ETH zürich

Fundamentals of Traffic Operations and Control
Mainline freeway control and VSL

Dr. Tasos Kouvelas

IVT – Institut für Verkehrsplanung und Transportsysteme

Departement Bau, Umwelt und Geomatik

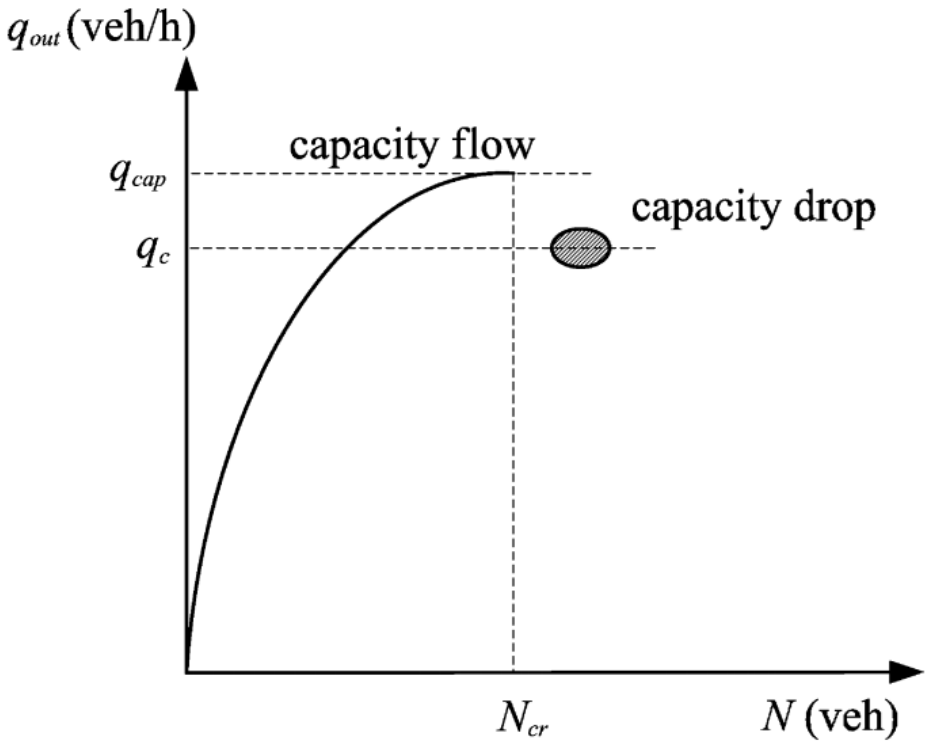
Today's contents

- Highway merging control
  - Bay Bridge case study
- Variable Speed Limits (VSL)
  - Current applications
  - Modeling (FD)
  - Implications to traffic flow
  - Simulation results
  - Optimal locations
- Highway maintenance and work zones
  - Flow control for optimal throughput

Revisiting capacity drop

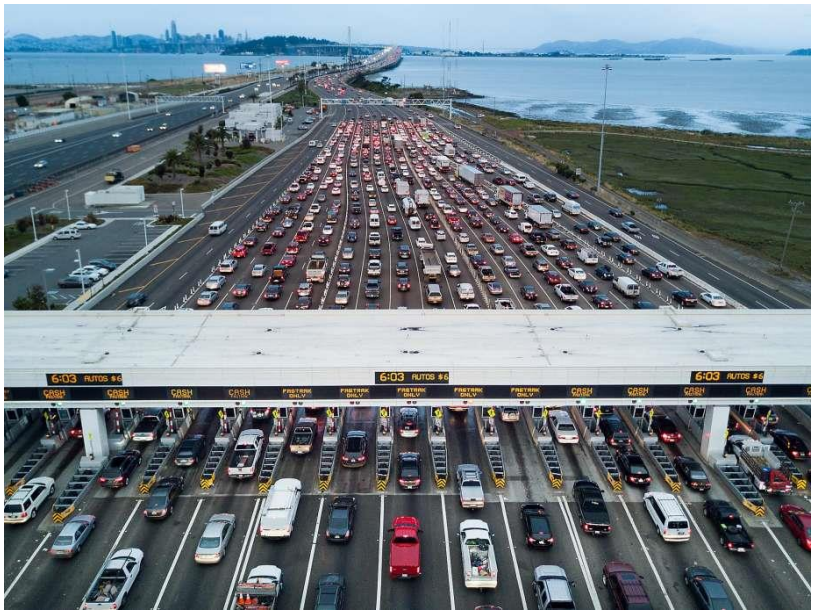
A simple example:

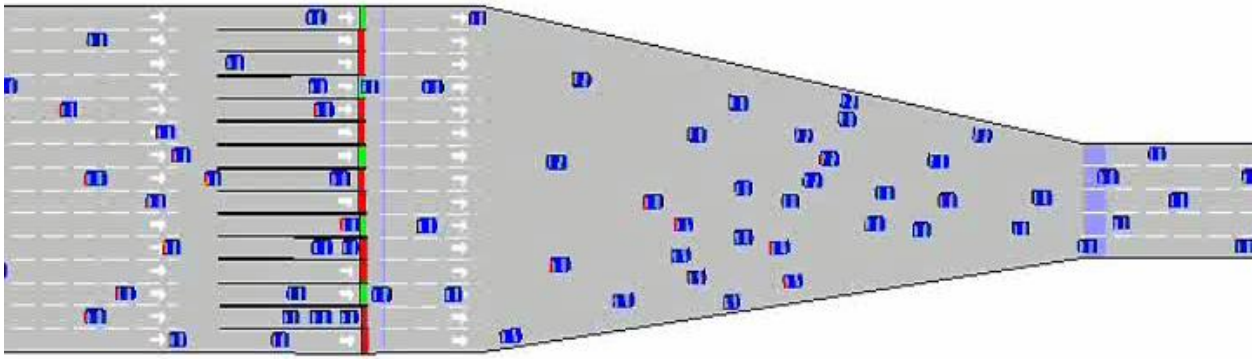
See sketch on blackboard!



FD of a merging area

Bay bridge toll plaza (San Francisco)

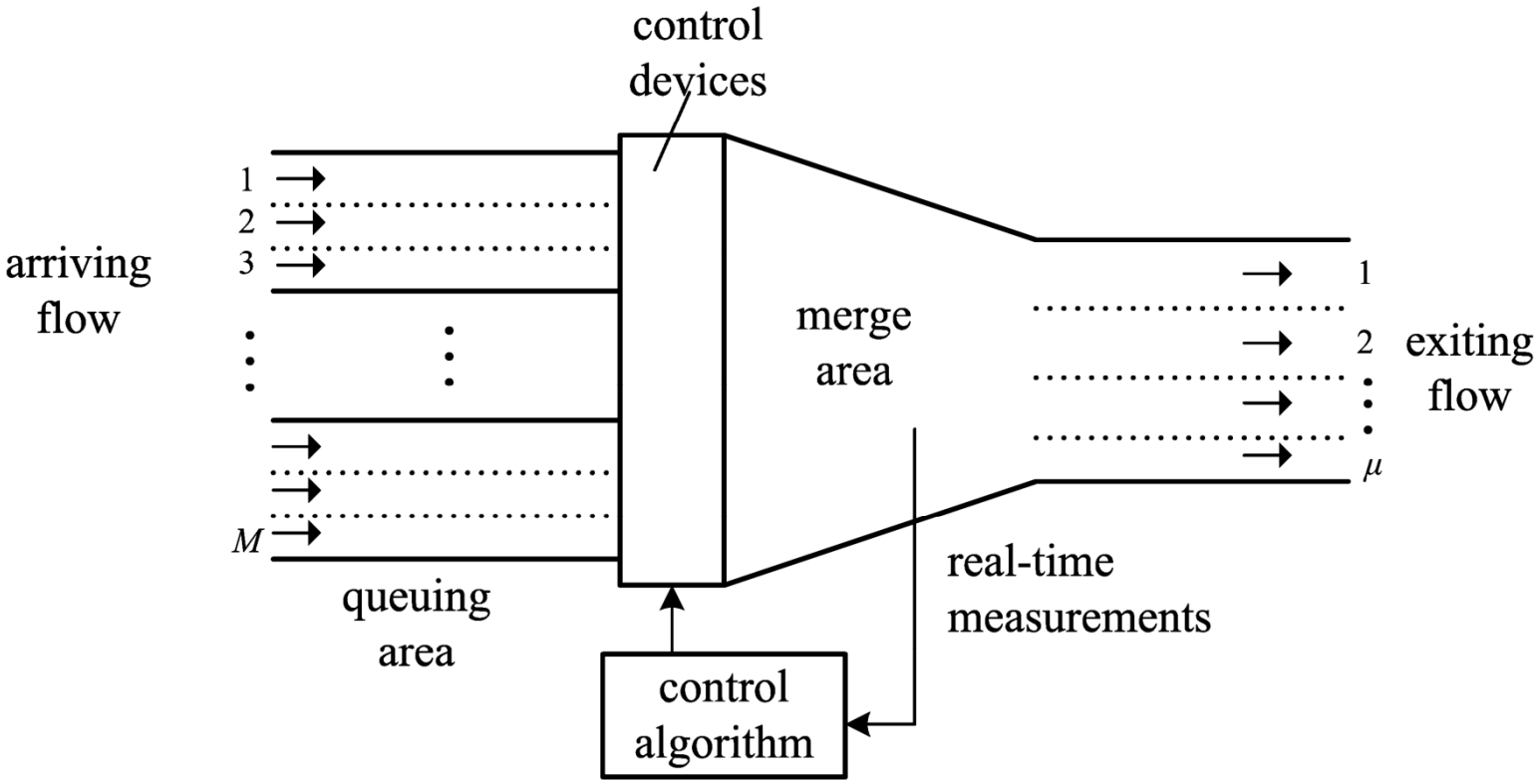




Merging traffic control

- Merging traffic infrastructures (M → μ lanes)
- Real-time information:
  - Merging of two highways
  - Motorway on-ramps
  - Toll plazas
  - Motorway work zones
- If arriving flow on M lanes > Capacity of μ lanes
  ⇒ Congestion ⇒ Capacity drop
- Merging traffic control to restore capacity flow

