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Faculty of Transportation and Traffic Sciences "Friedrich List"

Self-Control of Traffic Lights in Urban Road Networks

Stefan Lämmer
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MOVING THE WORLD.

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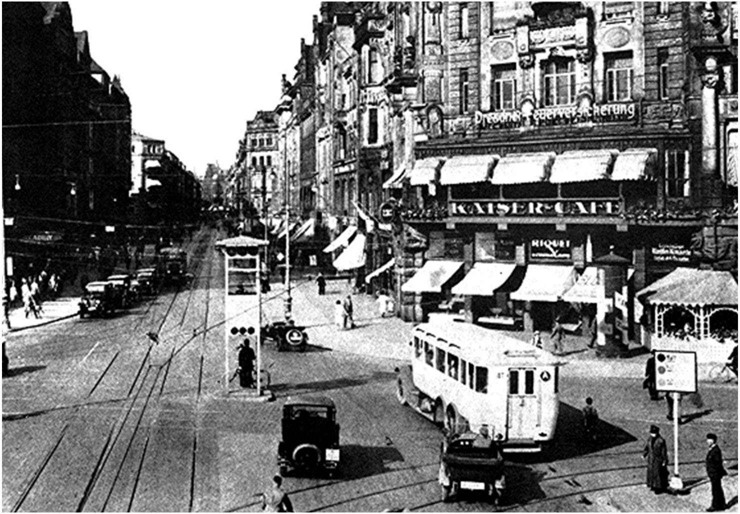
Dresden 1927



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Zurich 2007

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Conflicting Paradigms

Coordination

- regular service, “Green Waves”
- continuous flow with no stopps
- assignment of fixed service capacities

Flexibility

- reaction on spontaneous events
- Public transport scheduling
- demand responsive service of variable inflows

Solution:
Treatment of special cases

Solution:
Flexible Self-Control

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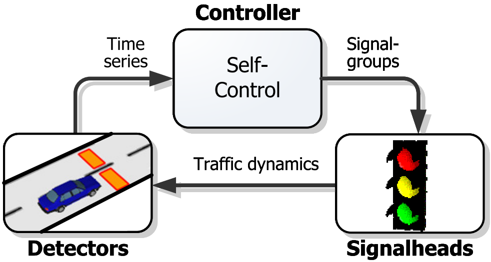
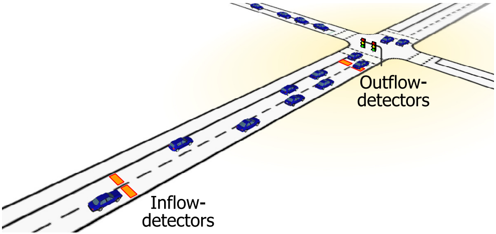
Control Approach





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Self-Control Principles

Short-Term Anticipation

How does the actual switching state influence future waiting times?

Lämmer, Donner, Helbing: Anticipative control of switched queueing systems. *The European Physical Journal* **B** 63(3) 341-347 (2007)

Local Optimization

What combination of switching states minimizes cumulative delays?

Lämmer, Helbing: Self-Control of Traffic Lights and Vehicle Flows in Urban Road Networks. *Journal of Statistical Mechanics: Theory and Experiment*, P04019 (2008)

Stabilization

How to ensure desired throughput and maximum red times?

Lämmer, Helbing: Self-Stabilizing Decentralized Signal Control of Realistic, Saturated Network Traffic. *Santa Fe Working Paper* 10-09-019 (2010)

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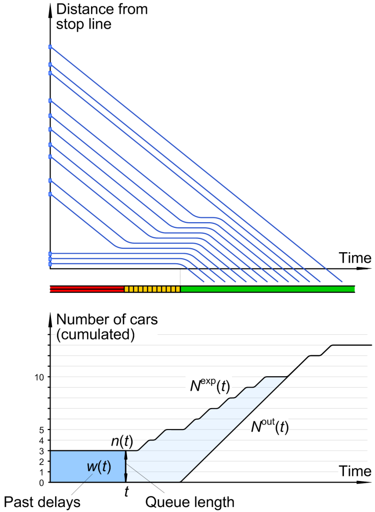
Queueing model



