ETH zürich

Increasing the capacity of traffic networks with connected/autonomous vehicles

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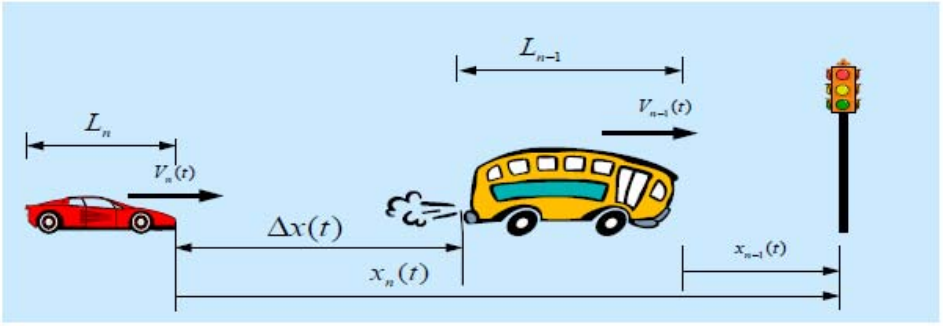
Traffic management in the era of connected and autonomous mobility

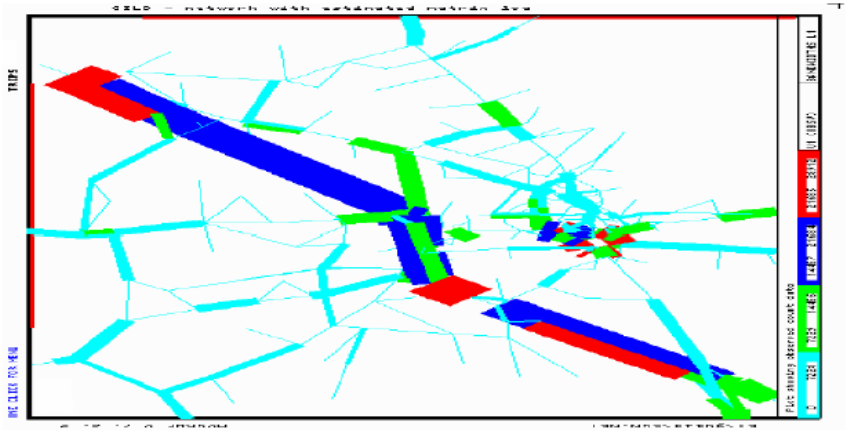
IVT – Institut für Verkehrsplanung und Transportsysteme

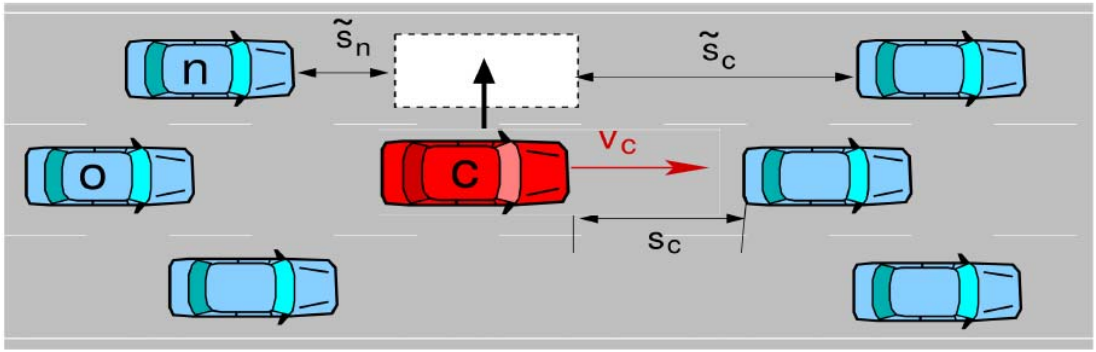
Agenda

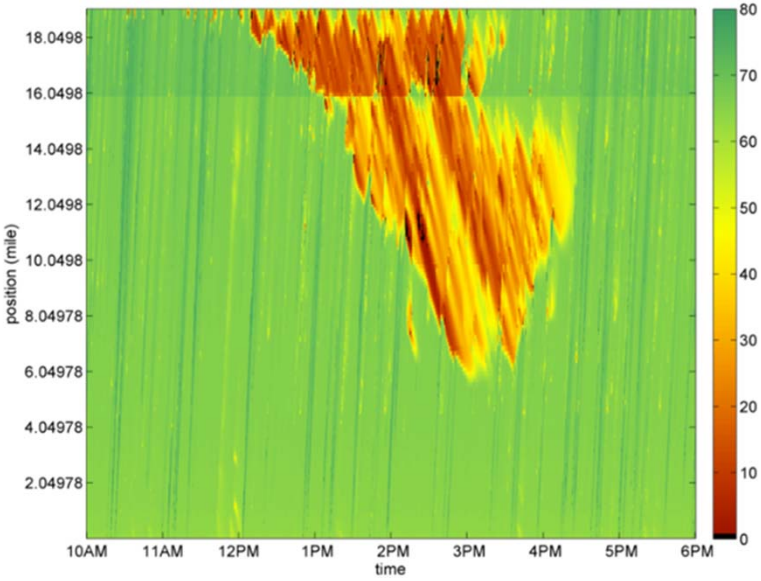
- Traffic flow theory 101
- Traffic management
  - Why capacity is important?
- Case studies
  - Highway mainline control
  - Ramp metering
  - Variable speed limits (VSL)
  - Urban traffic signal control
- Implications of connected and autonomous vehicles
  - Capacity, anisotropy, safety, traffic flow

Different scales of traffic modeling

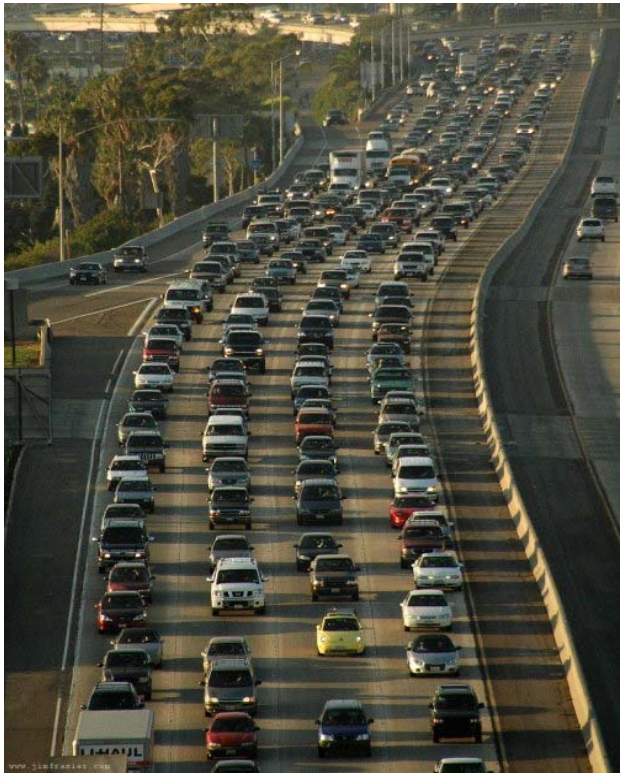


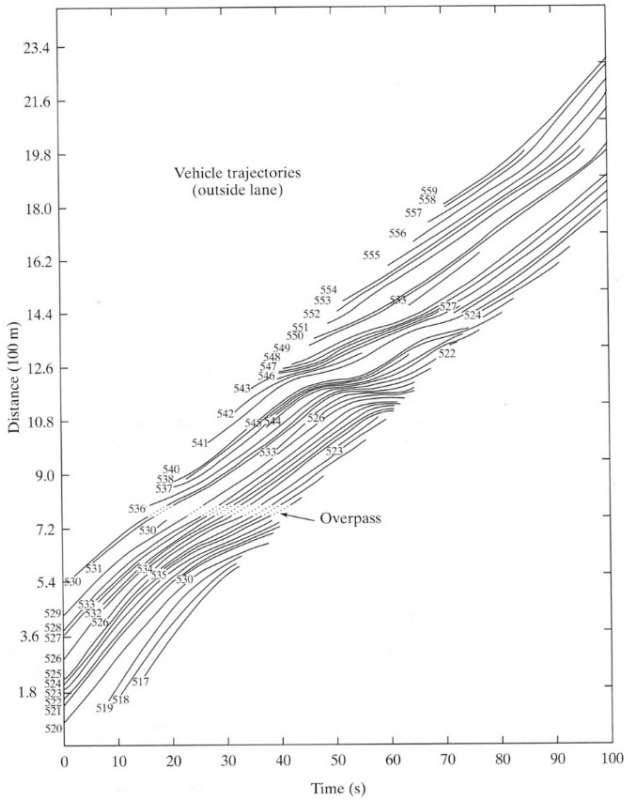






Traffic flow as a fluid (or not?)