Structure and elements

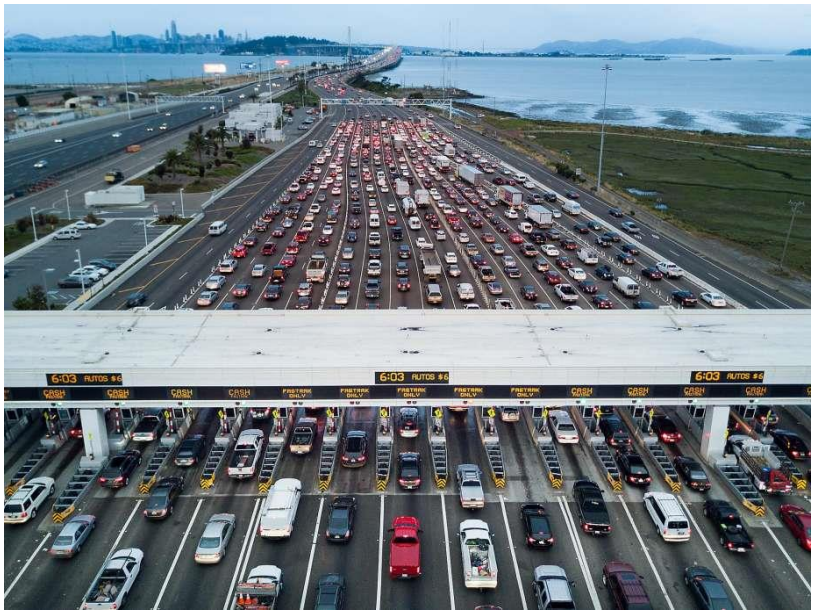


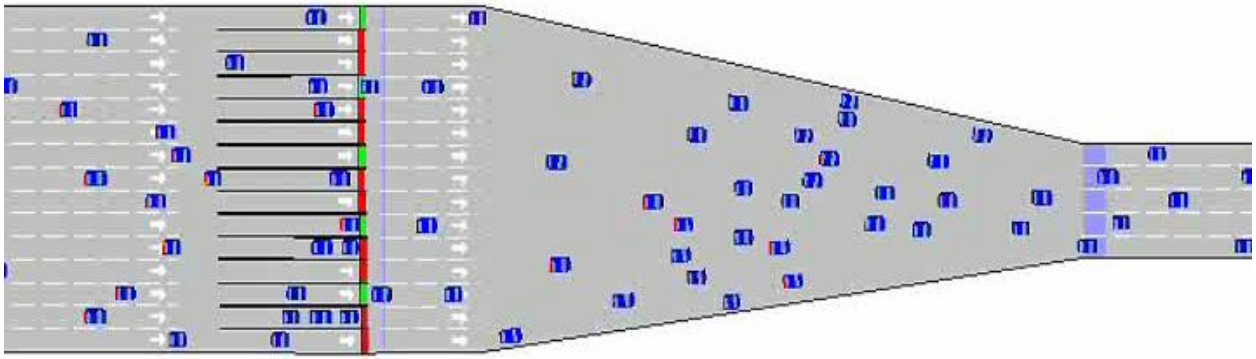
Control Algorithm Main Goal

$N \approx N_{cr}$ (or $o \approx o_{cr}$)

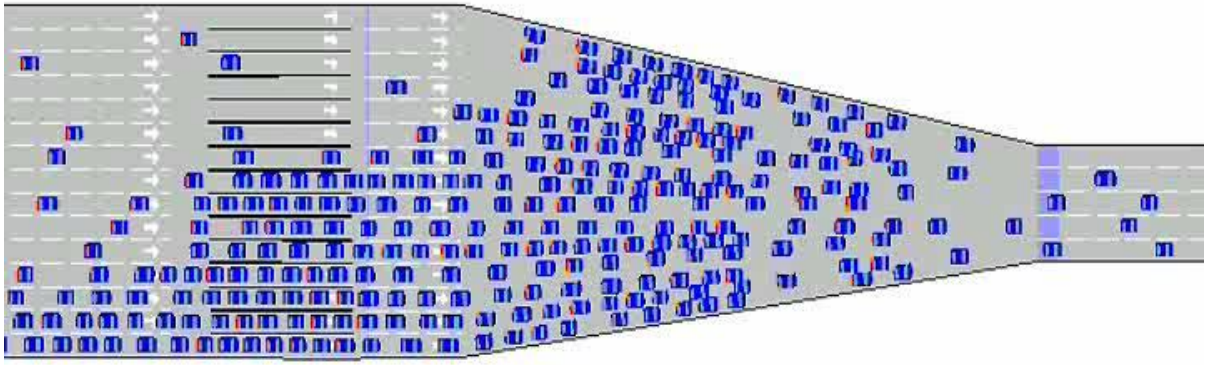
Bridges in the Bay Area

Bay bridge toll plaza (San Francisco)

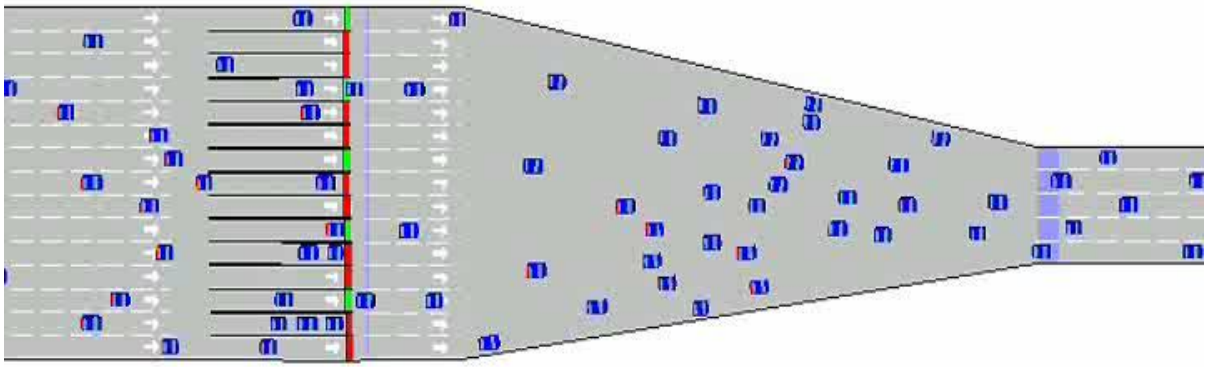




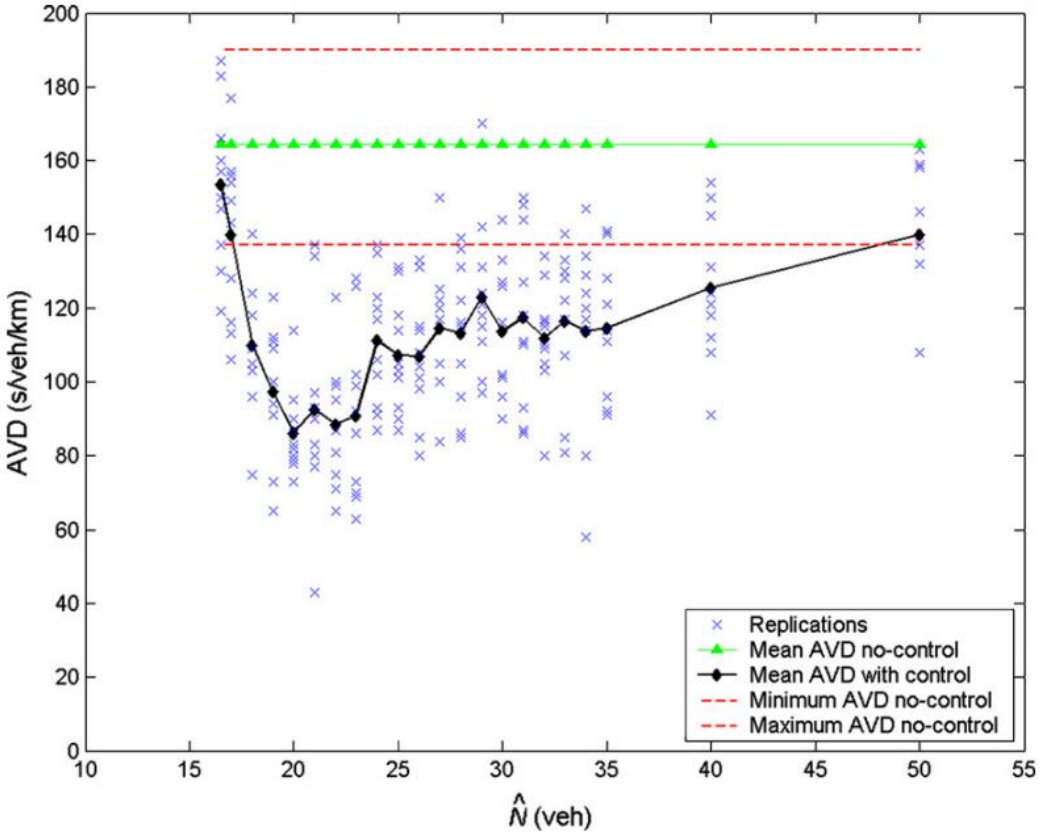
Simulation results (no control)



Simulation results (merging control)



Many stochastic replications



Papageorgiou, M., Papamichail, I., Spiliopoulou, A.D. and Lentzakis, A.F., 2008. Real-time merging traffic control with applications to toll plaza and work zone management. Transportation Research Part C, 16(5).