Service process

$= \text{setup } \tau + \text{green time}$

Queue length $n(t)$

$$n(t) = N^{\text{exp}}(t) - N^{\text{out}}(t)$$

Past delay $w(t)$

$$\frac{d}{dt} w(t) = n(t)$$

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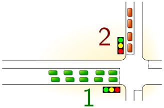
Pressure-Principle



n_1, n_2 ... queue lengths
q_1, q_2 ... max. service rate
τ_1, τ_2 ... setup times

Start serving phase 1, if ...

$$\text{total delay } 1 \rightarrow 2 \quad < \quad \text{total delay } 2 \rightarrow 1$$

$$\tau_1(\cancel{n_1} + n_2) + \frac{n_1}{q_1}(\cancel{n_1/2} + n_2) + \cancel{\tau_2 n_2} + \cancel{n_2^2/(2q_2)} \quad < \quad \tau_2(n_1 + \cancel{n_2}) + \frac{n_2}{q_2}(\cancel{n_2/2} + n_1) + \cancel{\tau_1 n_1} + \cancel{n_1^2/(2q_1)}$$

$$\tau_1 n_2 + \frac{n_1}{q_1} n_2 \quad < \quad \tau_2 n_1 + \frac{n_2}{q_2} n_1$$

$$\pi_2 := \frac{n_2}{\tau_2 + n_2/q_2} \quad < \quad \frac{n_1}{\tau_1 + n_1/q_1} =: \pi_1$$

It is optimal ...

...to start serving phase i with highest "pressure" $\pi_i = \dfrac{n_i}{\tau_i + n_i/q_i}$

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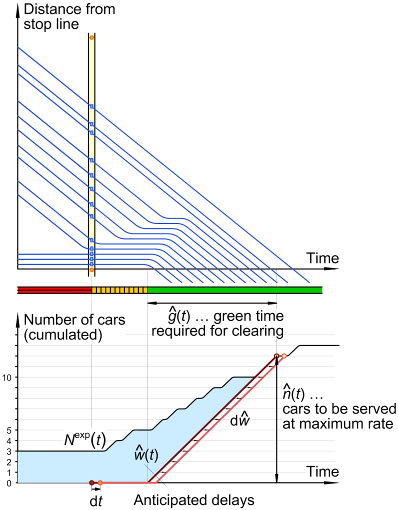
Anticipation model



Future delay

$$\frac{\mathrm{d}}{\mathrm{d}t}\hat{w}(t) = \begin{cases} \hat{n}(t), & \text{no service} \\ 0, & \text{service} \end{cases}$$

Integral transformation

$$\begin{array}{ccc} w(t) & \circ\!\!-\!\!\bullet & \hat{w}(t) \\ \frac{\mathrm{d}}{\mathrm{d}t}\downarrow & & \downarrow\frac{\mathrm{d}}{\mathrm{d}t} \\ n(t) & \circ\!\!-\!\!\bullet & \hat{n}(t) \end{array}$$

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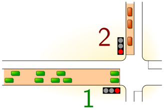
Optimization



$\hat{n}_1, \hat{n}_2$ . . . anticipated vehicles
$\hat{g}_1, \hat{g}_2$ . . . anticipated green times
τ_1, τ_2 . . . setups

Start serving phase 1, if . . .

$$\text{future delay } 1 \rightarrow 2 \quad < \quad \text{future delay } 2 \rightarrow 1$$

$$\hat{n}_2\,(\tau_1 + \hat{g}_1) \quad < \quad \hat{n}_1\,(\tau_2 + \hat{g}_2)$$

$$\pi_2 := \frac{\hat{n}_2}{\tau_2 + \hat{g}_2} \quad < \quad \frac{\hat{n}_1}{\tau_1 + \hat{g}_1} =: \pi_1$$

It is optimal, . . .