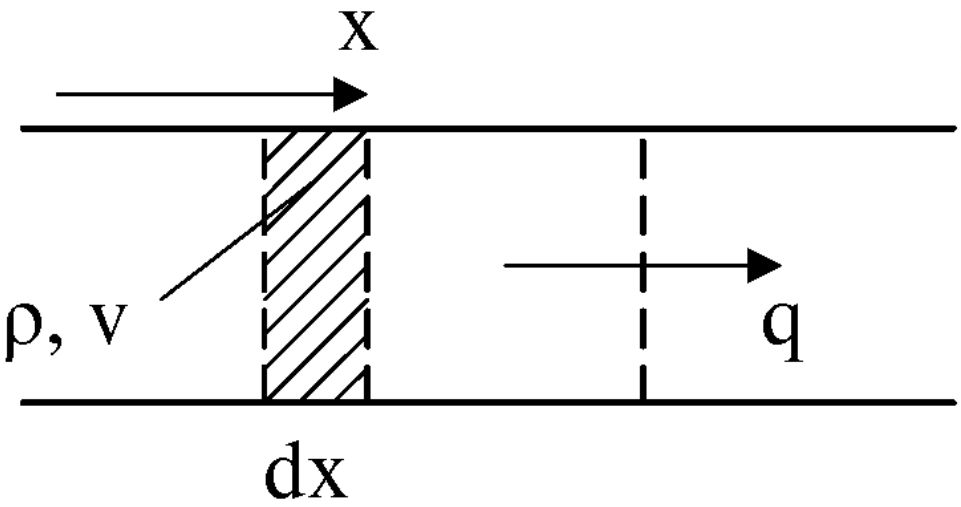


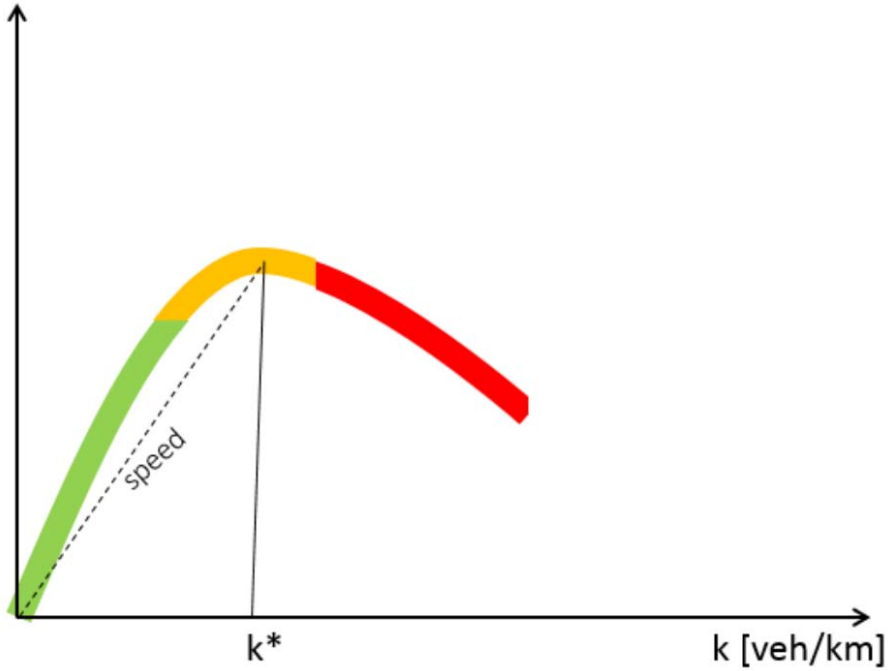
Traffic flow on roads has some similarities to fluid mechanics, but also some differences!

Macroscopic modeling

Macroscopic traffic variables:

- traffic density ***ρ(x, t)*** in *veh/km*
- traffic volume ***q(x, t)*** in *veh/h*
- mean speed ***v(x, t)*** in *km/h*





mathematical abstraction

Analogy to fluids: LWR theory

Lighthill-Whitham-Richards (LWR)

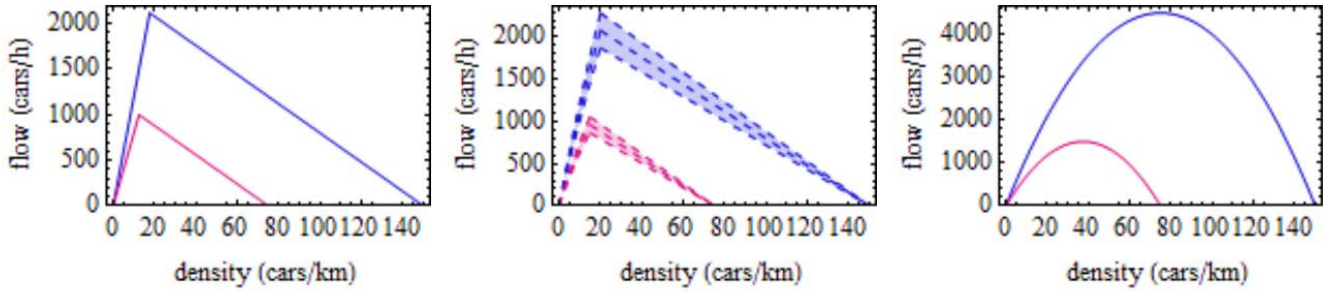
Conservation law derived from fluid mechanics:

$$\frac{\partial \rho(x,t)}{\partial t} + \frac{\partial \phi(x,t)}{\partial x} = 0$$

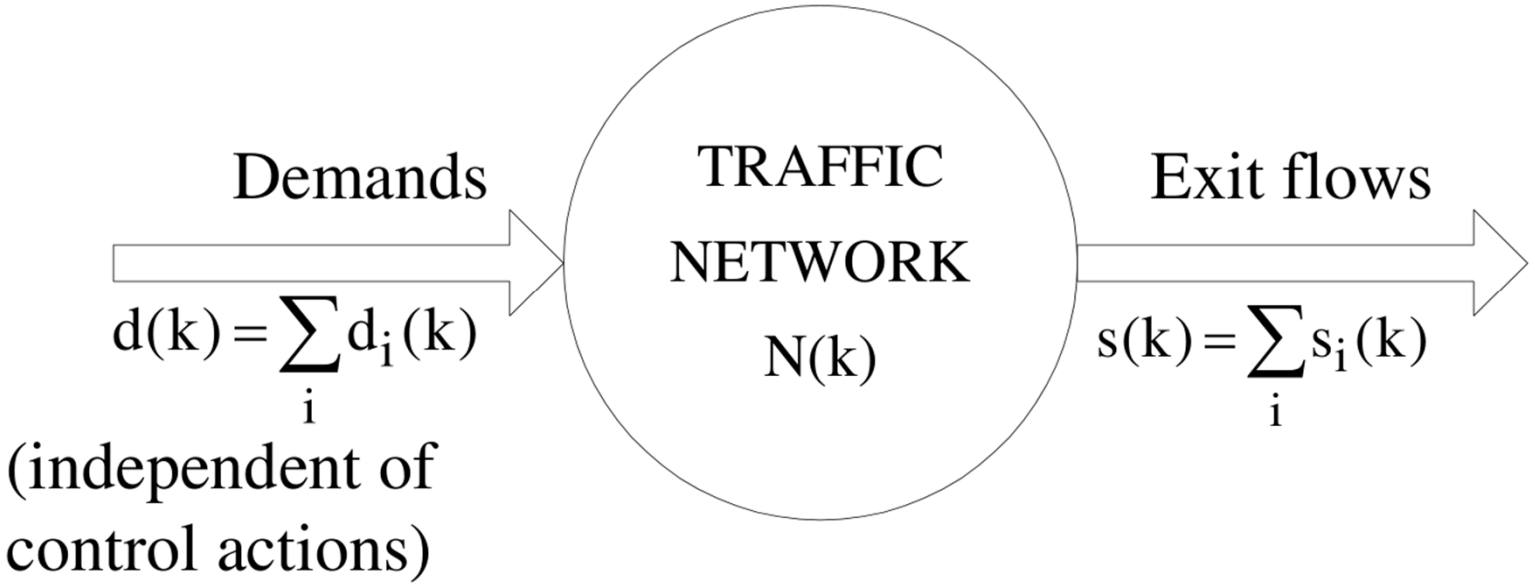
$\rho(x,t)$: density at location x and time t
$\phi(x,t)$: flow at location x and time t

Numerical discretization in space and time consistent with LWR model.

...	(ρ_1, φ_1, v_1)	(ρ_2, φ_2, v_2)	(ρ_3, φ_3, v_3)	...