Control devices

- Traffic lights (appropriate switching)
- Physical barriers (toll plaza)
- Variable speed limits
- Emerging vehicle-to-infrastructure technologies
- Some lanes may be free
- Control algorithm (three parts):
  - a) Exit flow regulation
  - b) Distribution per (controlled) lane
  - c) Translation of control decisions

ALINEA-type regulator

- ALINEA:

$$q \rightarrow \boxed{q(k) = q(k-1) + K_R[\hat{o} - o(k-1)]}$$

- Distribution per (controlled) lane :

$$q_i \rightarrow \boxed{q \rightarrow q_i,\ i = 1,\ldots,M}$$

- Translation of control decisions:

  Different signal switching policies to coordinate the merging of vehicles.

Evacuation of SF by using the bridges

The bridges can serve 40’000 veh/h.

How much time does it take to evacuate 120’000 veh?

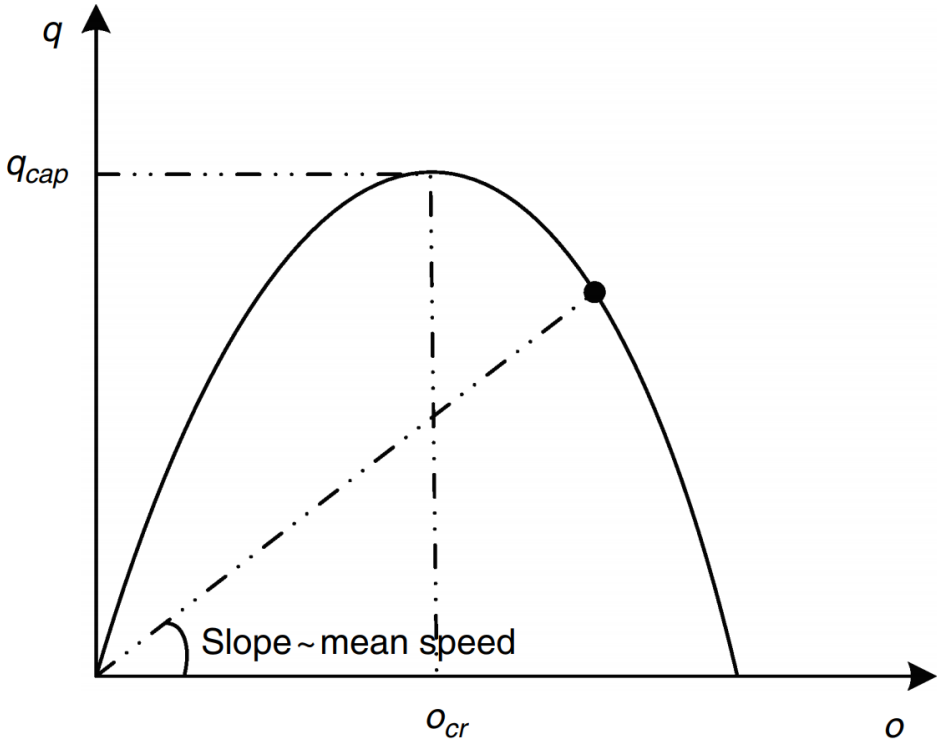
Can I do it in 3 hours?

Variable Speed Limits (VSL)

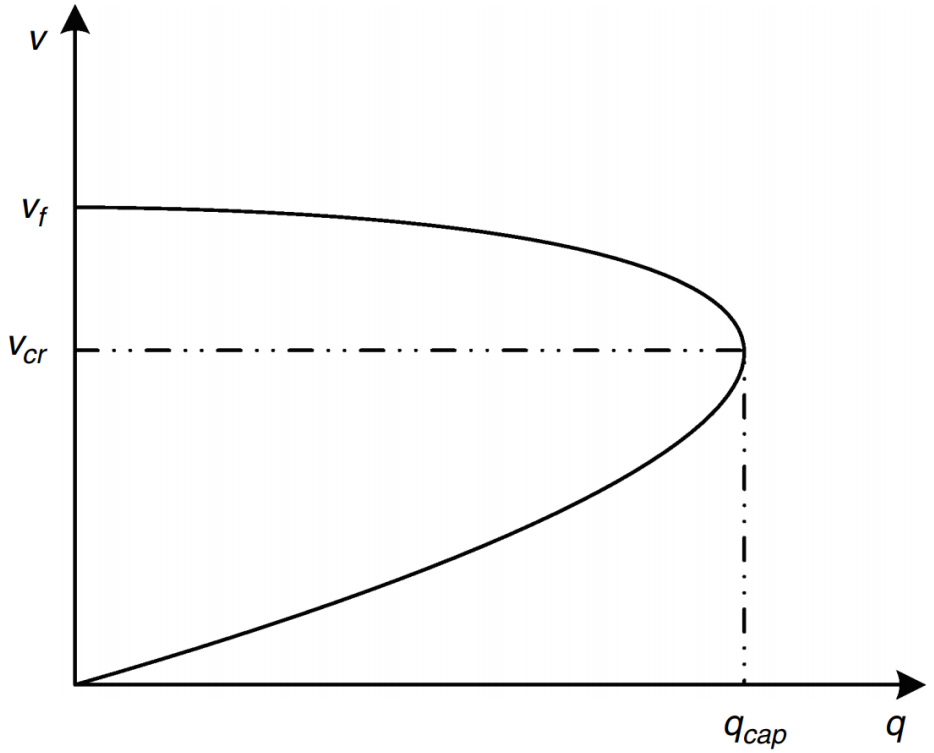
VSL overview

- Many application stretches in Germany (> 60 systems covering a total of 1200 km), The Netherlands, U.K., …
- Harmonization of speed
- Homogenization of traffic flow
  - higher capacity (?)
  - higher ρ_{cr} (?)
  - more stable conditions (?)
  - Less accidents: 30% less accidents in Germany
- Very limited systematic studies about traffic flow

Modeling VSL



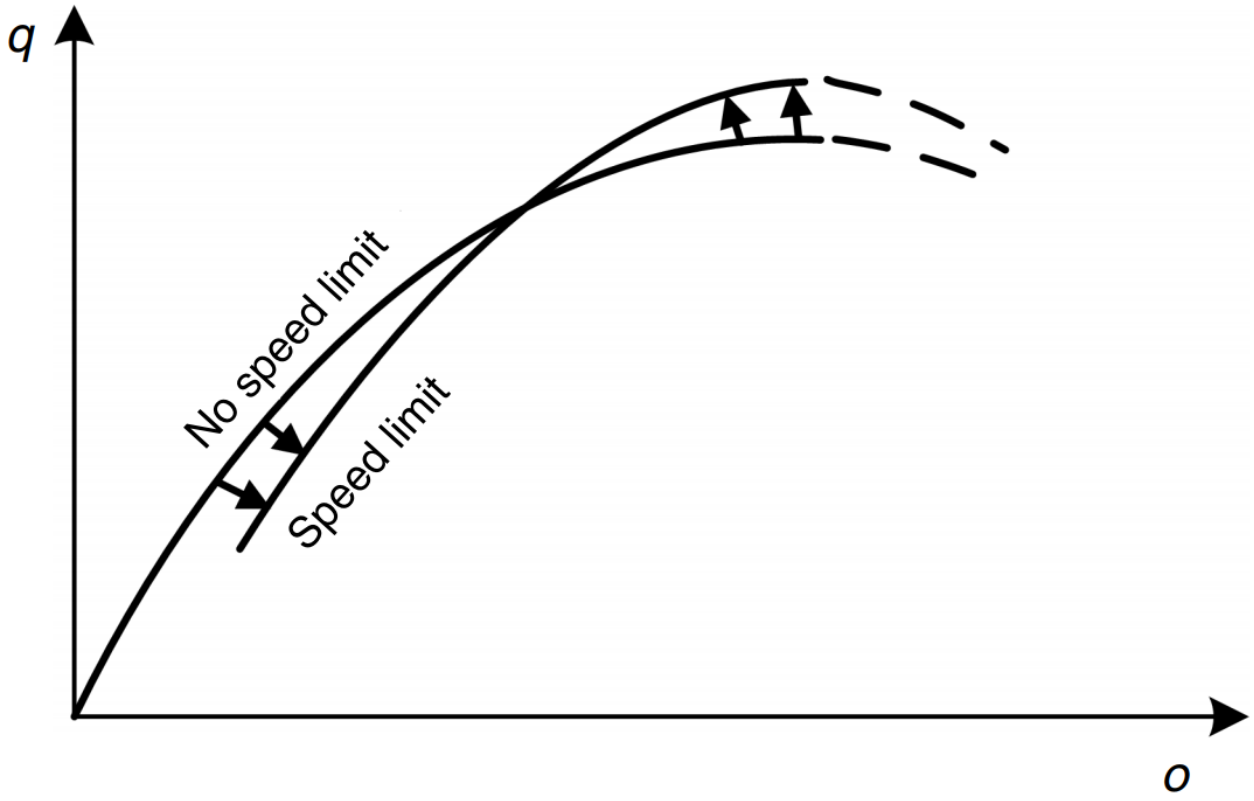
Flow-density FD



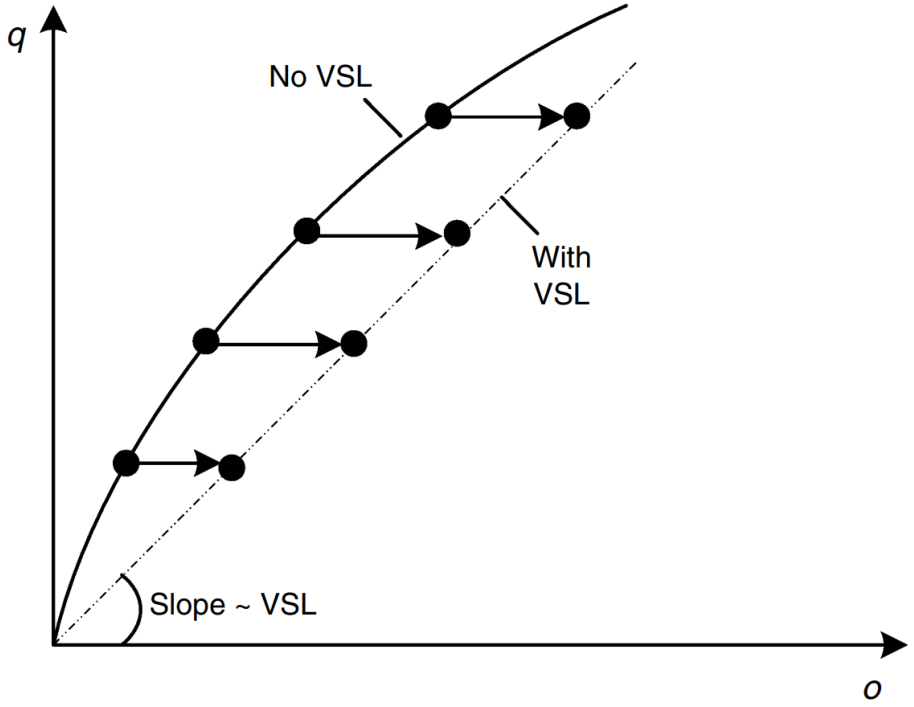
Speed-flow FD

Impact of VSL on the FD (1)