. . . to start serving phase i with highest "pressure" $\pi_i = \dfrac{\hat{n}_i}{\tau_i + \hat{g}_i}$

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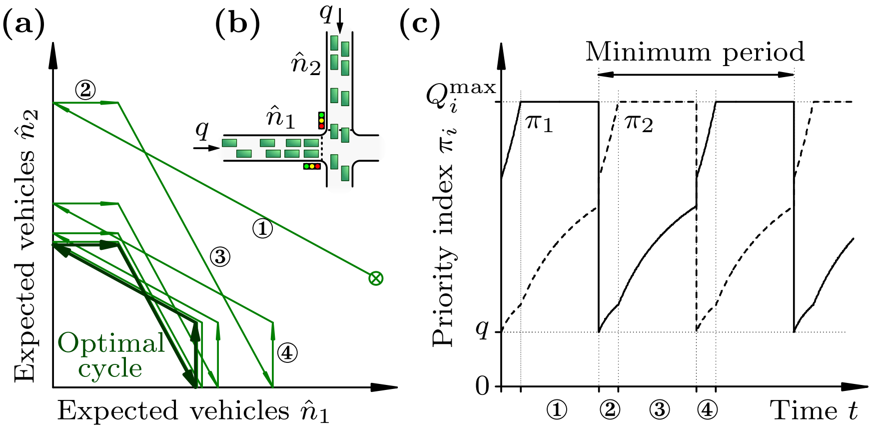
Limit cycle



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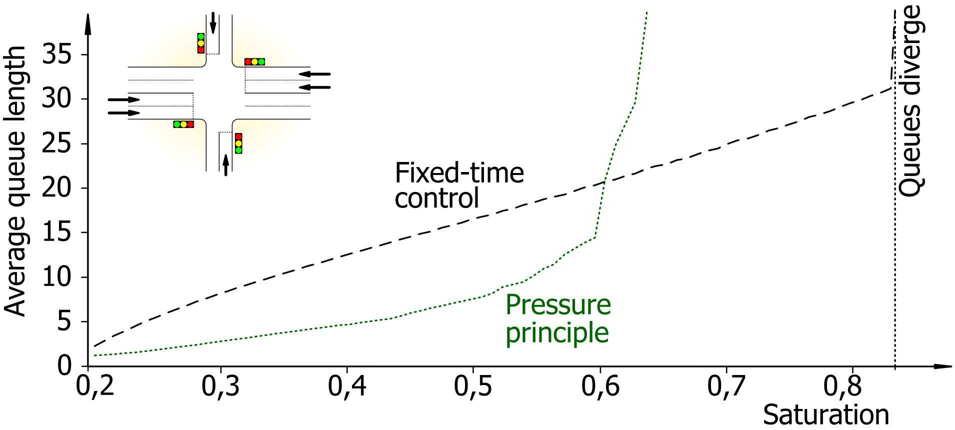
Single intersection control



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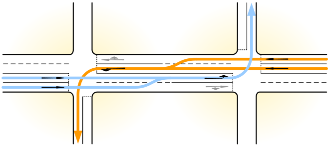
Kumar-Seidman-Network

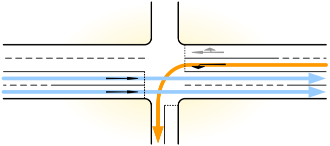
Simple scenario

- Network of two intersections
- two intersecting flows
- deterministic inflow



Single intersection control

- Clear queues one after the other
- No extension of green times (Clear-Largest-Buffer-Rule)



Properties (desired, but not achievable with fixed-time-control)

- maximum service capacity
- minimum cycle is a global attractor!
- minimum total delays (especially with random arrivals)

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Instability

In the network, however, we observe

- "optimal" controller fails
- service periods become infinite
- queues grow longer and longer

What is responsible?