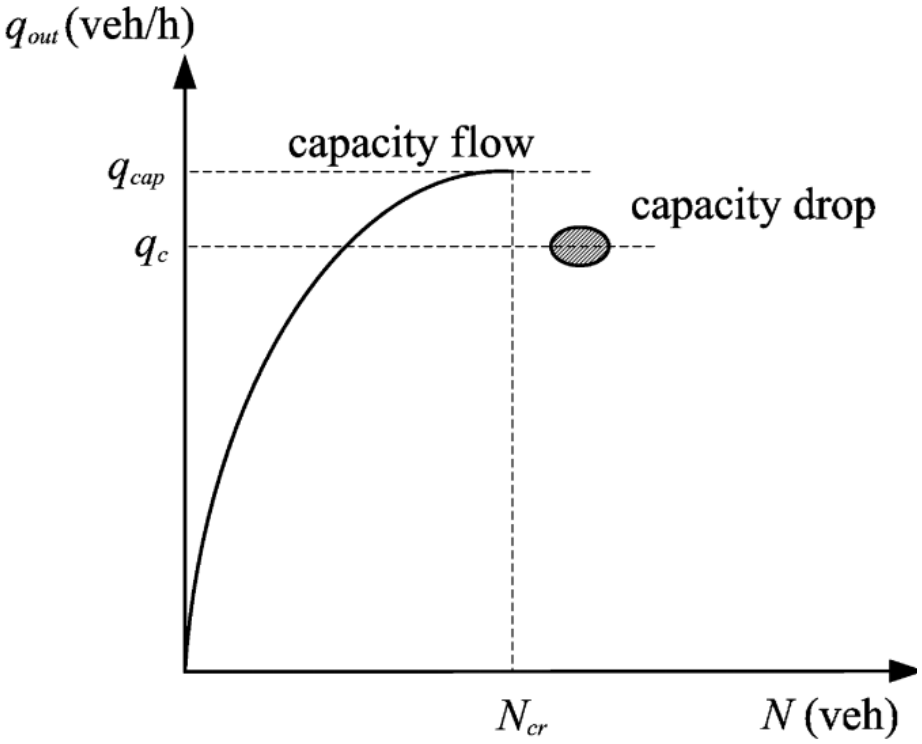


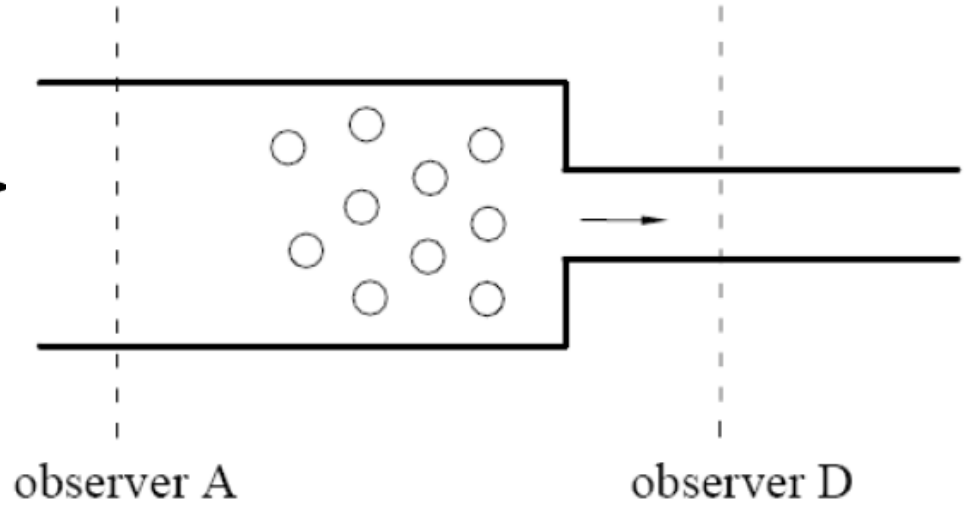
Traffic network: Demand-Supply system



Maximize Supply → Minimize Delays

Capacity drop!

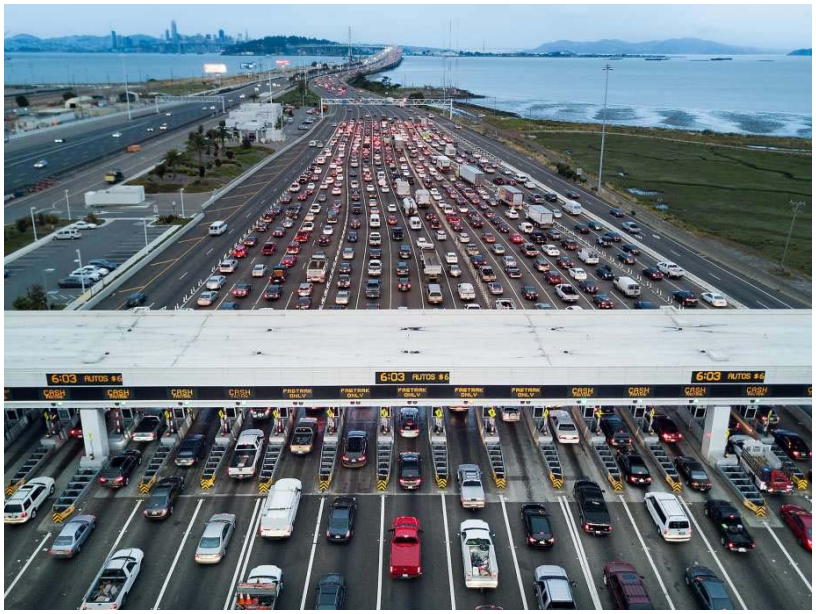


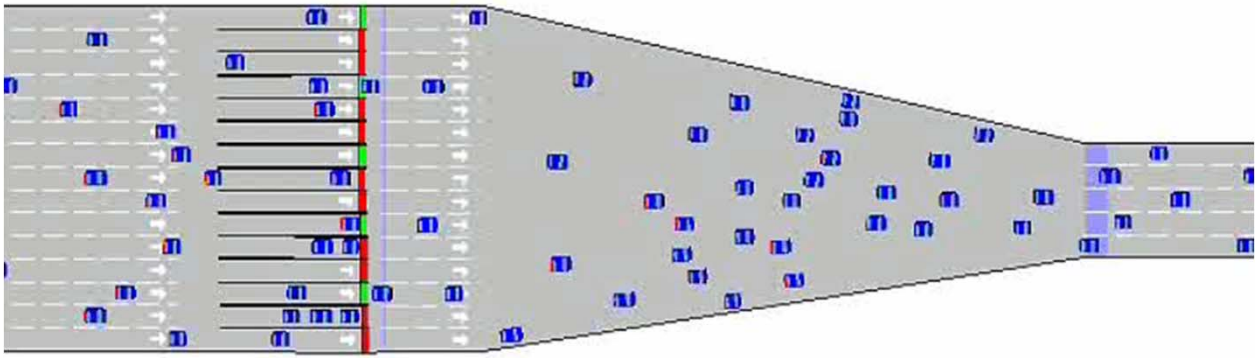


FD of a merging area

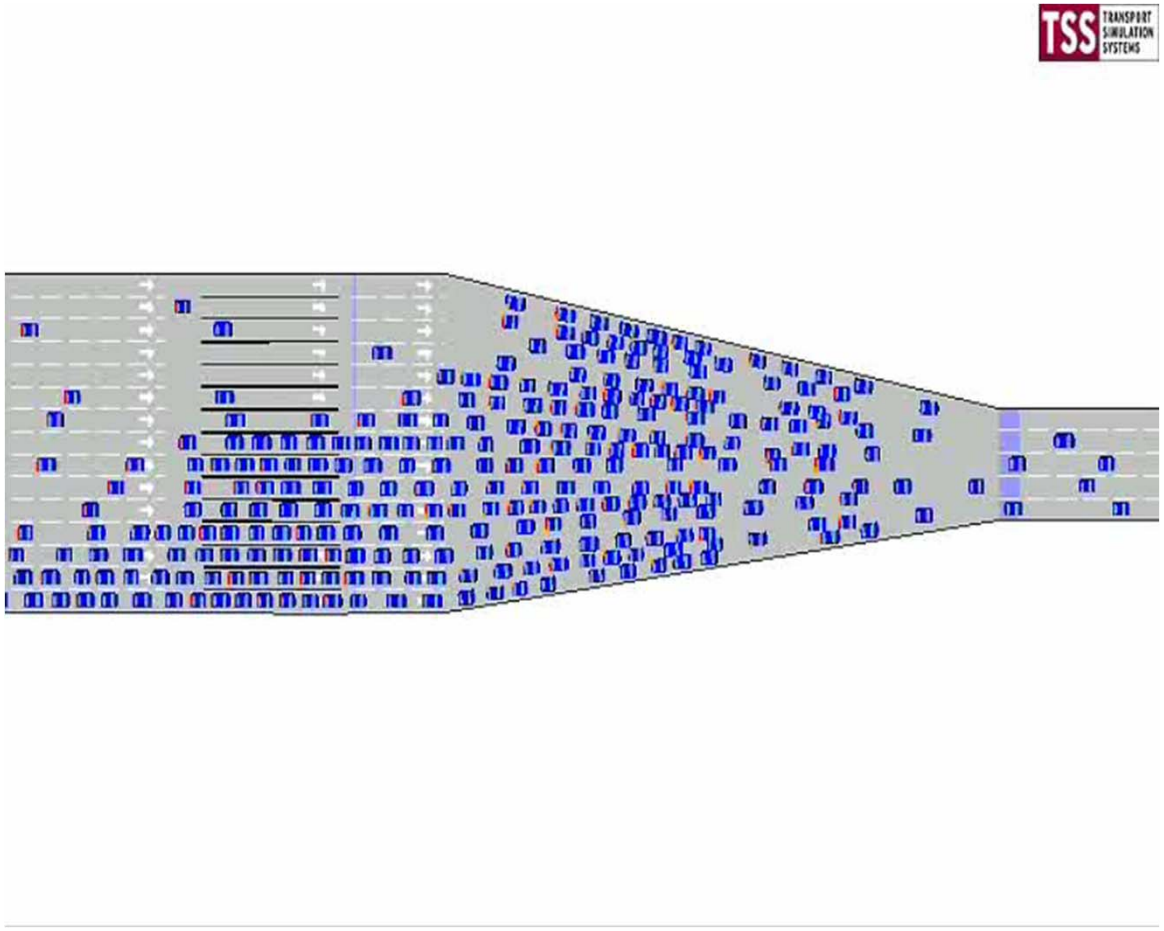
Case study: Bay Bridge, Bay Area

Bay bridge toll plaza set-up



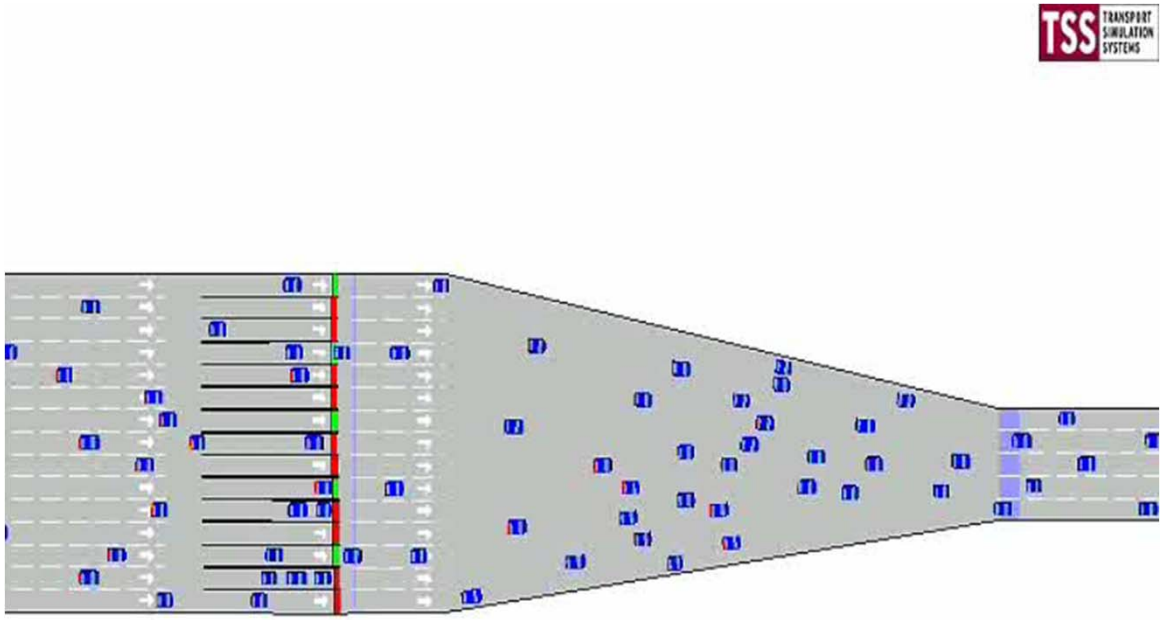


Simulation replication (NC)



