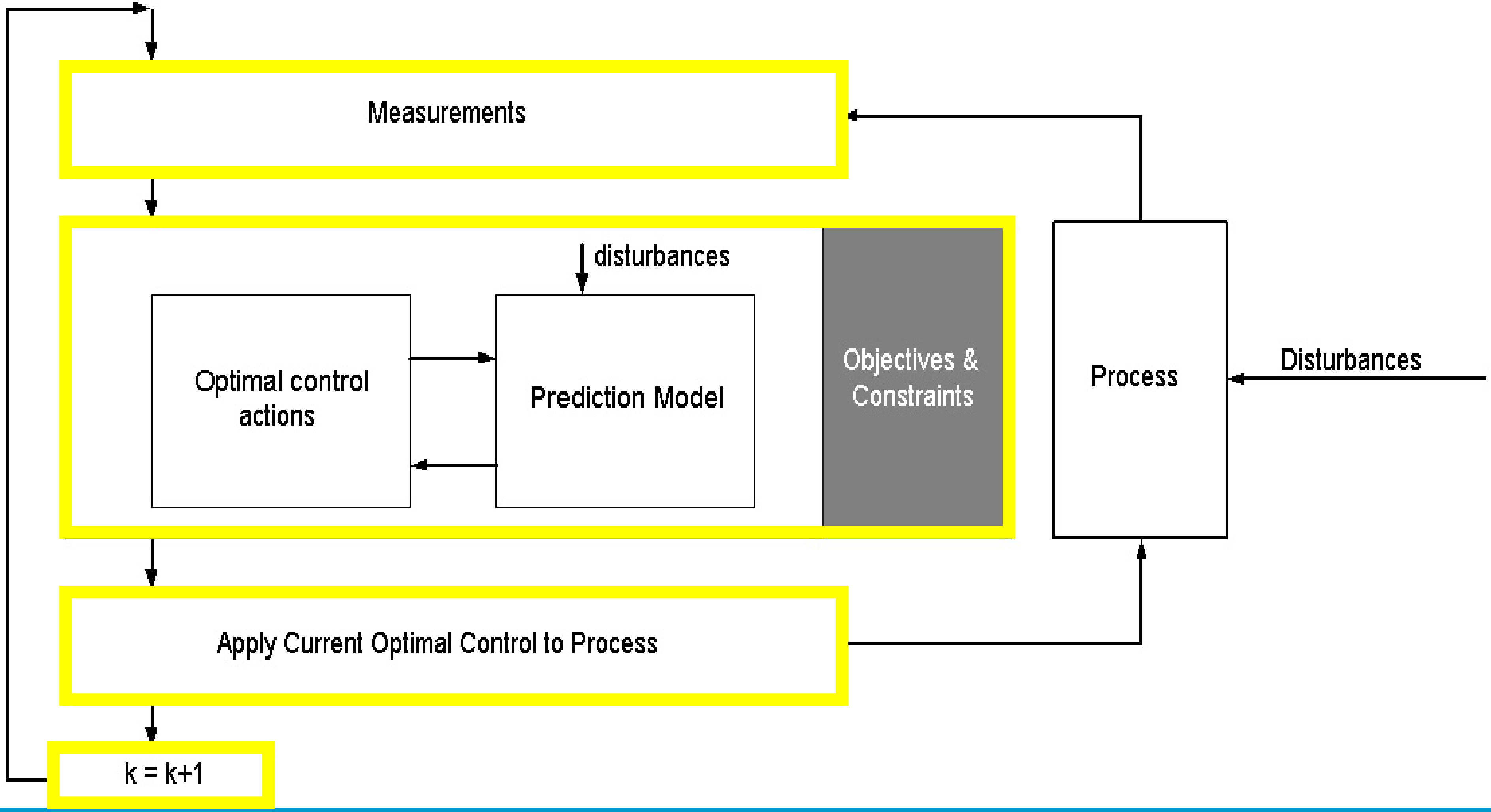
Model predictive control



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