- time-delayed feedback
- traffic flow transmits information
- each loop in the net is a feedback-loop
- positive feedback leads to instability

▶ **Instability:** Unlimited growth of vehicle queues

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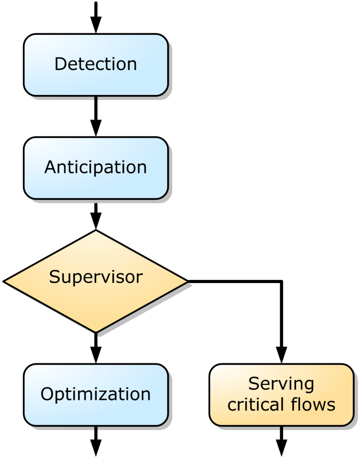
Stabilization principle



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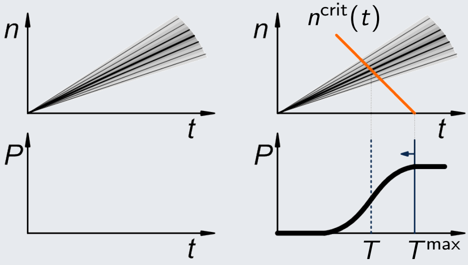
Supervision

Principle

If optimization failed to serve the vehicles typically arriving within T, serve them now!

Supervisor



Control parameters

$$T^{max} > T > T^{cyc,min}$$

Optimization:
Scheduling problem

Stabilization:
Assignment problem

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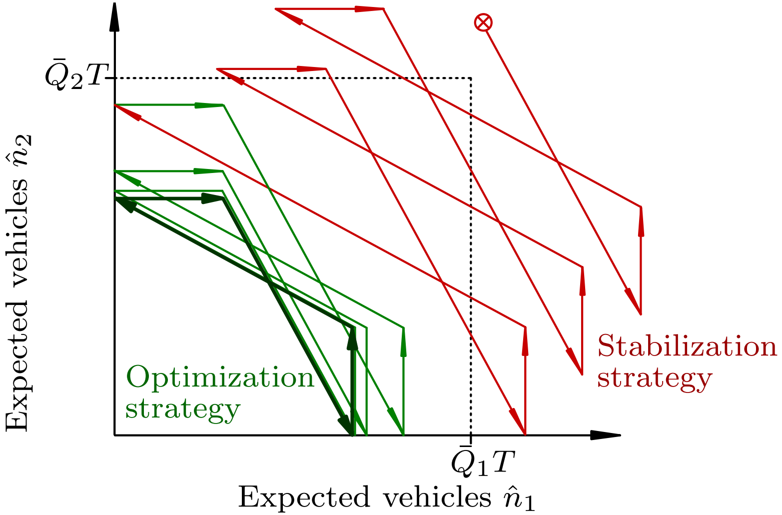
Limit cycle



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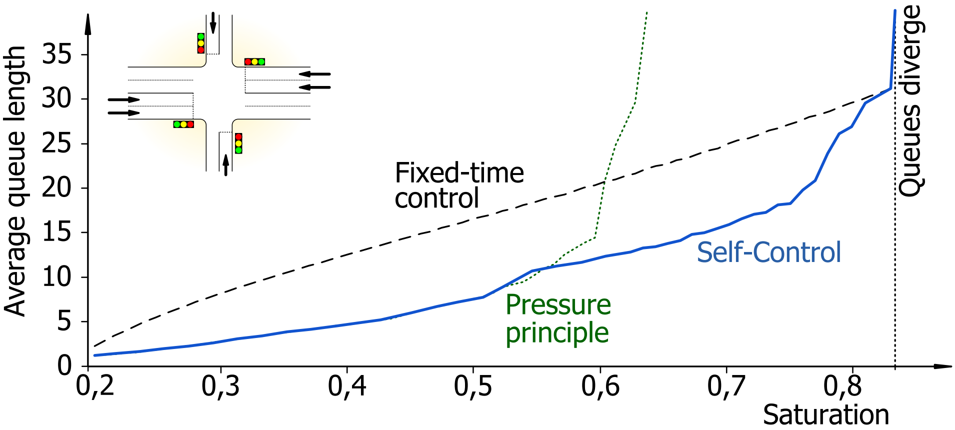
Single intersection - deterministic