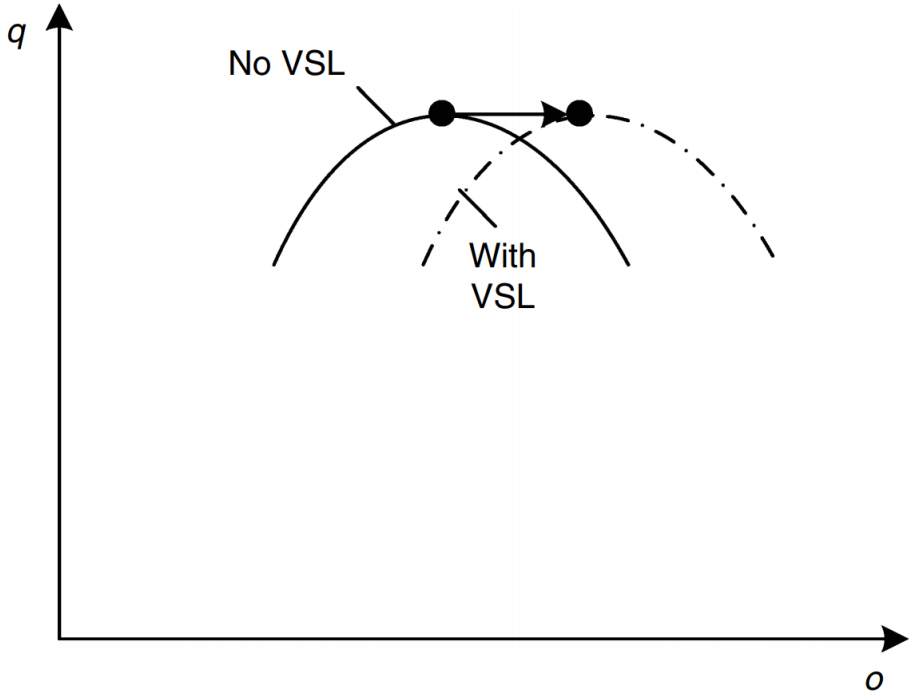
Zackor (1991)



Impact of VSL on the FD (2)



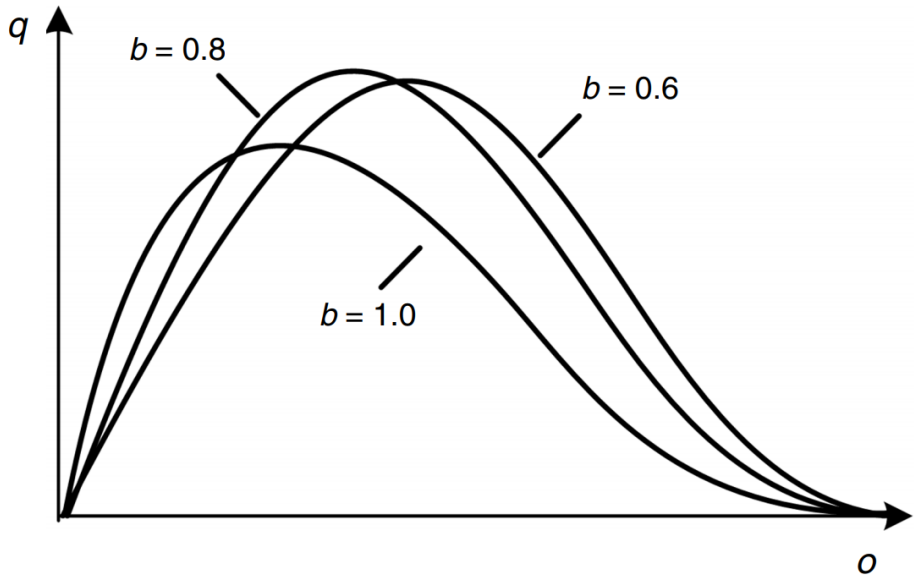
Uncongested conditions



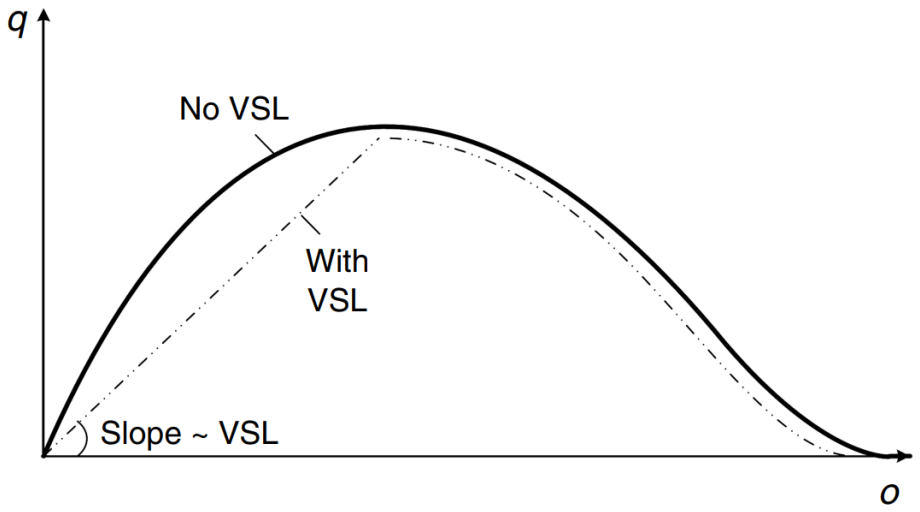
Effect on critical density

Impact of VSL on the FD (3)

Cremer (1979)



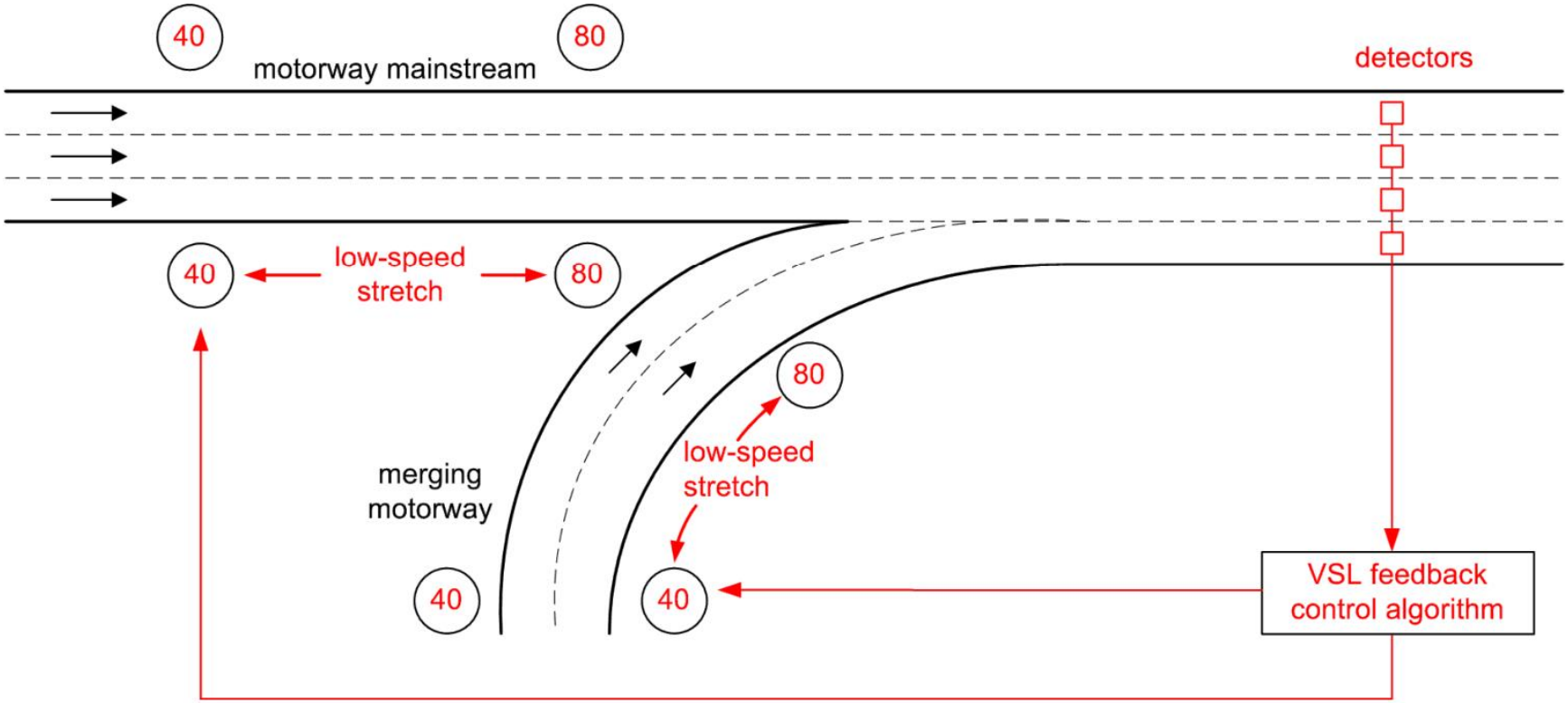
Hegyi (2004)