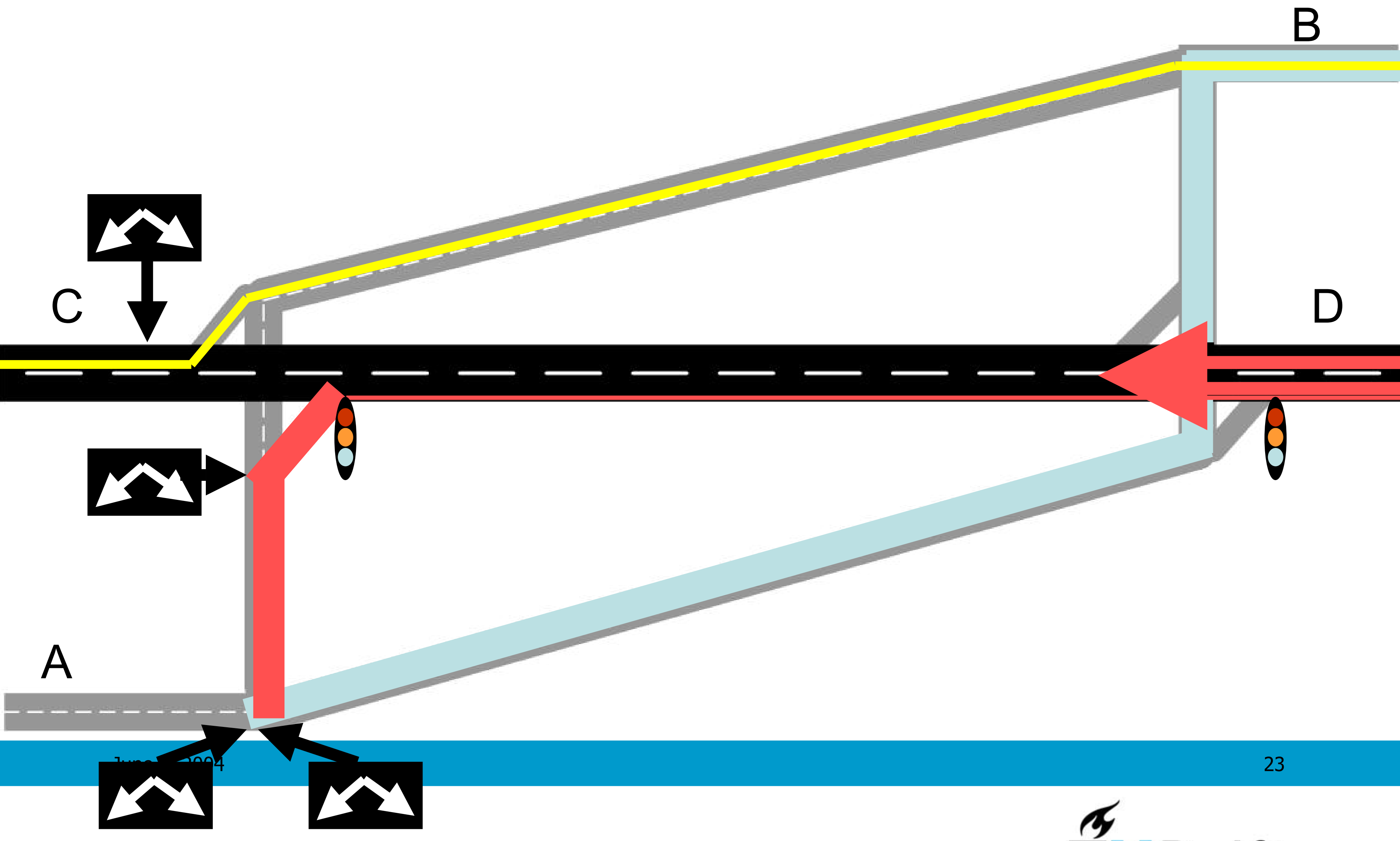
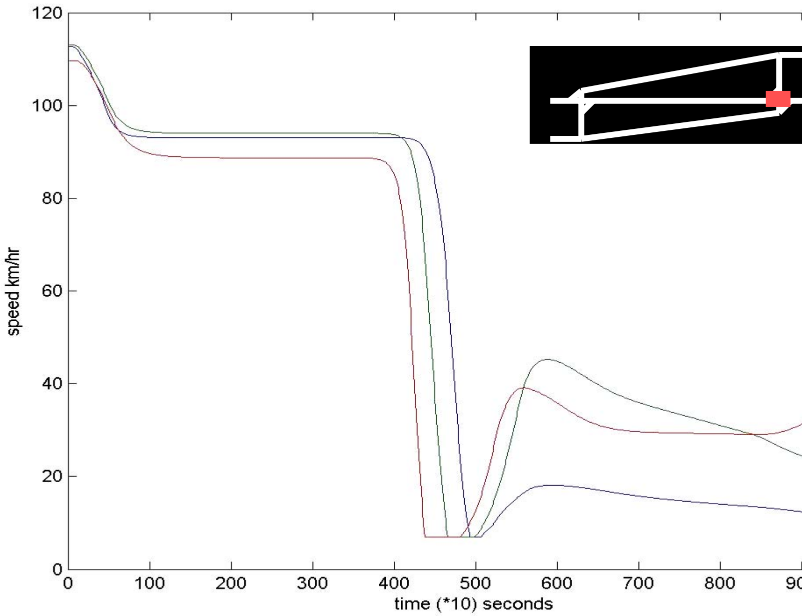
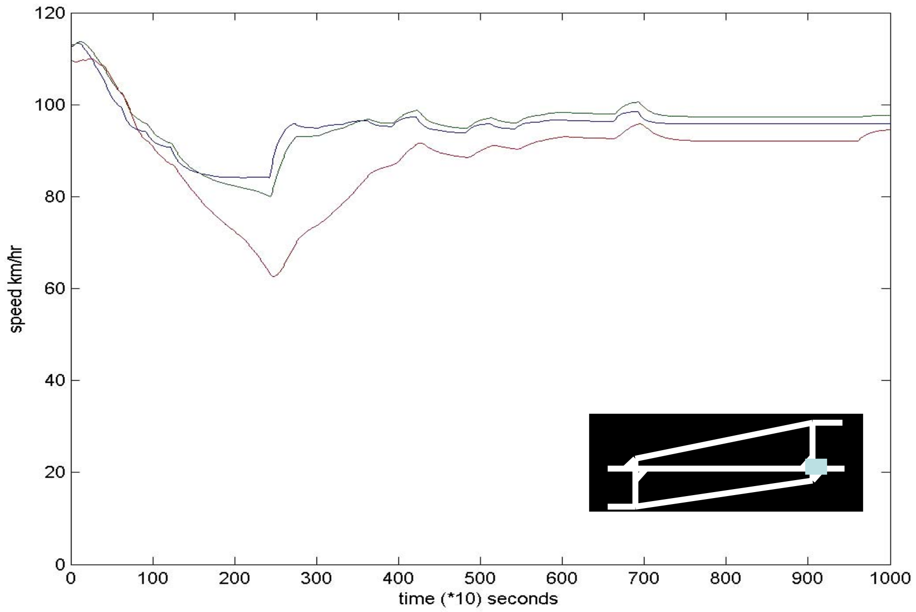
Effect of the controller