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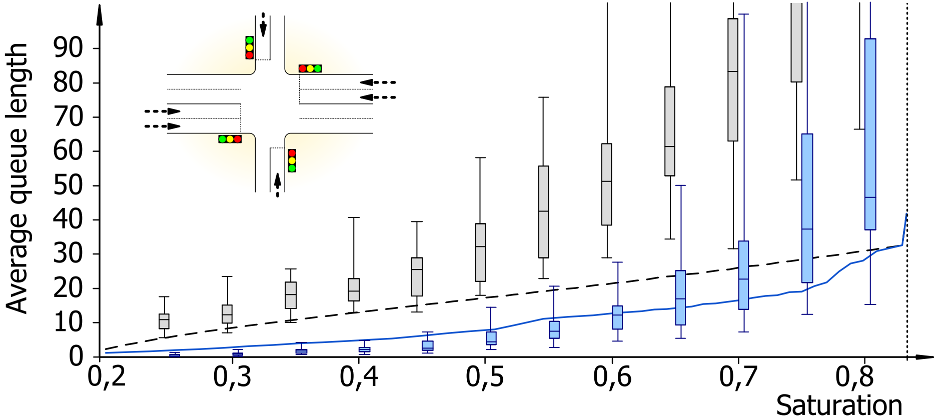
Single intersection- stochastic



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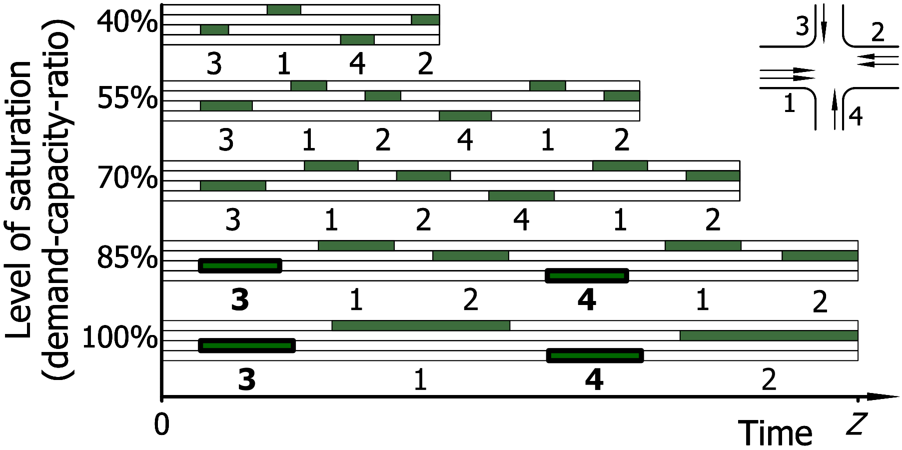
Single intersection control



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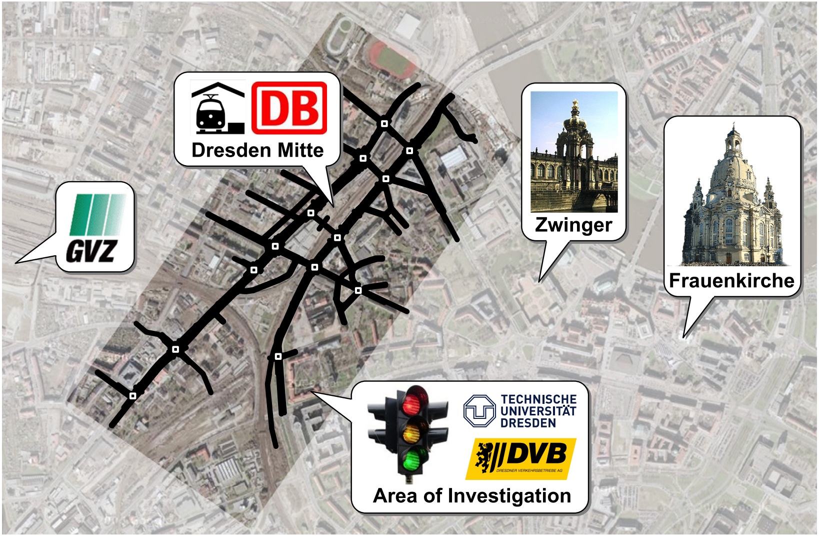
Area of Investigation