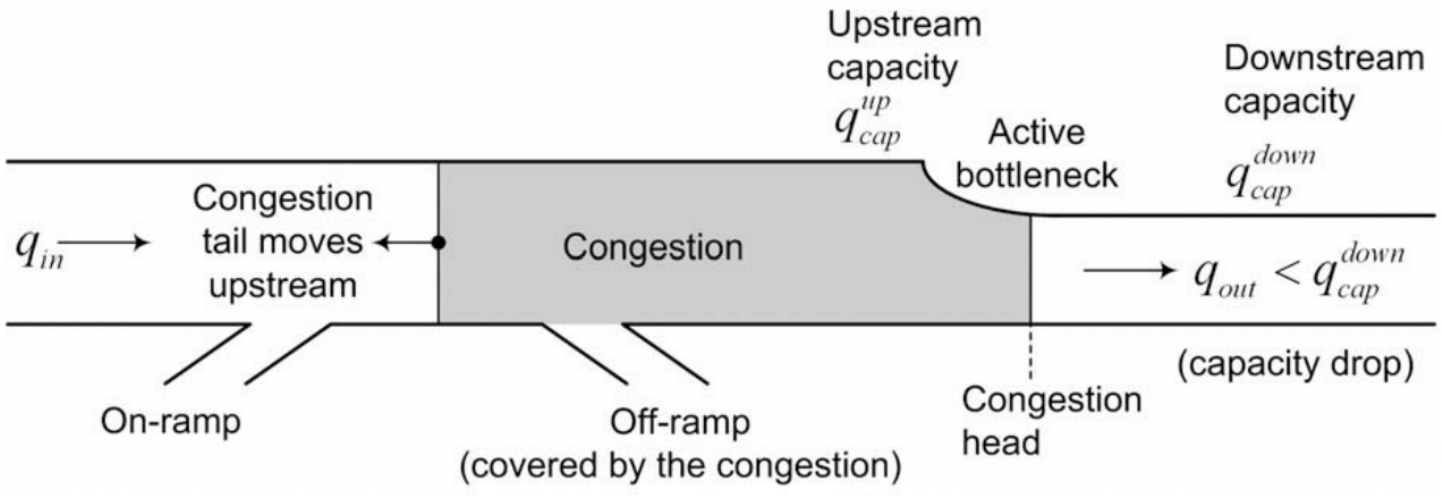
Papageorgiou, M., et al., 2008. Real-time merging traffic control with applications to toll plaza and work zone management. Transportation Research Part C, 16 (5).

Simulation replication (metering)

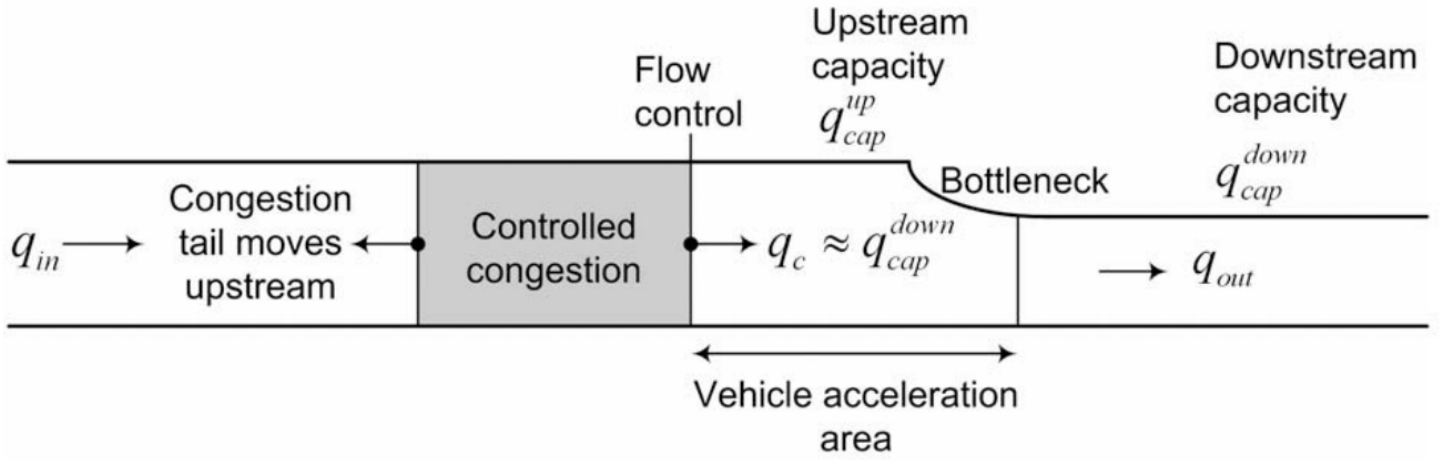


Papageorgiou, M., et al., 2008. Real-time merging traffic control with applications to toll plaza and work zone management. Transportation Research Part C, 16 (5).

Can we achieve the same result with VSL?



No Control



VSL

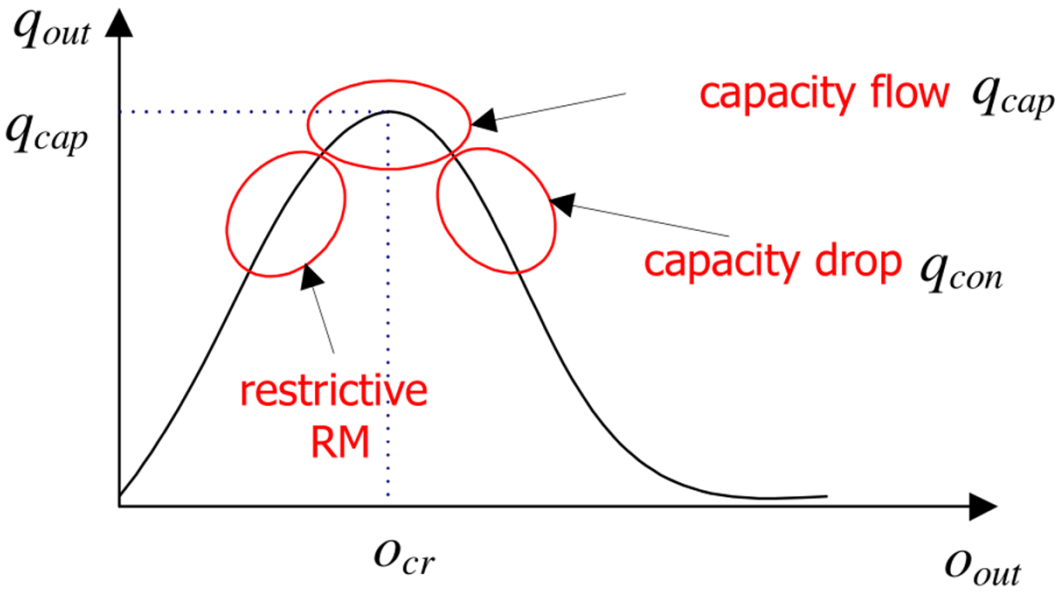
Evacuation of SF by using the bridges

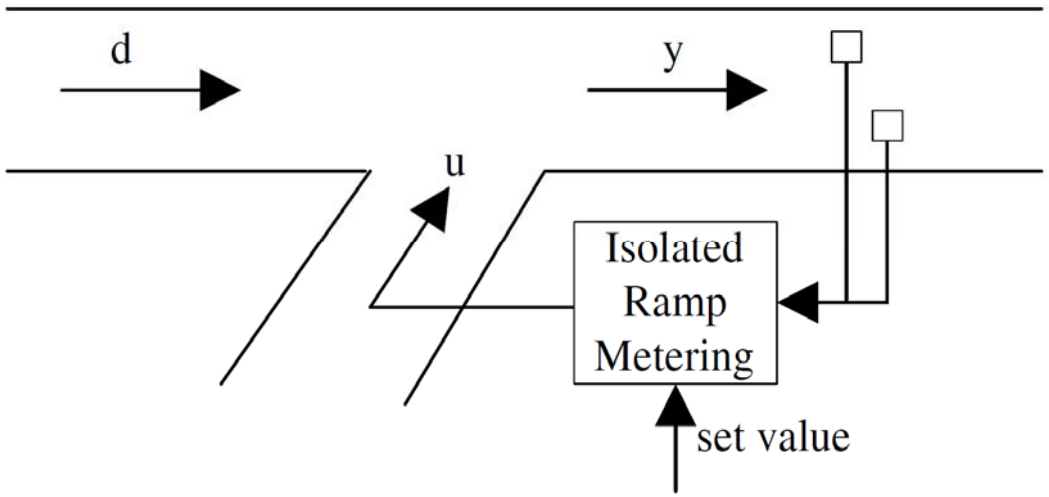
The bridges can serve 40’000 veh/h.

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

Can I do it in 3 hours?