Without control (left) and with MPC (right)





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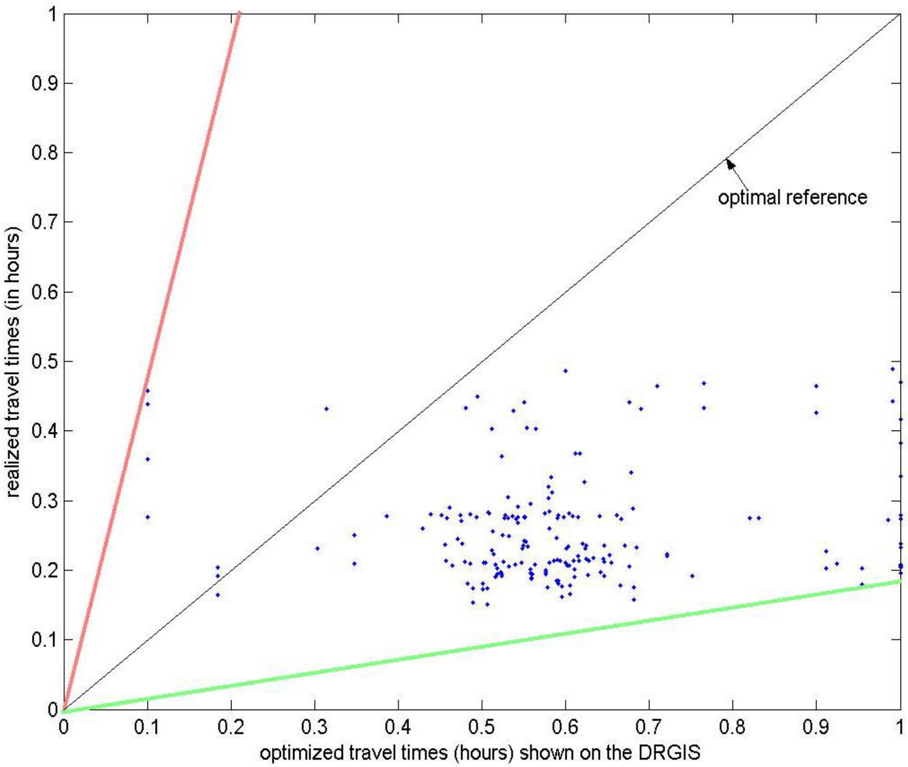
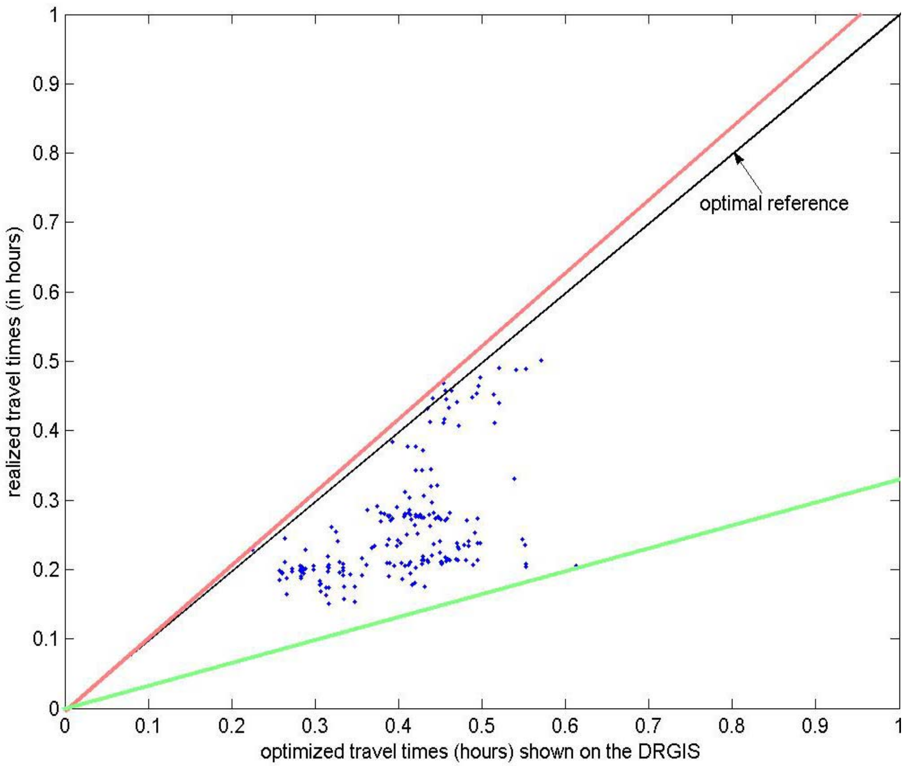
Deviation in travel time information with MPC <u>without</u> and <u>with</u> prediction error minimization in cost function