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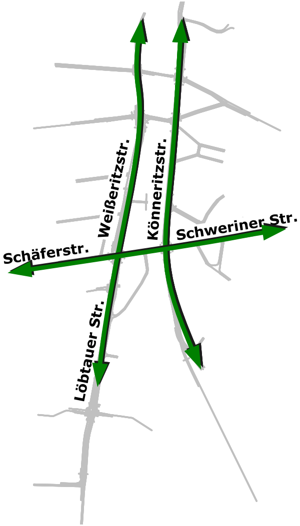
Network Layout



Road Network

- size: 0.8 × 1.7 km
- 13 traffic light controlled intersections
- 4700 vhcl/h total inflow
- 68 pedestrian crossings
- 8 Public Transport linies (10-minute-clock)
- 28 Public Transport stops

Original-Control

- traffic-responsive control (VS-PLUS)
- cycle time 100 seconds
- Green Waves in all major directions
- had been optimized within same framework

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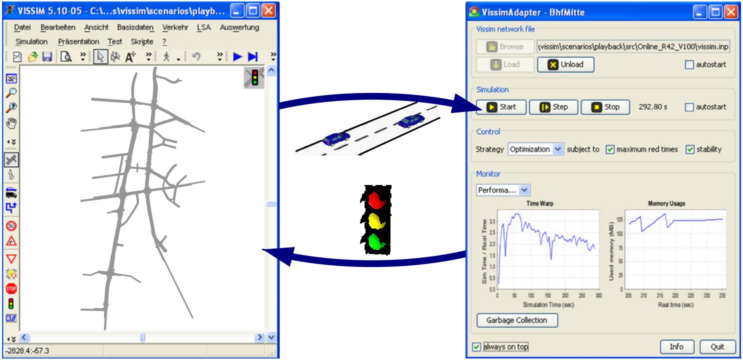
Implementation

PTV Vissim | **COM-Interface** | **Java-Application**



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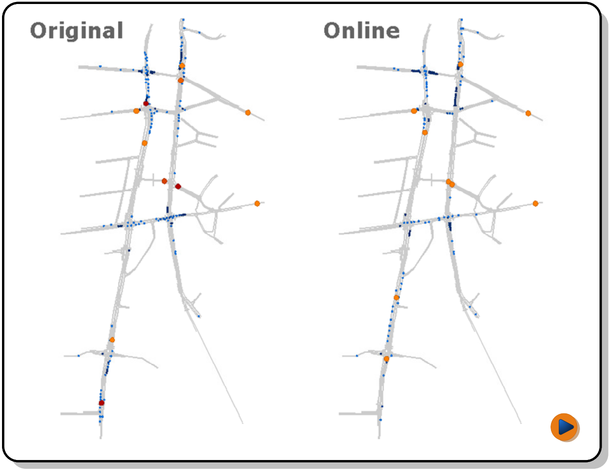
Simulation Video



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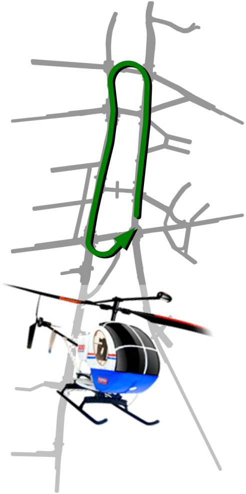
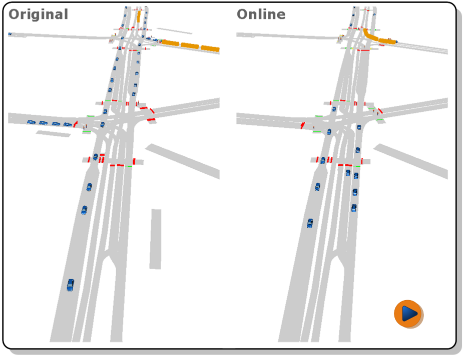
Simulation Video