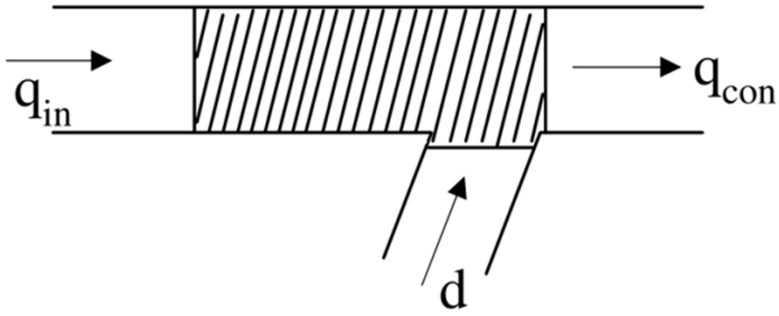
Ramp metering





Ramp metering and capacity

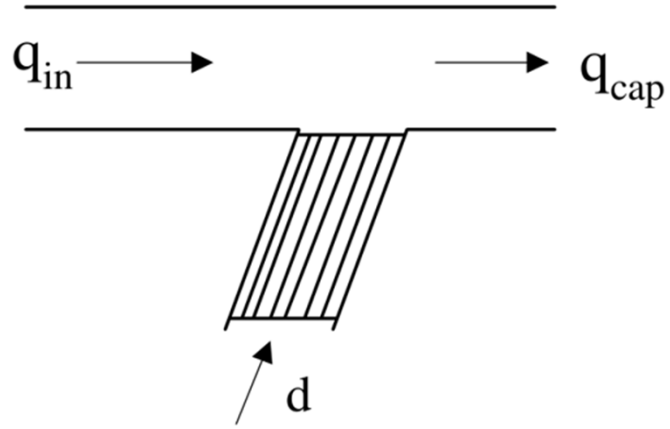
no control



steady-state performance improvement:

$$\Delta\bar{T}_s = \lim_{T\to\infty} \Delta T_s = \frac{T_s^{nc} - T_s^{rm}}{T_s^{nc}} = \frac{q_{cap} - q_{con}}{q_{in} + d - q_{con}}$$

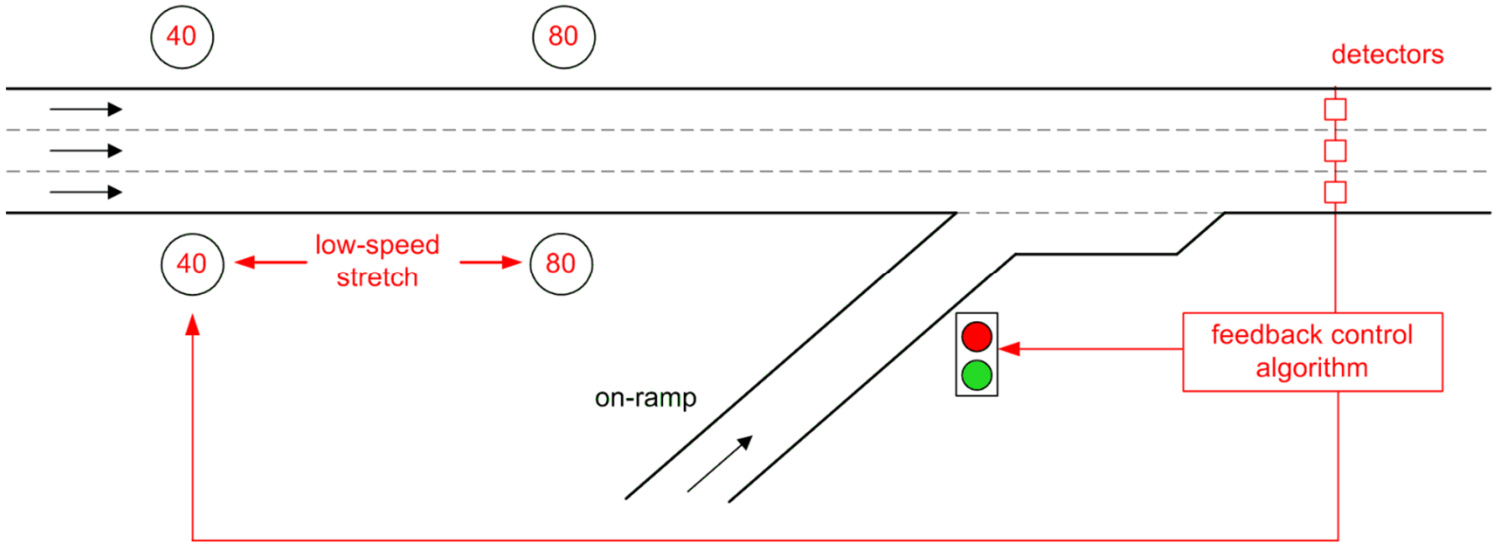
ramp metering



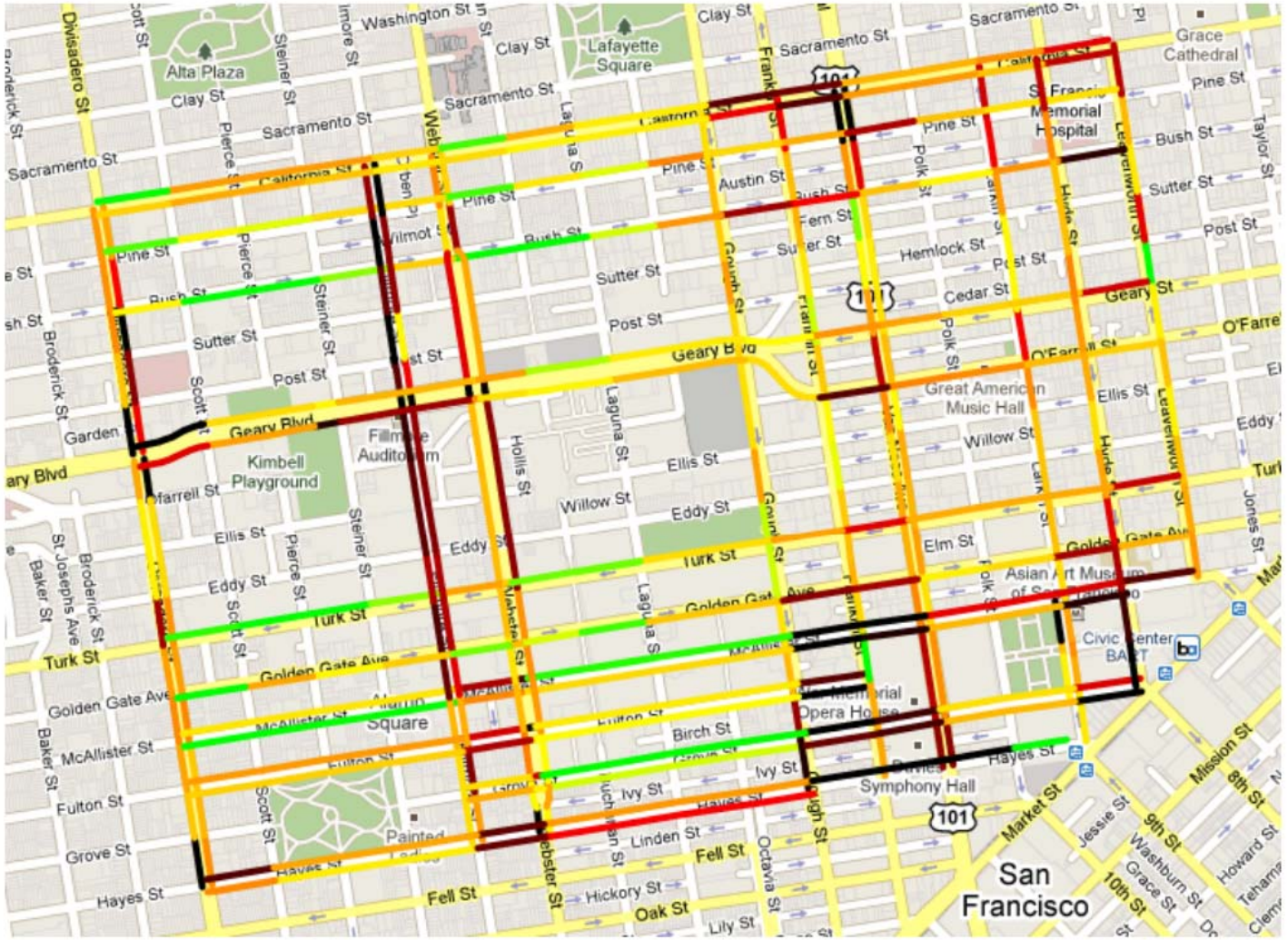
e.g. $q_{con} = 0.95\ q_{cap}$; $q_{in}+d = 1.2\ q_{cap}$