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Results

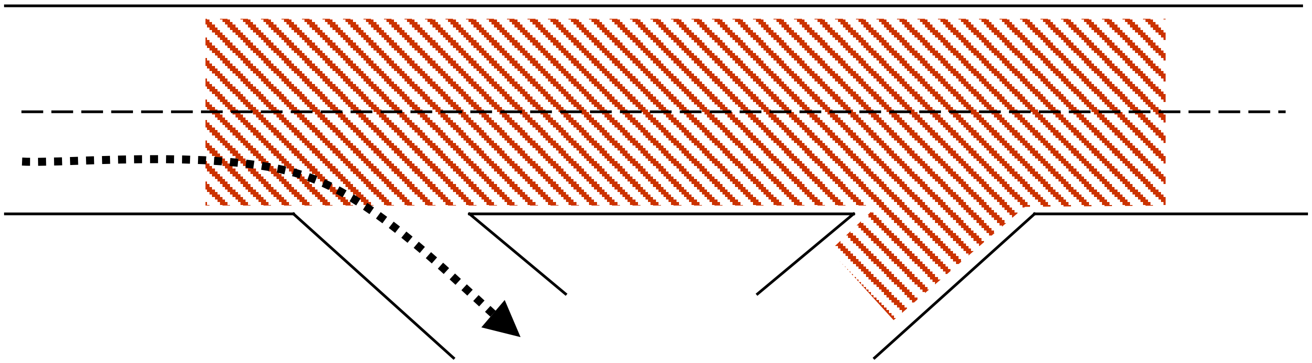
- Cost function with prediction error minimization guarantees optimal and precise travel times
- MPC algorithm for integral control can significantly reduce the total time spent (~20%)
- Prototype traffic control system possible in MATLAB, quick implementation on the road

Shock waves

A8
A7
A9
A10
Amsterdam
A6
A27
A44
A1
A2
Den Haag
A4
A28
A12
A12
A13
Utrecht
A20
A27
Rotterdam
A2
A15
A29
A16
ANWB