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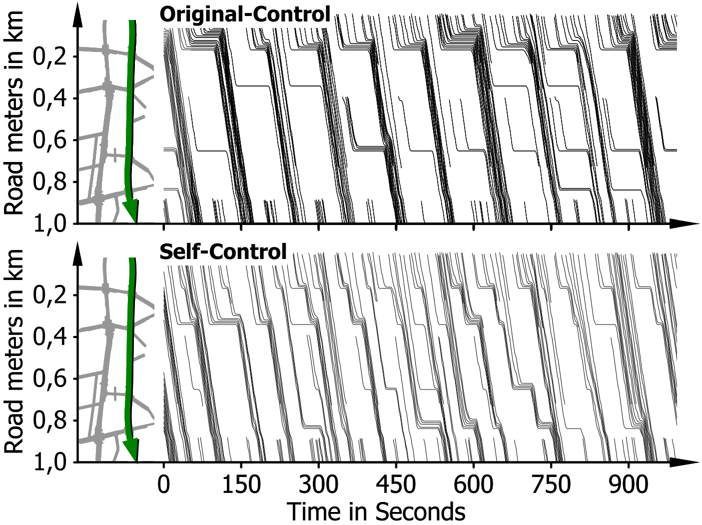
Vehicle Trajectories



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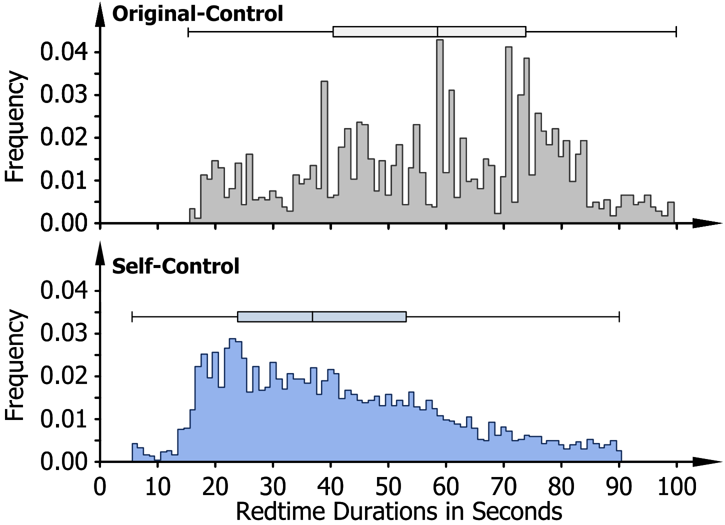
Pedestrian Redtimes



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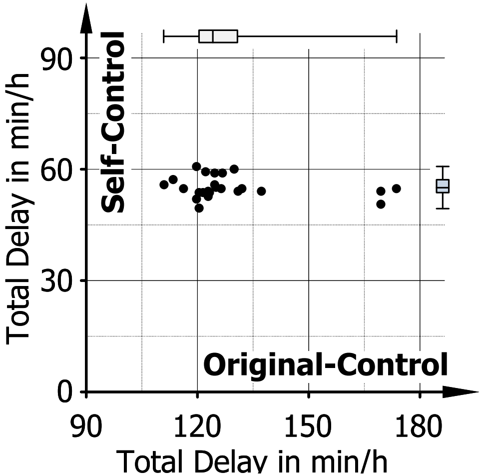
Buses and Trams



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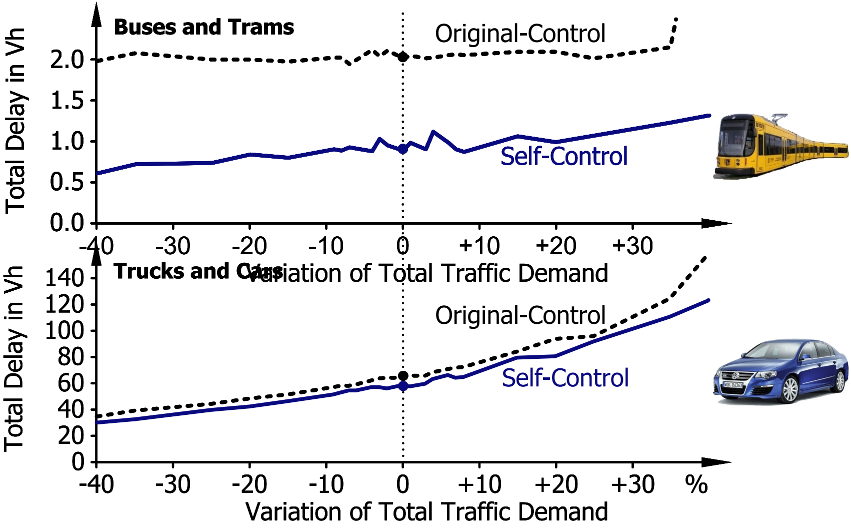
Variation of Traffic Demand