$\rightarrow \Delta T_s \triangleq 20\%$

Coordinated VSL and ramp metering control

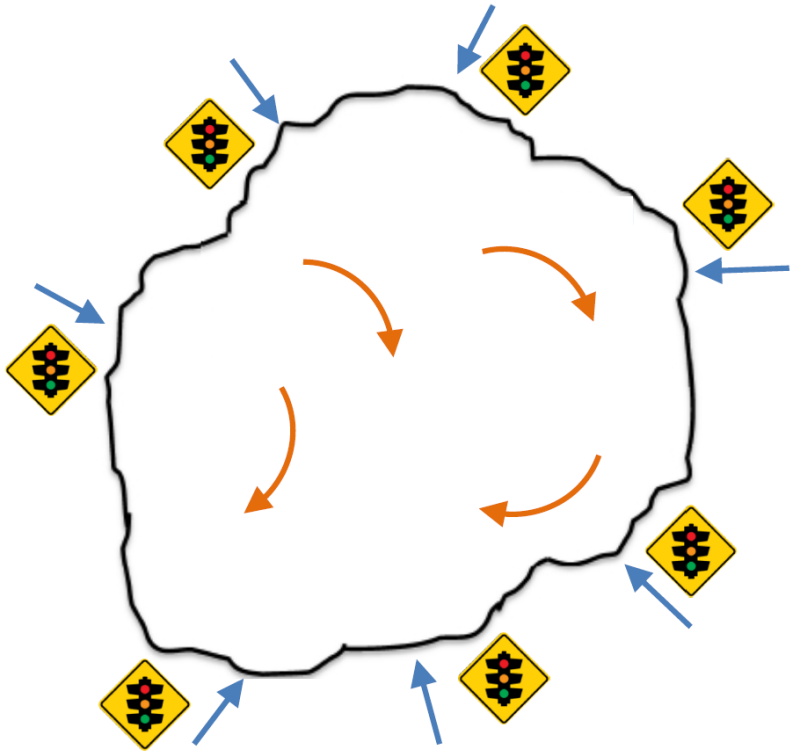


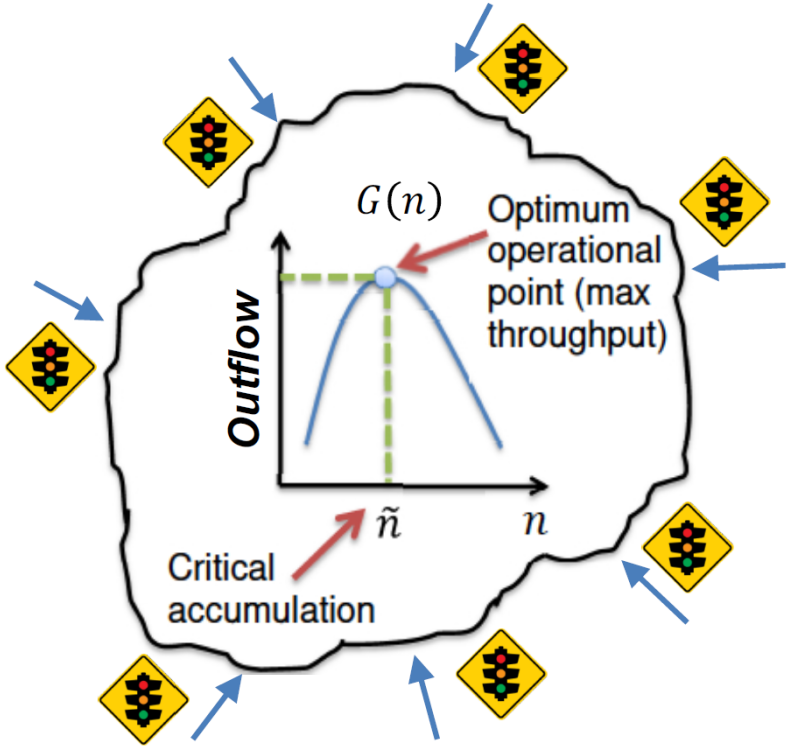
Controlling the traffic lights of a city



Traffic Management Center (TMC)

Single region control (gating)

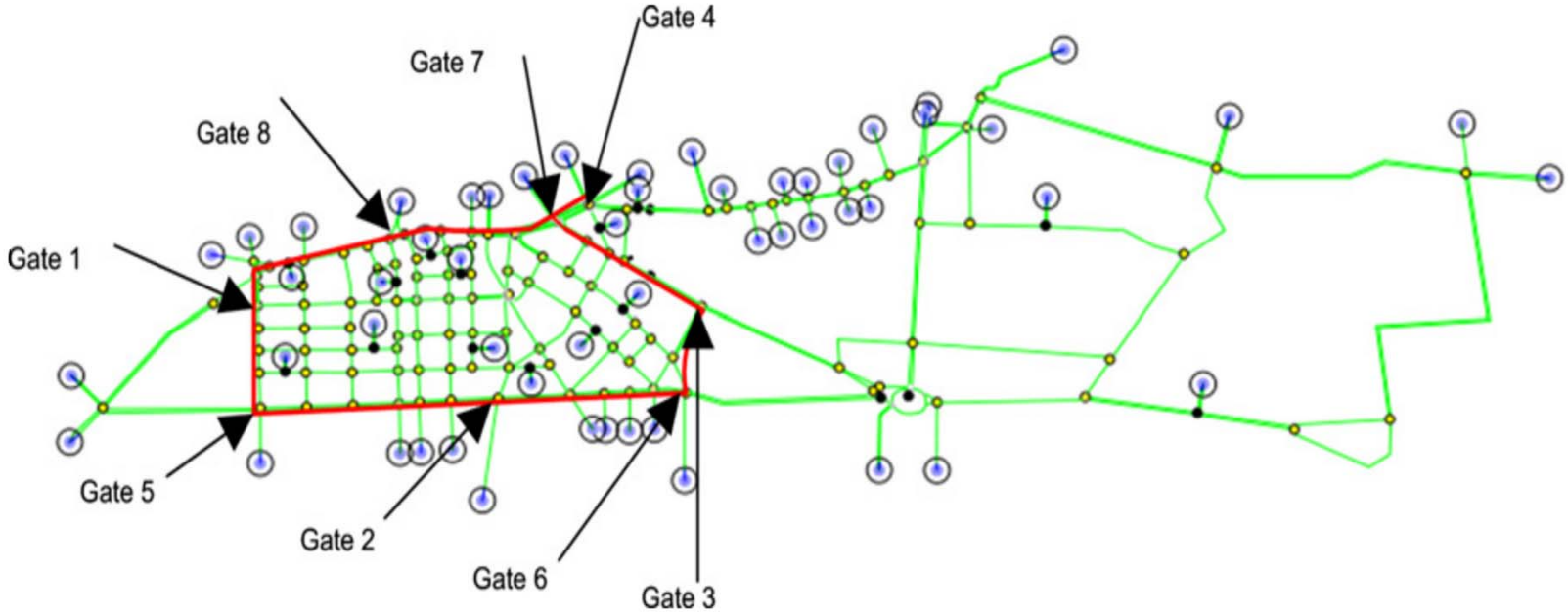


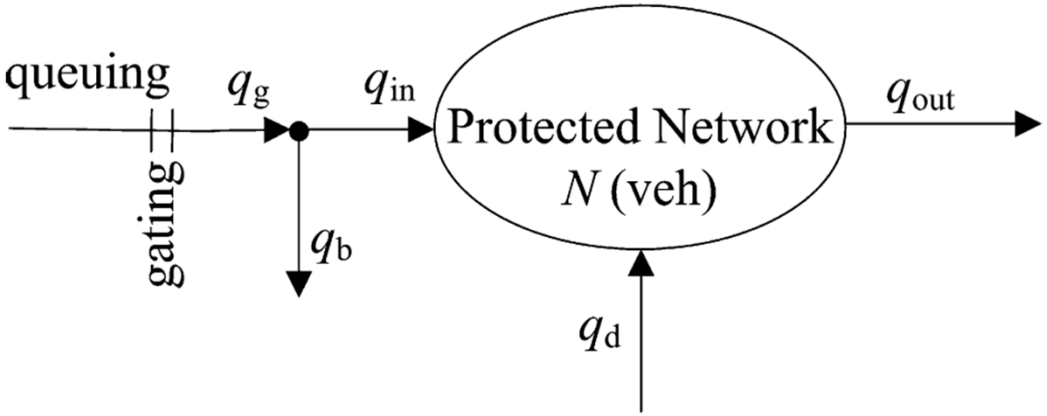


Internal inflow (uncontrolled)

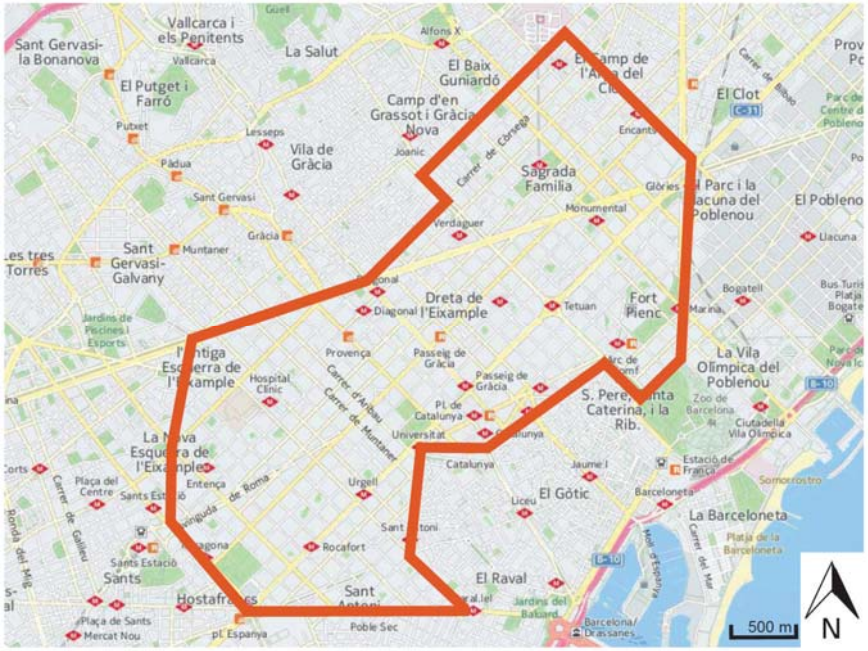
External inflow (controlled)