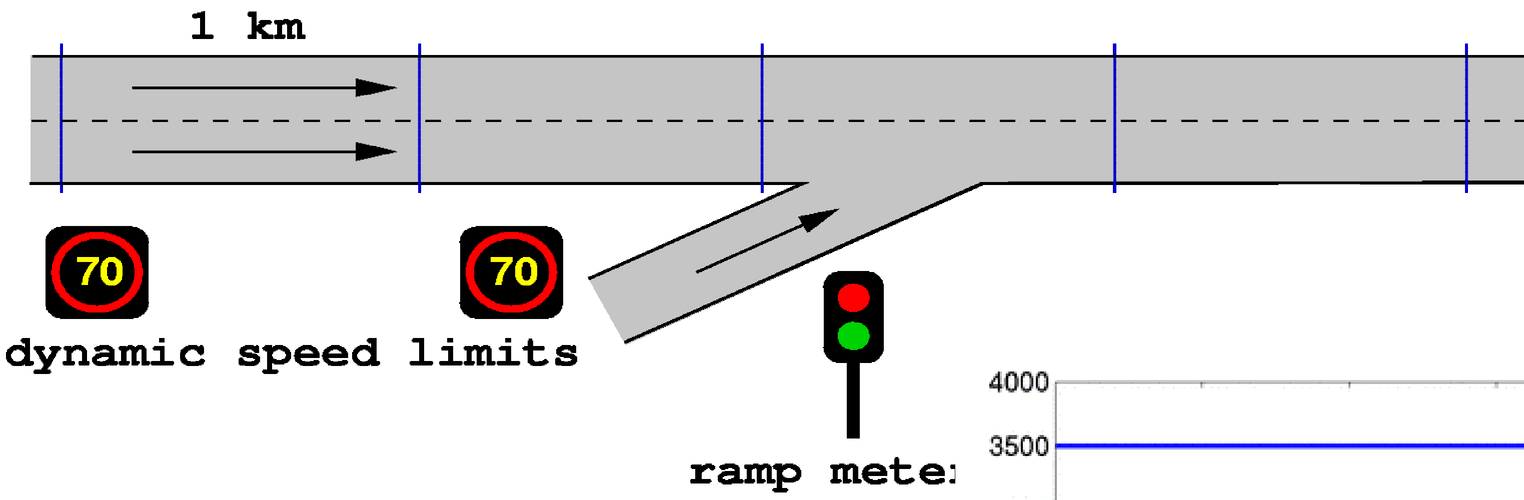
Network traffic
local vs. global

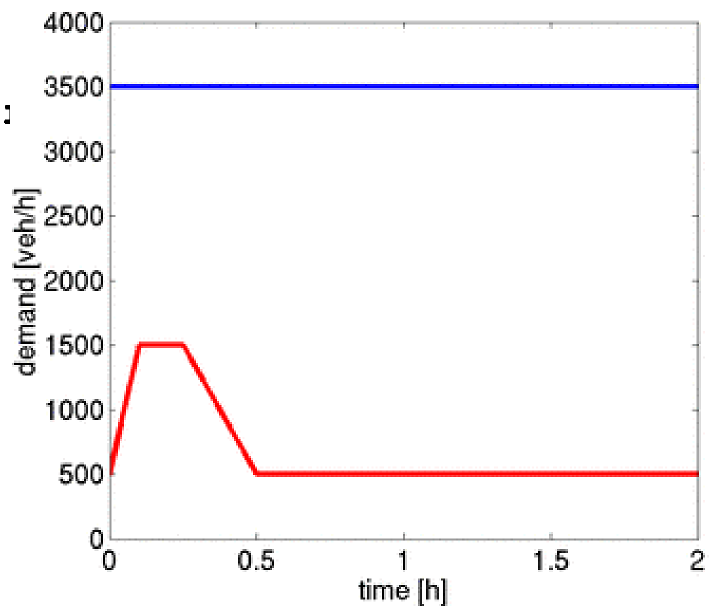
- coordination
  - blocking of other streams



  - influences possible on whole route

Experimental Setup





- compare *ramp-metering only* with *ramp metering and speed limits*
- minimize TTS + small control variation penalty

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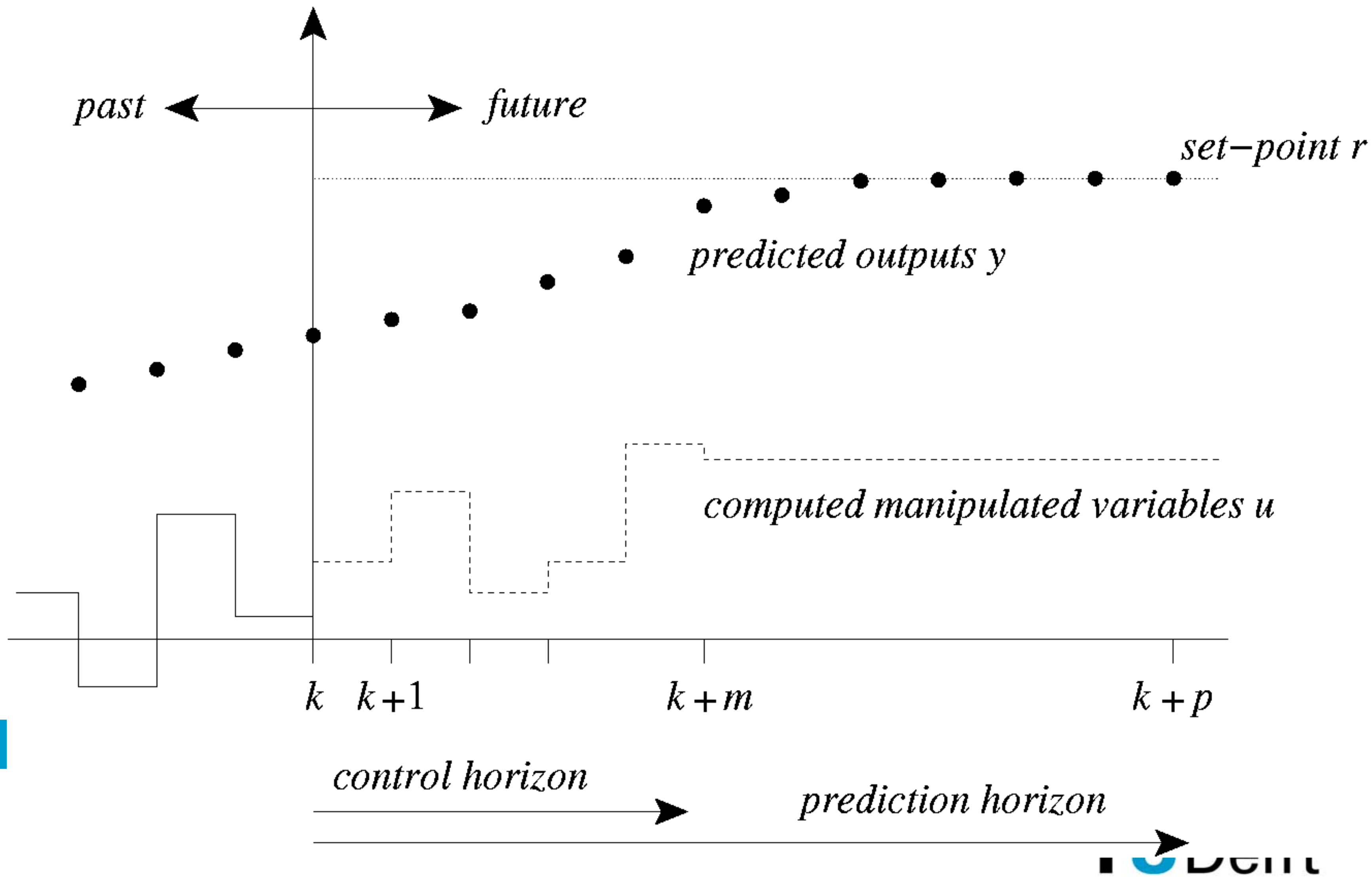
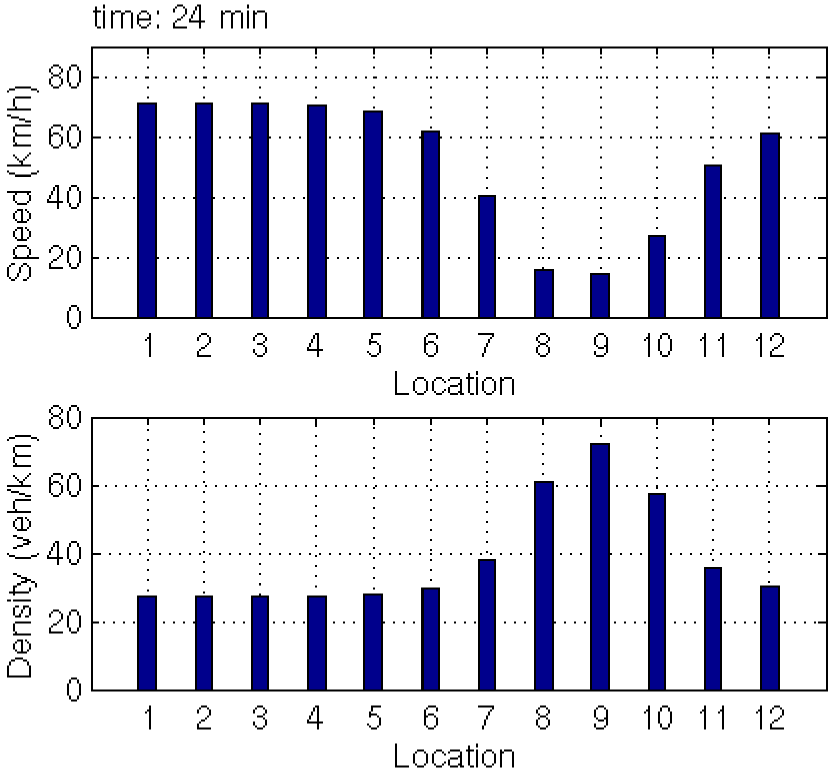
Model Predictive Control