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Partners

SIEMENS — Mobility Division Berlin

DVB DRESDNER VERKEHRSBETRIEBE AG — Center Traffic Management

City of Dresden

TECHNISCHE UNIVERSITÄT DRESDEN — Institute of Intelligent Transportation Systems

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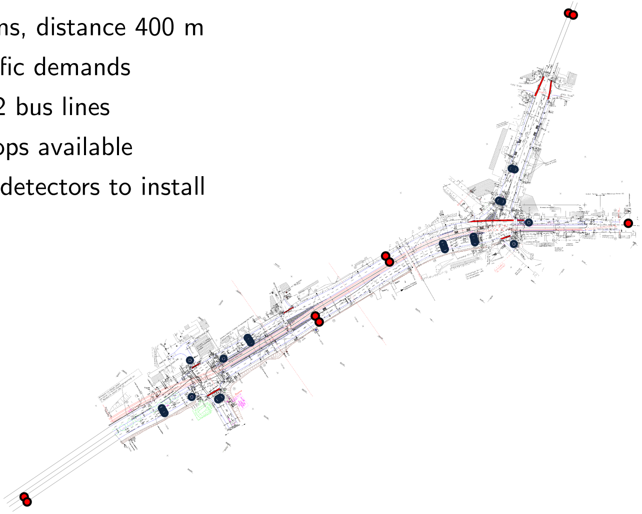
Test Area

- 2 intersections, distance 400 m
- irregular traffic demands
- 1 tram and 2 bus lines
- induction loops available
- 9 additional detectors to install



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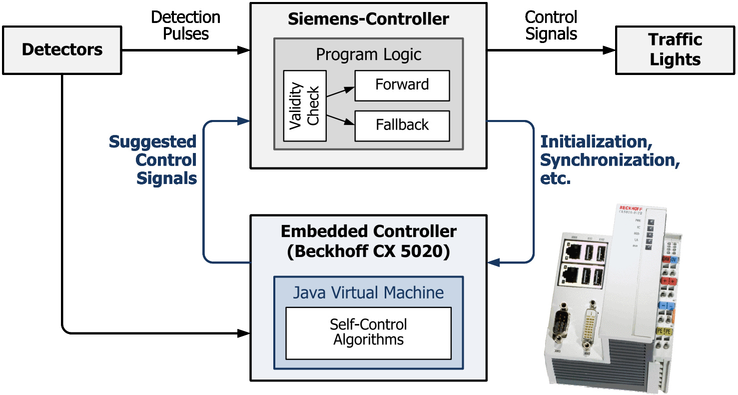
Hardware Architecture



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Summary

Self-Control

- flexible control on operative level
- fully traffic responsive scheduling
- emergent coordination
- harmonic public transport prioritization
- promising simulation results

Technical Requirements

- 2 (or more) detectors per stream and lane
- inflow-detector 200 m upstream stop line
- undelayed communication between detector and controller

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Parameterisation

System Parameters

- number and type of traffic streams
- intergreen times
- detector positions
- reference demand
- ...

Control Parameters

- desired service period (e.g. 90 s, stochastic)
- maximum red time (e.g. 120 s, definite)
- service capacities on saturation
- weigthing of stopps (e.g. 50 s per stop)
- weighting of vehicle types (e.g. 15 for buses and trams)
- weighting of particular streams (e.g. 1.5 for main road)

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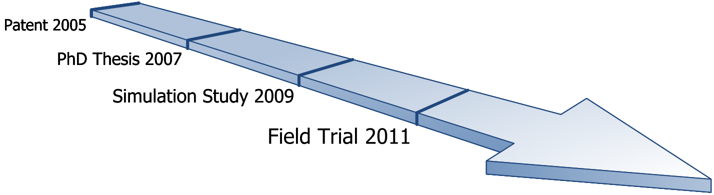
What's next?



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