Drivers' compliance

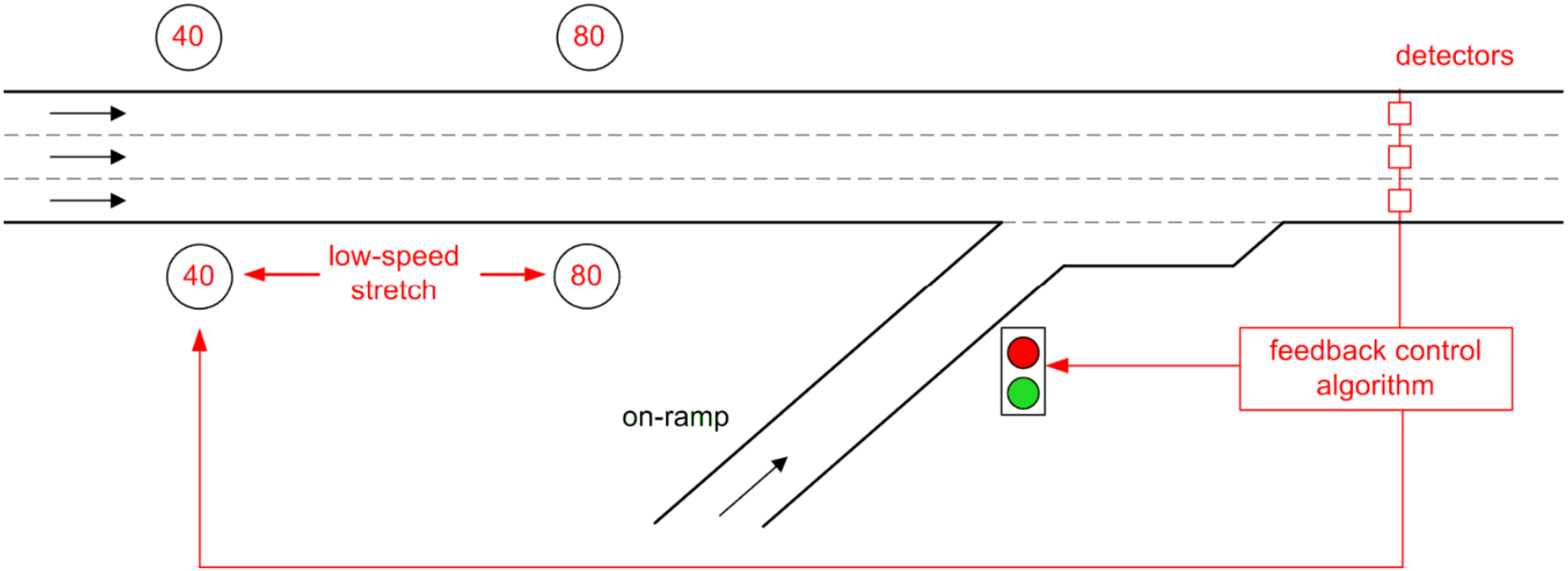
- Drivers' compliance can affect real implementations
- Studies with different percentages of compliance
- Currently VSL do not go lower than 60 km/h
- Driver behavior in different countries (USA, Europe, Asia, Africa)
- Awareness of drivers for homogeneous flows
  - Driving close to your leader/follower
  - When obtaining driving license
  - Abrupt speed changes can have dramatic congestion effects

Application example



Merging of two highways

Integration with ramp metering



Coordinated control: VSL and ramp metering

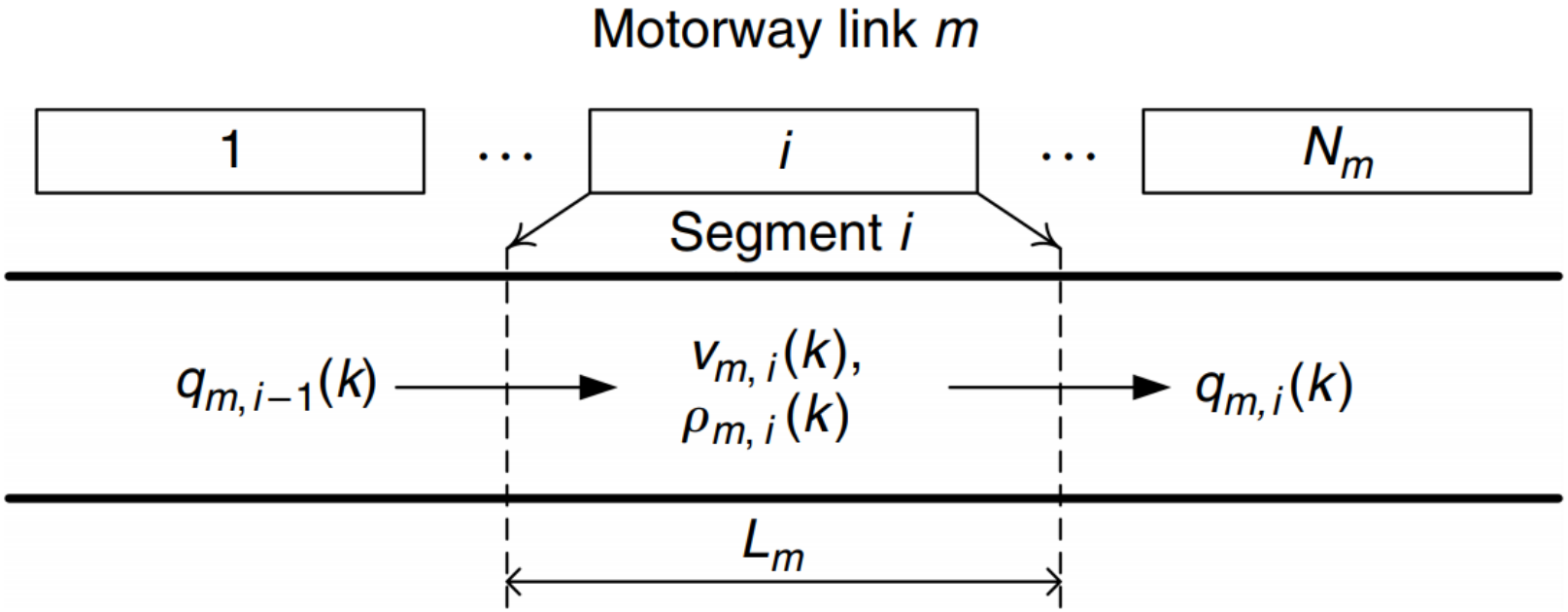
References for VSL control

Carlson, R.C., Papamichail, I., Papageorgiou, M., Messmer, A., 2010. Optimal motorway traffic flow control involving variable speed limits and ramp metering. Transportation Science, 44(2).

Carlson, R.C., Papamichail, I., Papageorgiou, M., Messmer, A., 2010. Optimal mainstream traffic flow control of large-scale motorway networks. Transportation Research Part C, 18(2).

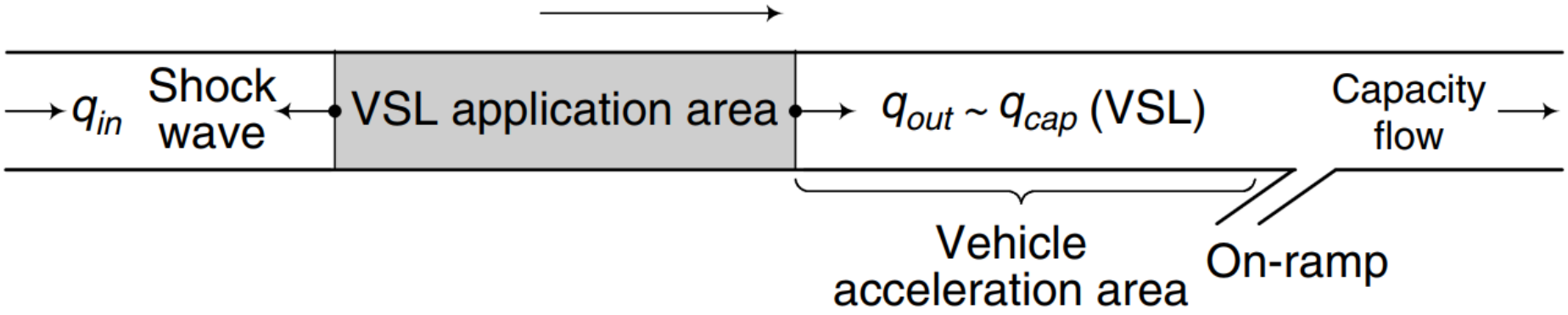
Carlson, R.C., Papamichail, I., Papageorgiou, M., 2011. Local feedback-based mainstream traffic flow control on motorways using variable speed limits. IEEE Transactions on Intelligent Transportation Systems, 12(4).