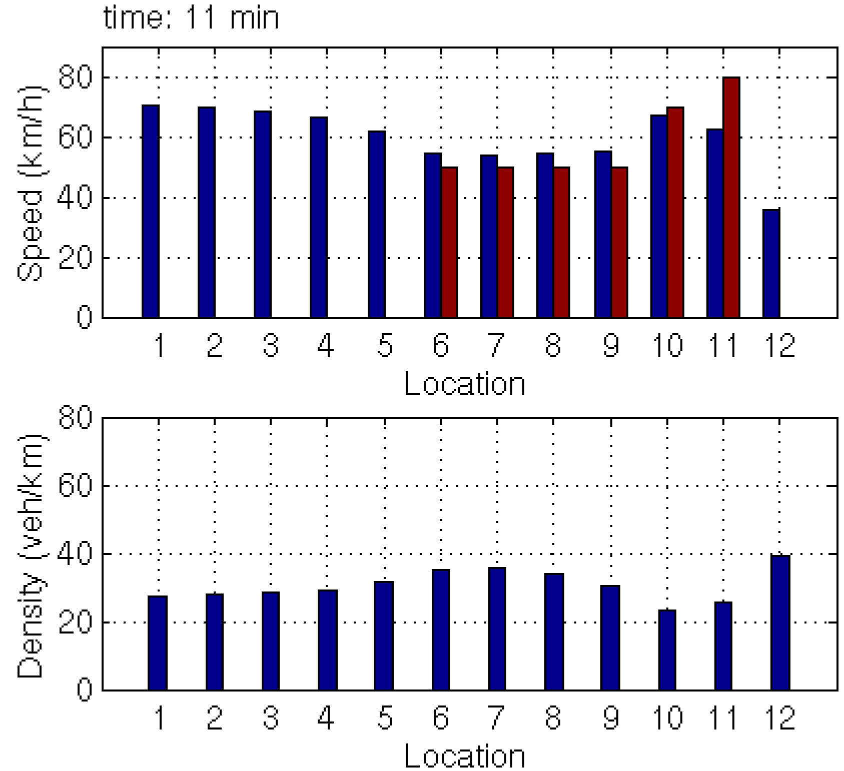


Results

without control



with control



Results

- Prediction horizon: 7 minutes
- Control horizon: 5 minutes
- Introduction of speed limits reduced TTS from 815 veh·h to 737 veh·h (9.6%)
- Congestion resolved in ca. 2 hours instead of 3 hours

- MPC suitable for coordinating ramp metering and speed limits
- Speed limits useful for congestion prevention/reduction