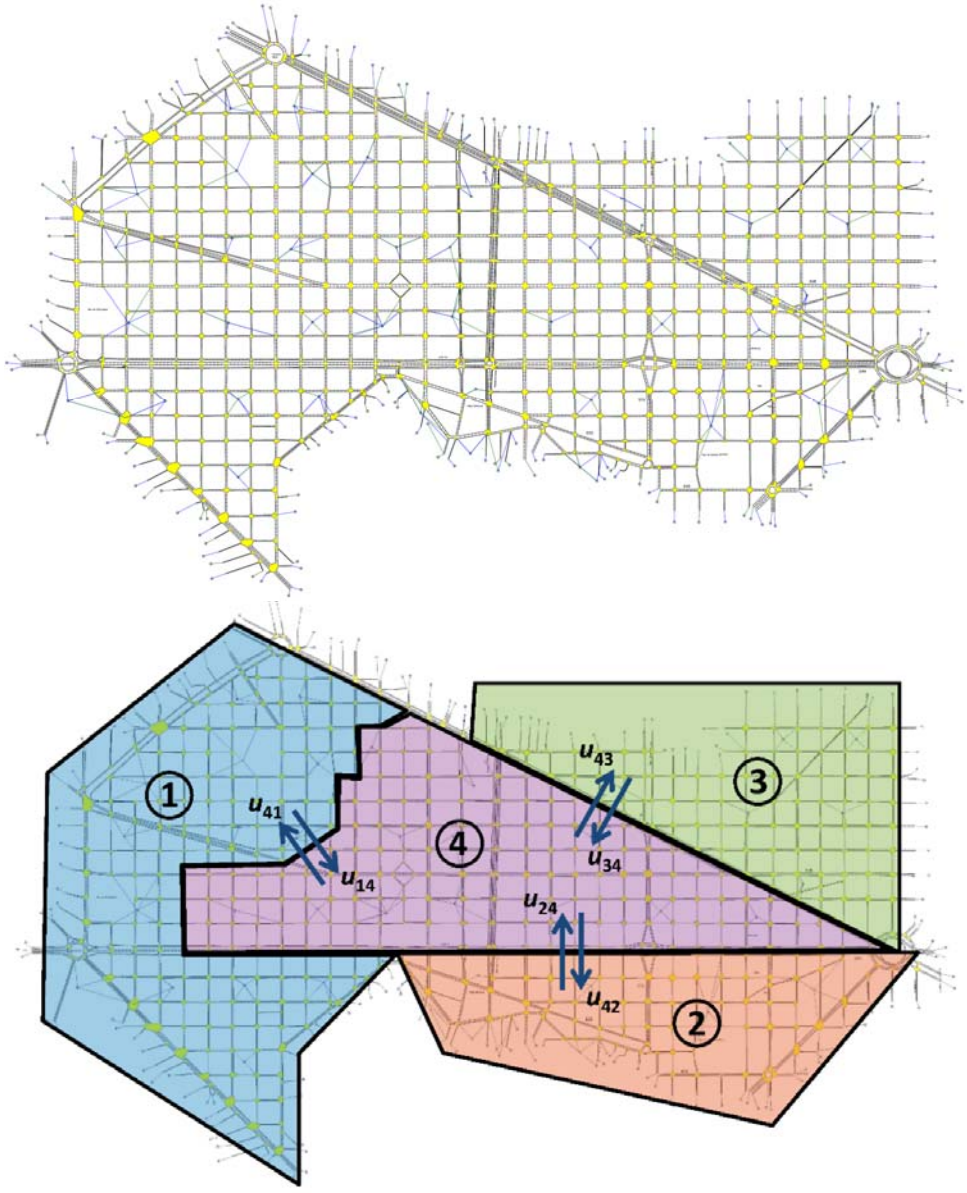
Case study: Chania network, Greece





Extension to multiple regions

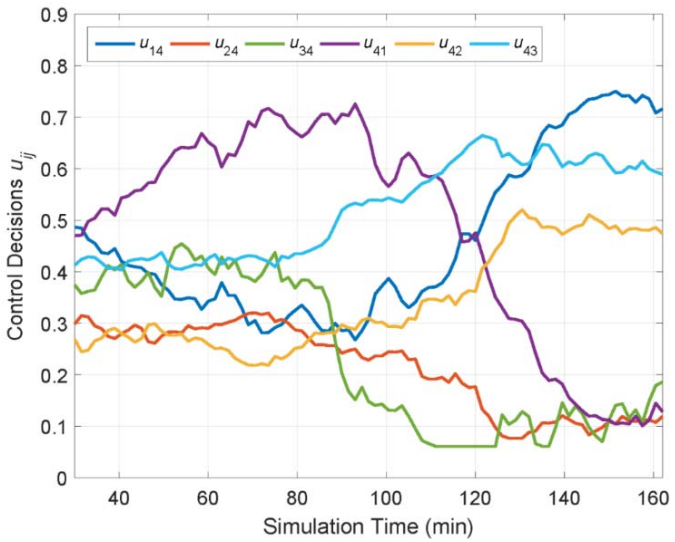


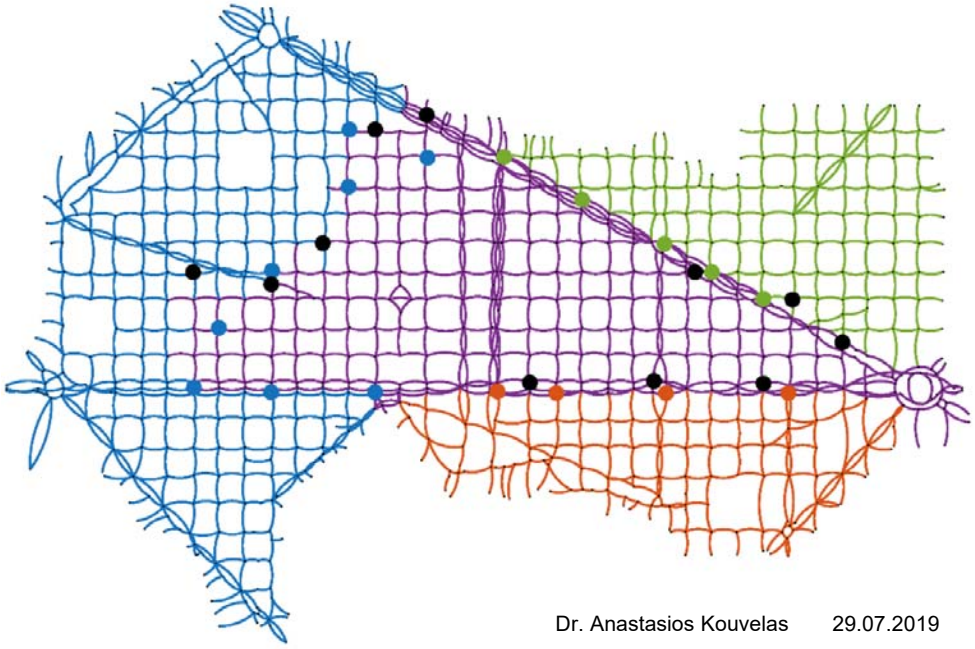


Multivariable PI regulator

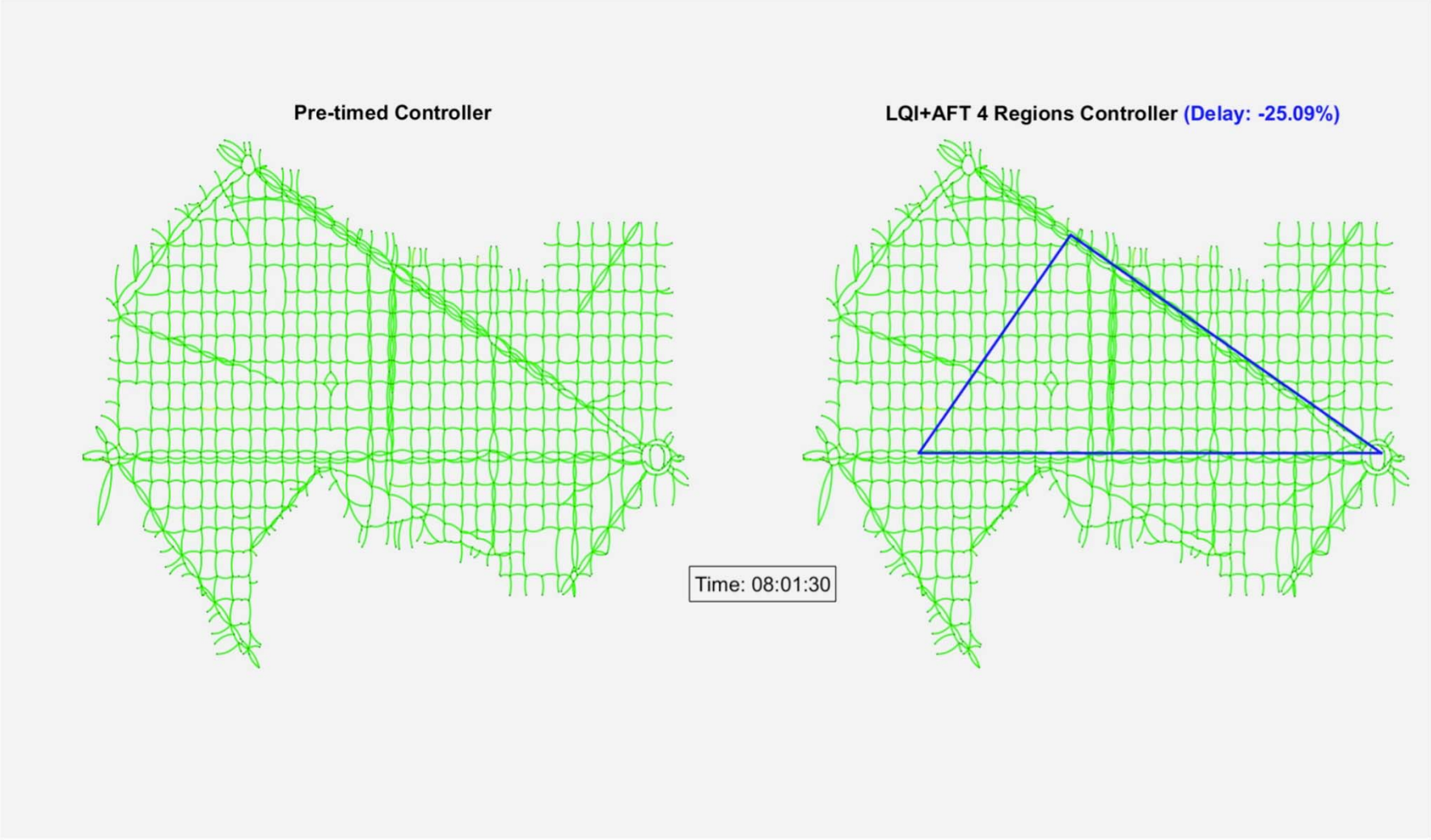
$$\mathbf{u}(k) = \mathbf{u}(k-1) - \mathbf{K_P}\left[\mathbf{n}(k) - \mathbf{n}(k-1)\right] - \mathbf{K_I}\left[\mathbf{n}(k) - \hat{\mathbf{n}}\right]$$

- $\mathbf{u}(k)$: control vector of $u_{ij}(k), \forall i \in \mathcal{N}, j \in \mathcal{N}_i$
- $\mathbf{n}(k) \in \mathbb{R}^N$: state vector of region accumulations $n_i(k), \forall i \in \mathcal{N}$
- $\hat{\mathbf{n}} \in \mathbb{R}^N$: vector of the set points $\hat{n}_i$ for each region i
- $\mathbf{K_P}, \mathbf{K_I}$: proportional and integral gains.