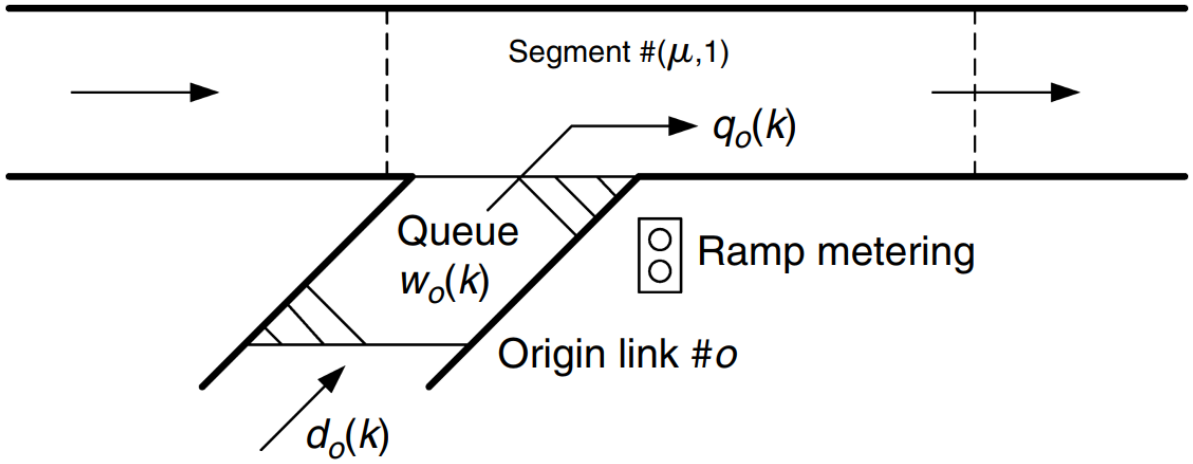
Application in different highway segments



In principle each segment could have a different VSL, in order to regularize congestion; clustering segments to mega-segments.

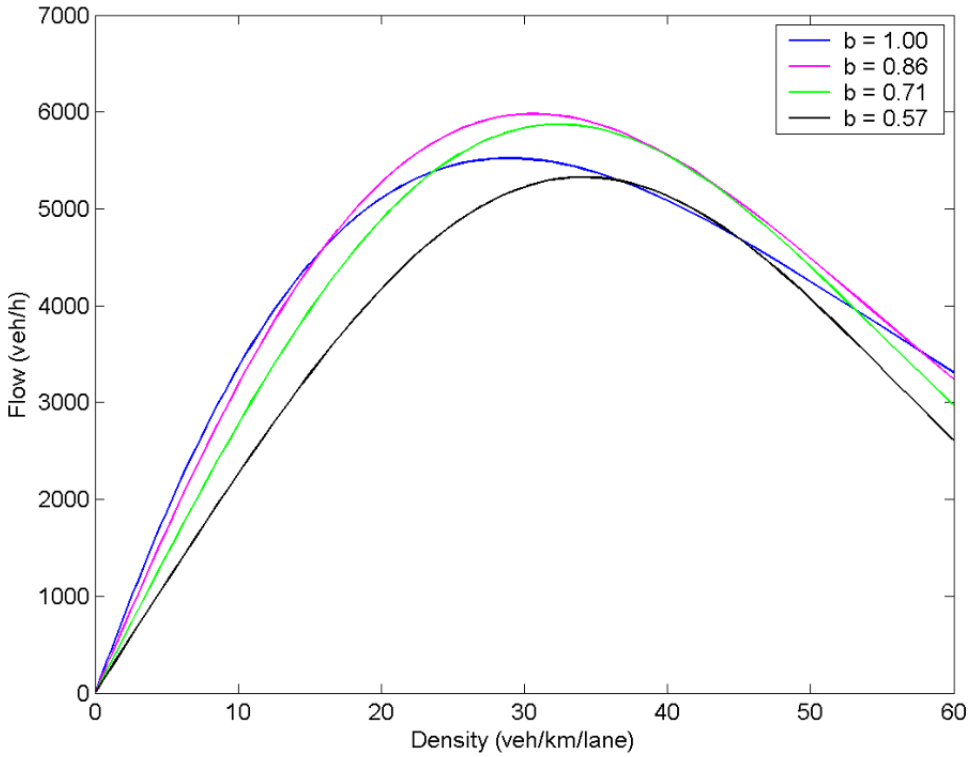
Application area in the mainline of the freeway





Ramp metering can be applied in coordination with VSL.

Control strategy design (optimization)



Modeling impact

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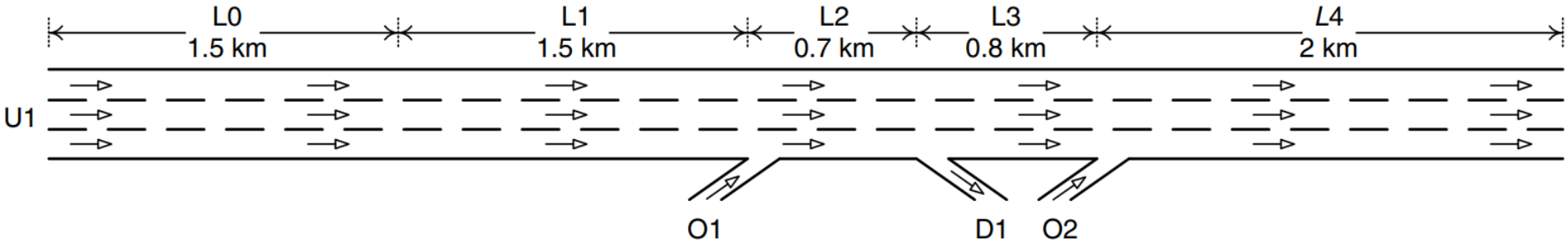
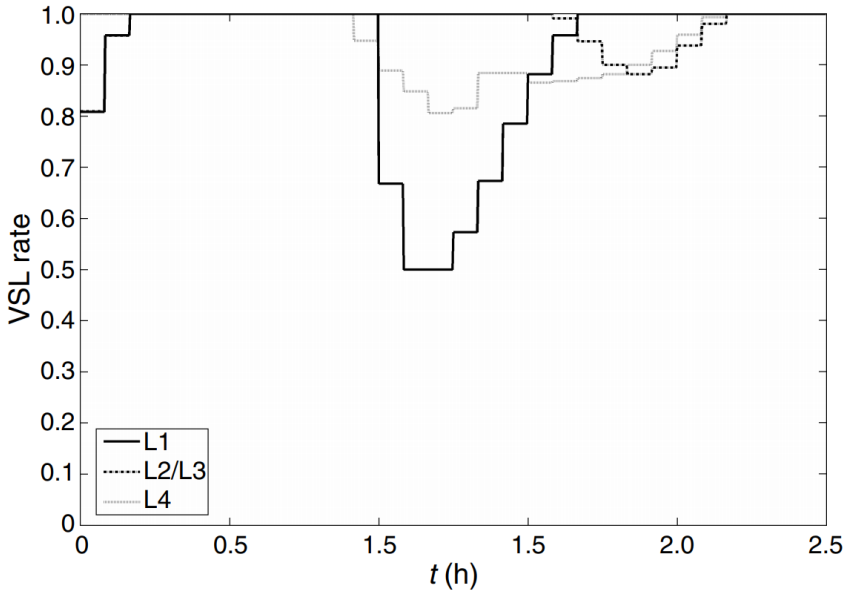
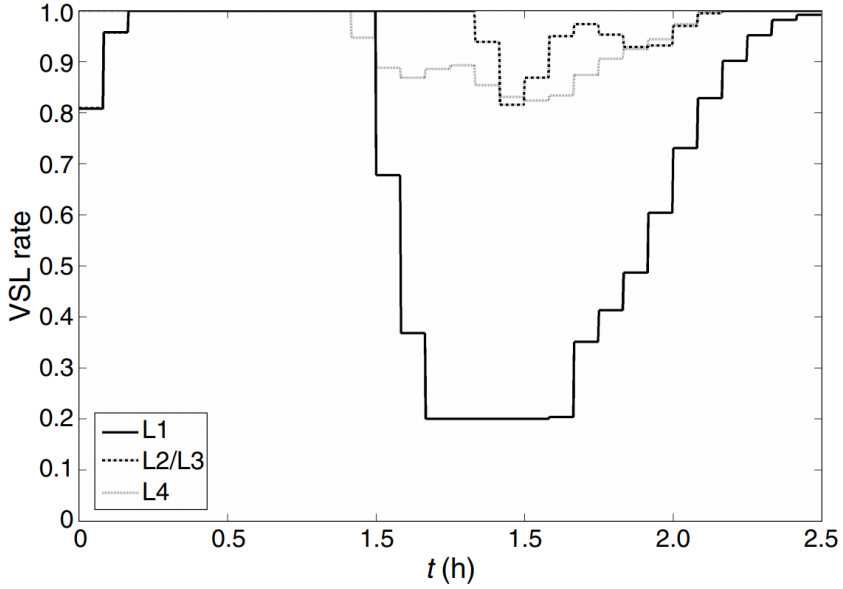
Control strategy design