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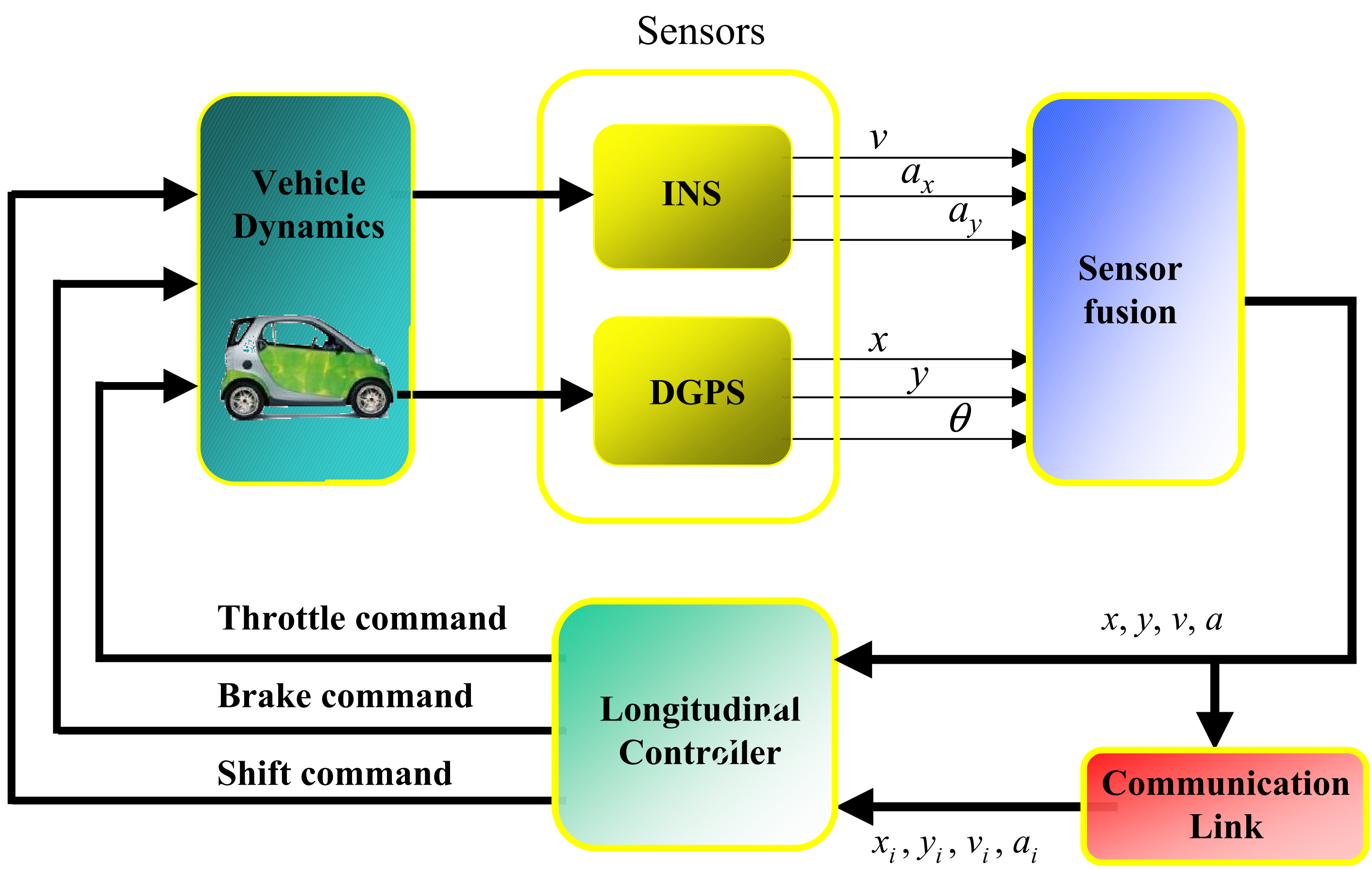
Autonomous driving

- Demo setup consisting of three vehicles with IR-communication
  - Communication up to 300m
  - Multi-hop

Overview of the closed-loop system



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Design of the inner loop(1)

- Acceleration control for fast reaction
- Model-free control or control method robust to model uncertainties must be chosen
- Sliding Mode Control (SMC) with a simple model is chosen:
  - Model: $ma + f = bu$
  - Control output: $u = \dfrac{(\frac{-\dot{\varepsilon}}{\lambda} + a_{ref})\hat{m} + \hat{f}}{\hat{b}} - \dfrac{k}{\hat{b}}\mathrm{sat}\left(\dfrac{S}{\phi}\right)$
- Two SMC controllers have been used for brake and throttle because of different dynamics
- Gearbox has been controlled by shift algorithm

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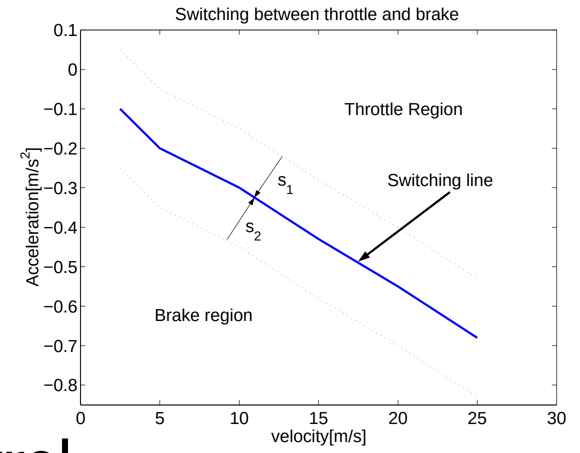
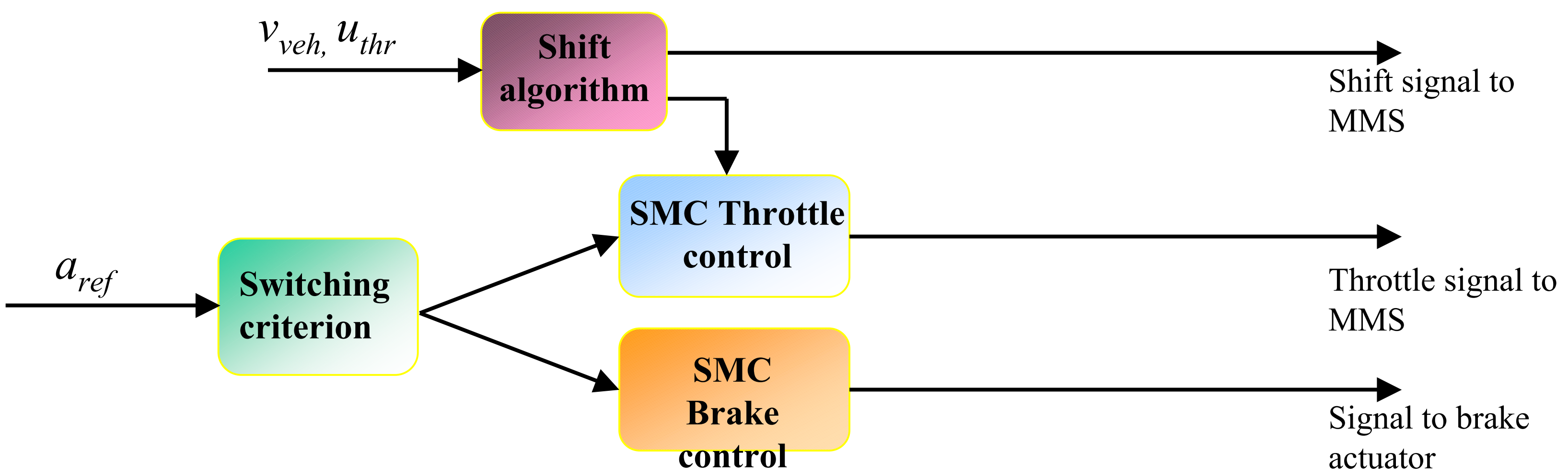
Design of the inner loop(2)

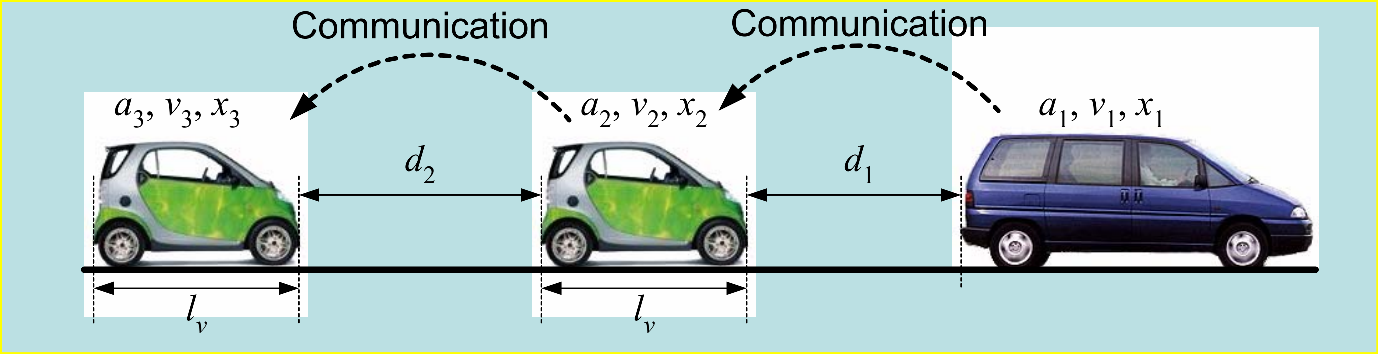


- Brake and throttle should not be applied at the same time therefore the following switching criterion has been used:
  - $a_{ref} - a_{res} > s_1$ switch to throttle control
  - $a_{ref} - a_{res} < s_2$ switch to brake control
  - $s_2 \leq a_{ref} - a_{res} \leq s_1$ do not switch
- Overview of total inner loop:



Design of the outer loop

- Design of the outer loop is done in a simulation environment with ATS/CAR vehicle models developed at TNO Automotive



- Main objective: keep a headway of $\boldsymbol{d_{ref}}$ to front vehicle
  - Used time headway: $h = h_0 - c\Delta v$
  - Desired headway: $d_{ref} = d_0 + hv_{veh}$
- Additional term to achieve 'natural' driving behaviour:

$$a_{MND} = \frac{-(v_2 - v_1)^2}{2(d - d_{ref} + dx)}$$

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Conclusions

- Traffic control is dependent of good models
- Traffic measures can be combined, but this is risky
- Large test sites with more cities and long highways will be extremely difficult to control

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