A simple case study



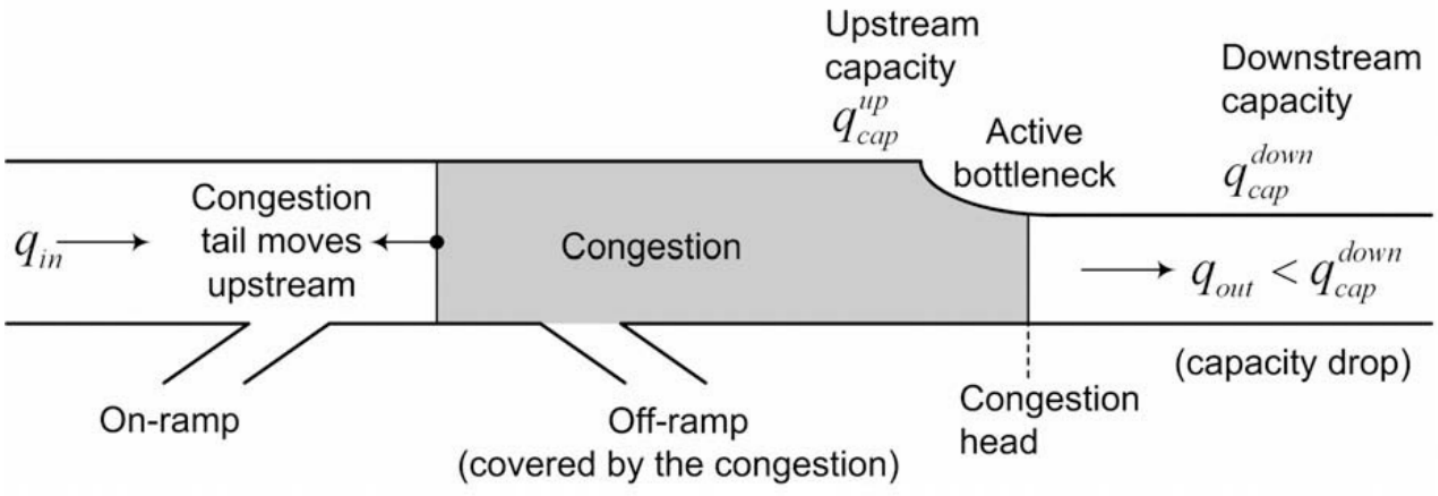


$\beta_{min} = 0.5$

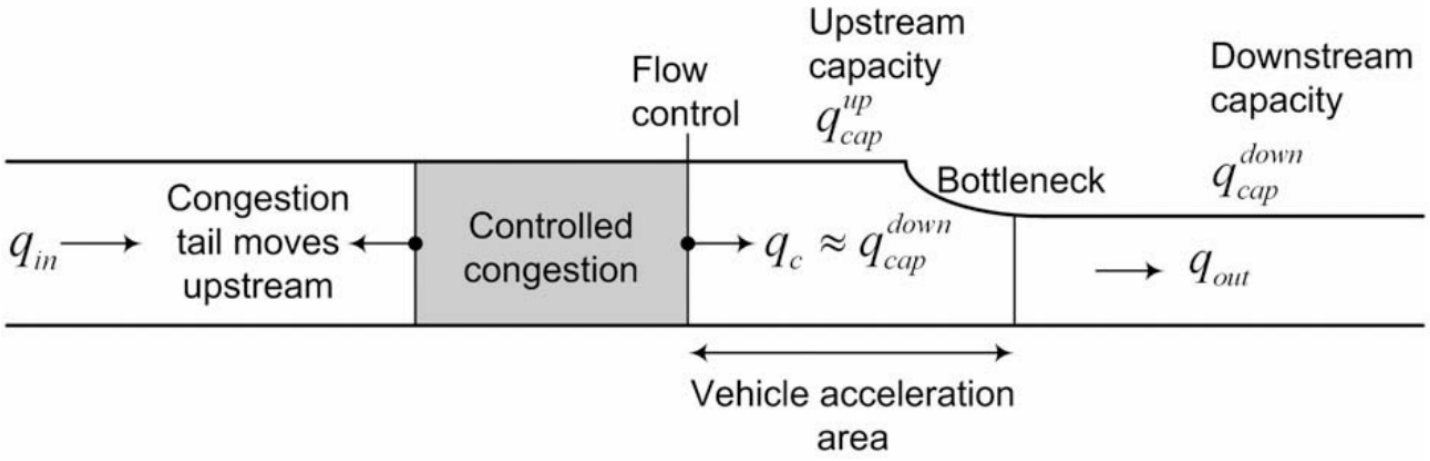


$\beta_{min} = 0.2$

Concept of mainline control

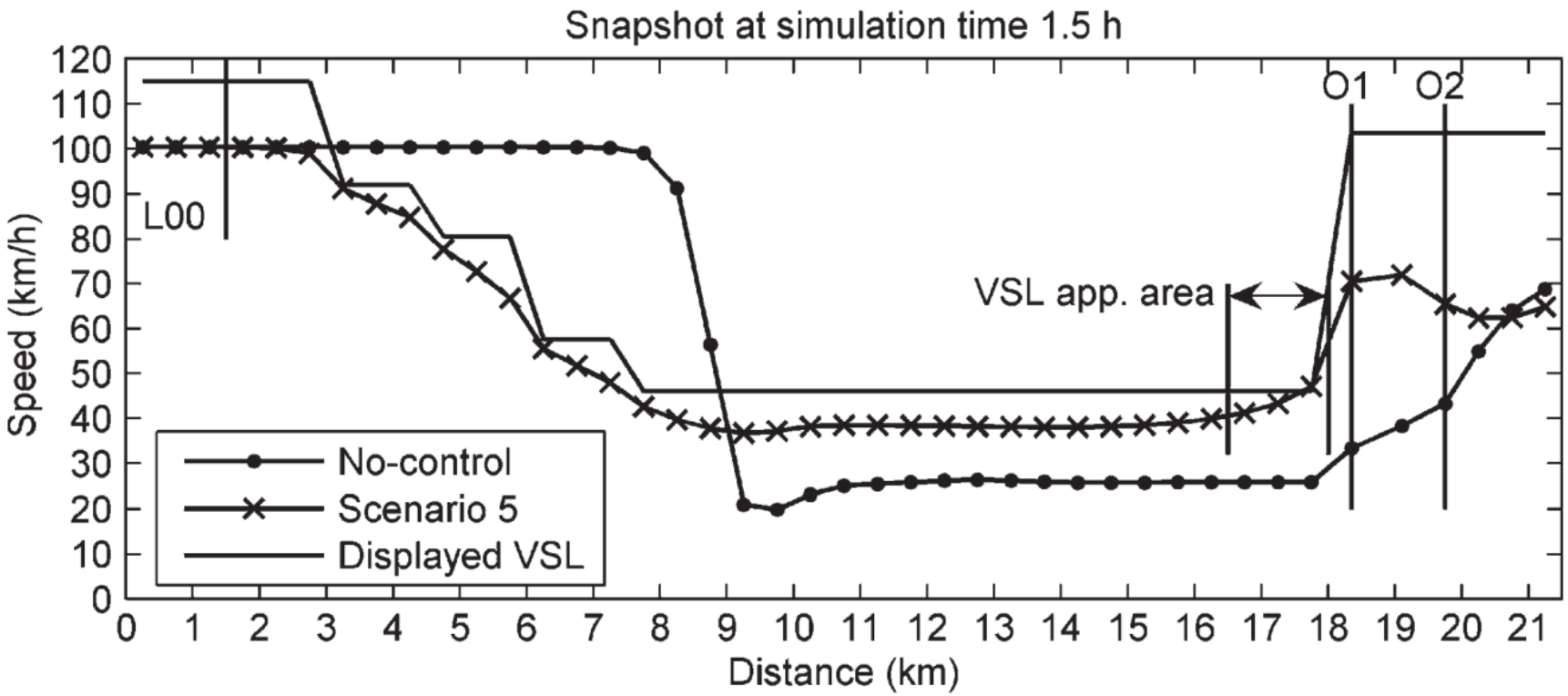


No Control

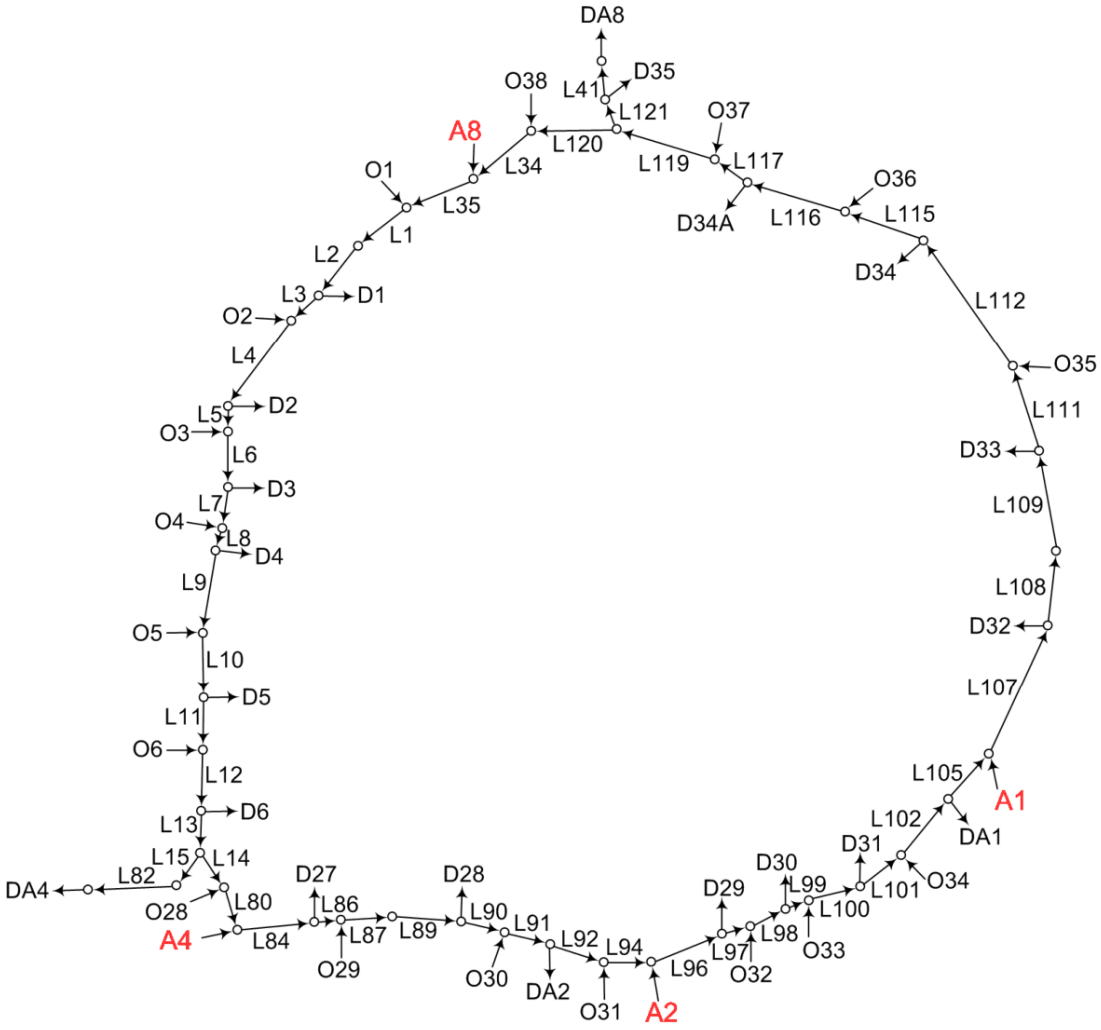


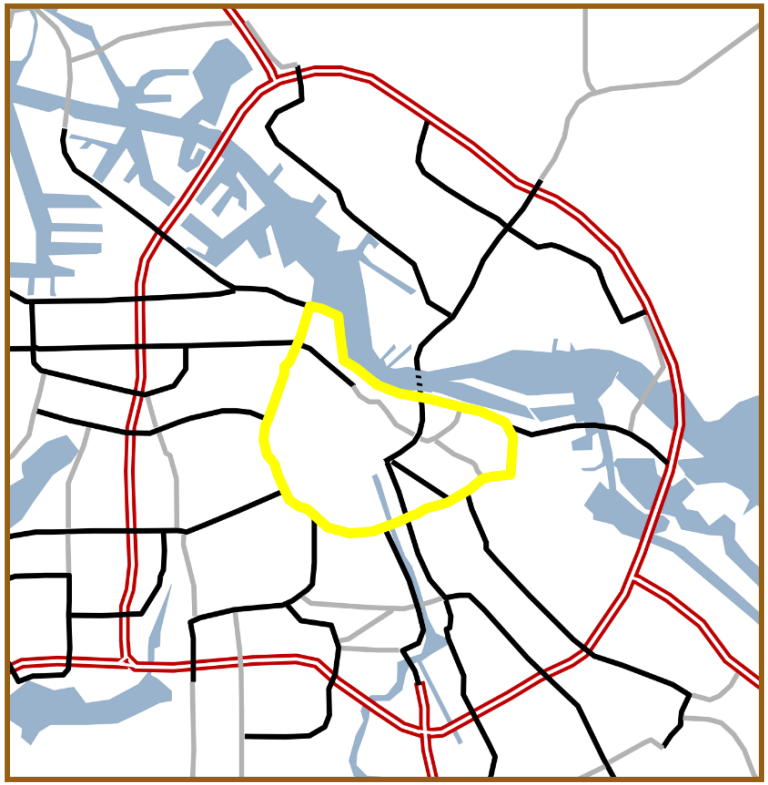
VSL

Simulation insights for VSL application

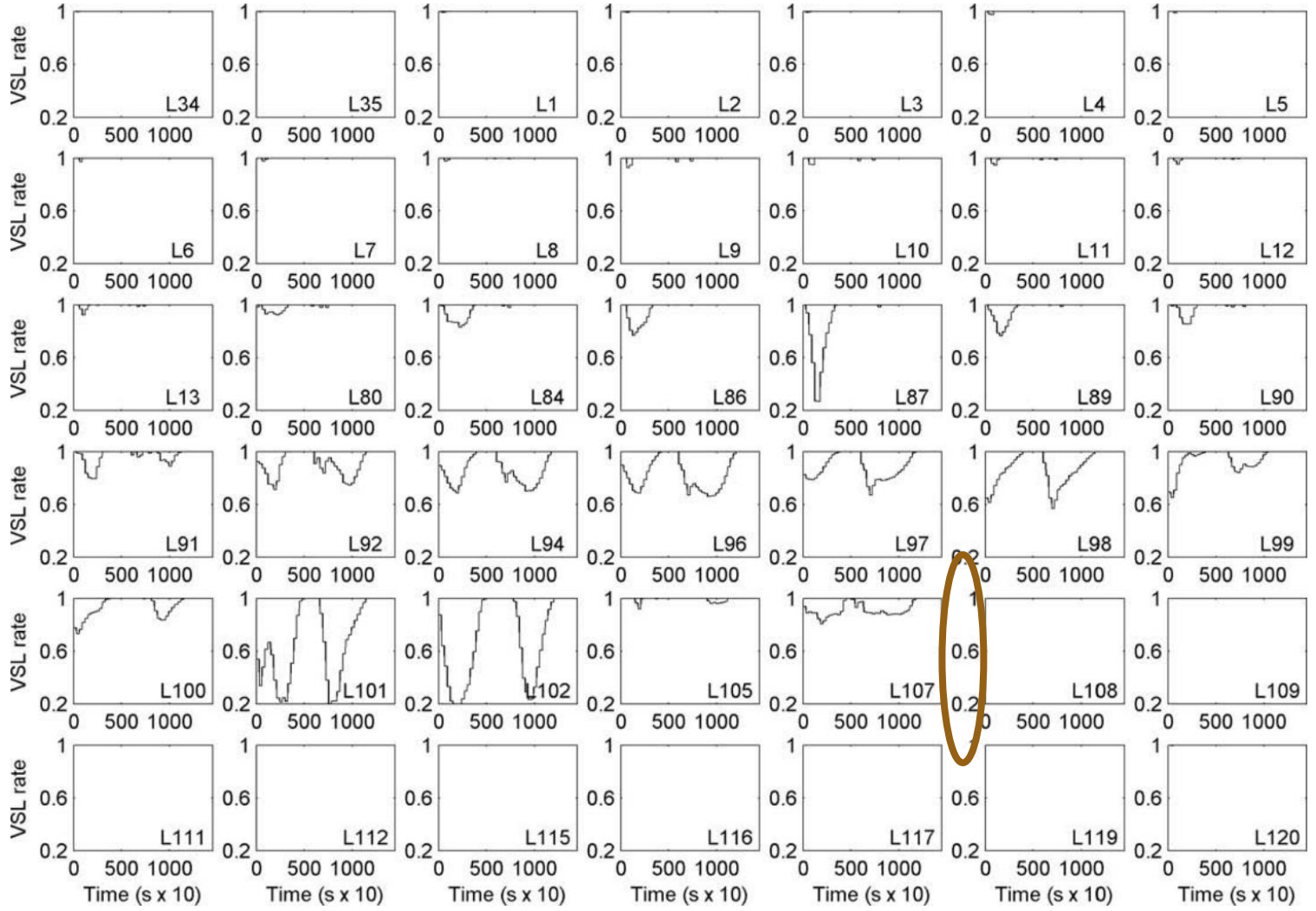


Amsterdam ring-road A10





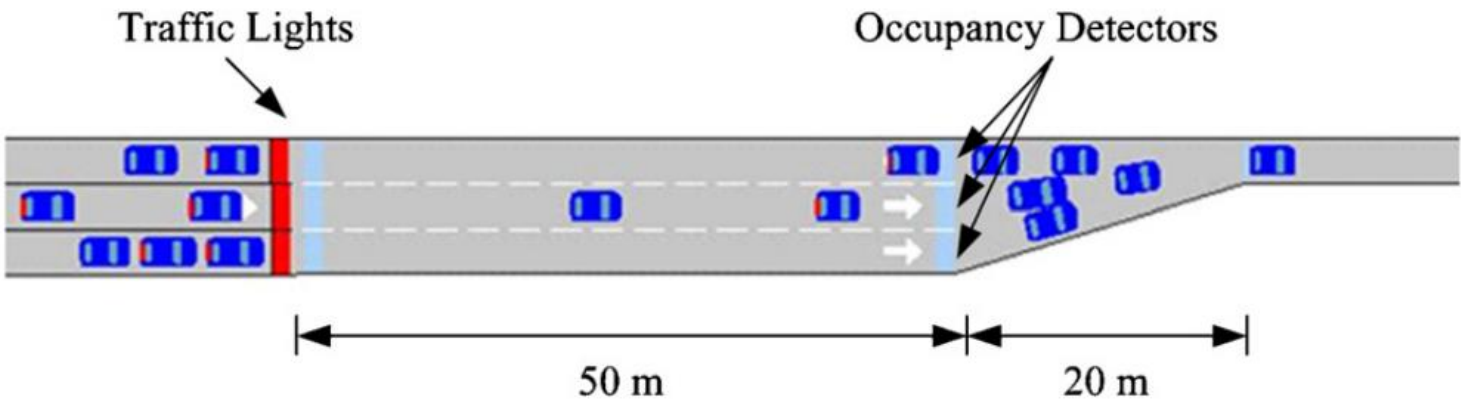
Optimal location for VSL (optimization)



Highway maintenance (work zones)

- Authorities need to maintain the highway infrastructure regularly (pavement, signs, telematics, etc.)
- Maintenance planning: optimization problem
- Sequential lane blockage
- Night works for less congestion / off-peak hours
- Temporary signals to accommodate traffic flow
  - Active bottlenecks
  - Optimal merging control
- Routing (next week)

Highway work zones



Reduced capacity because of work zones

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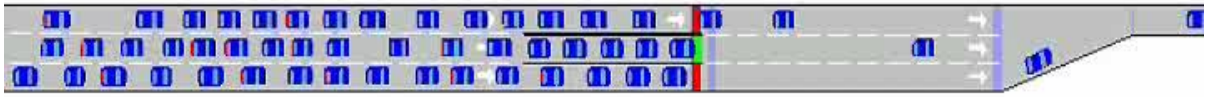
Same principle!

Work zone scenario (no control)

Work zone scenario (merging control)



Walking experiment Part 2: Ramp metering

Walking experiment Part 2: Ramp metering

Crowd Management (crowded events)

Crowd management (gating, and other)

Subway station: Santiago, Chile

Experiment: managing the masses

kouvelas@ethz.ch

Questions and discussion!