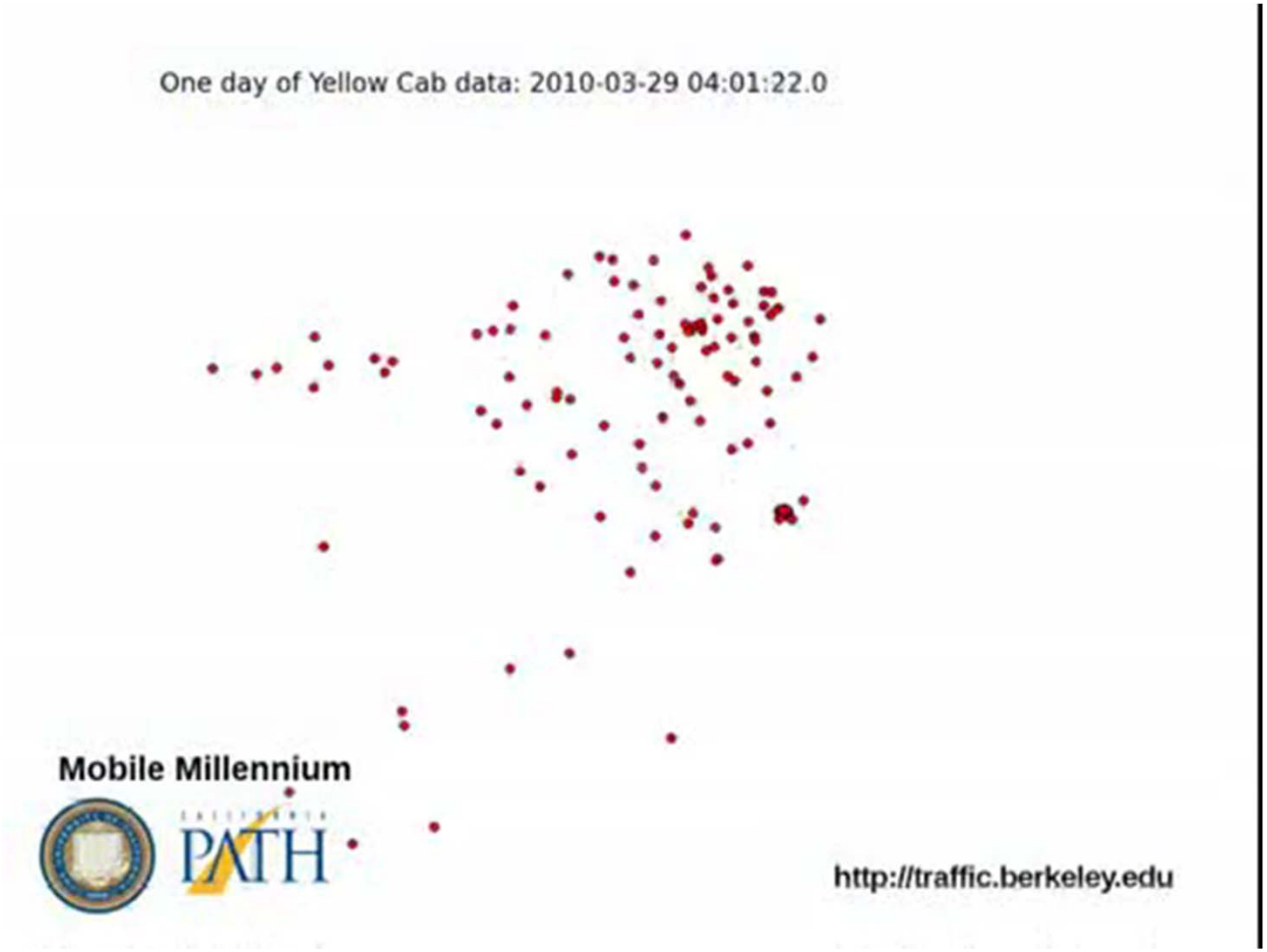




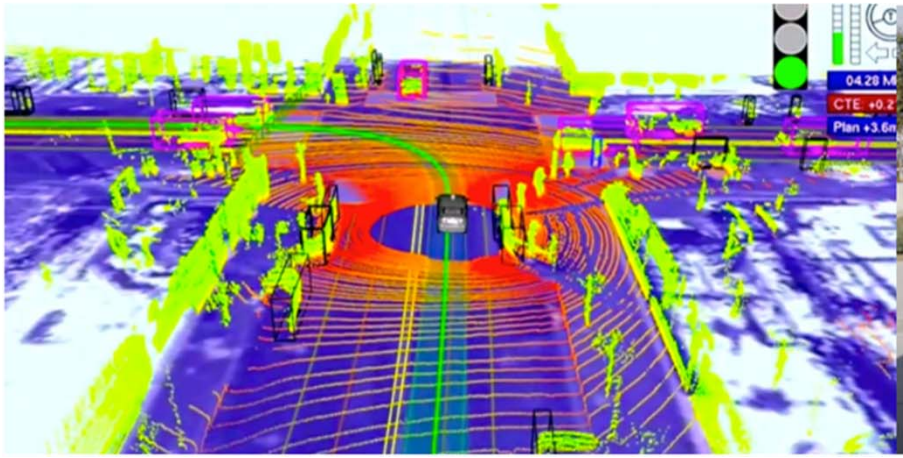
Simulation scenario for Barcelona



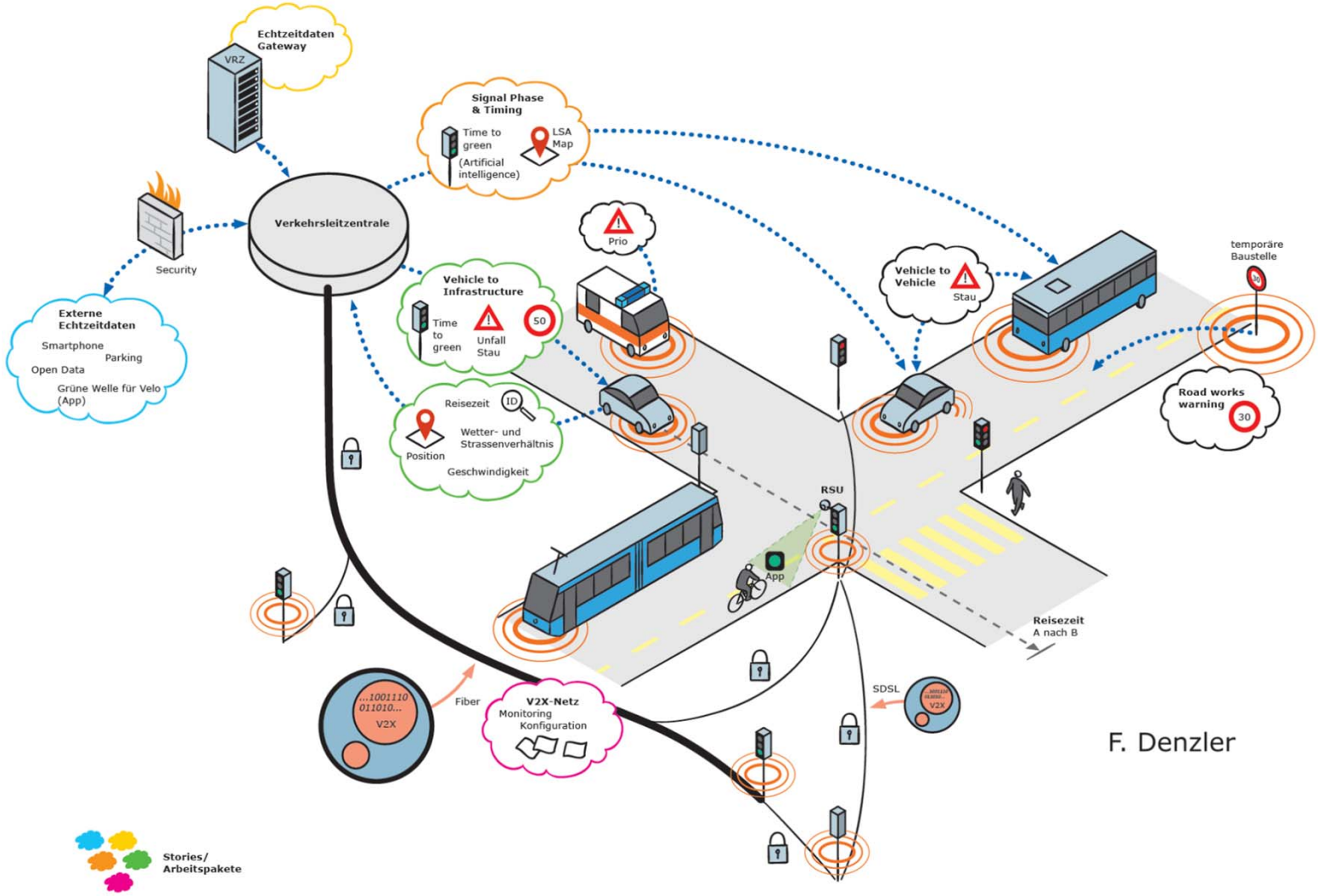
One day of taxi data, San Francisco



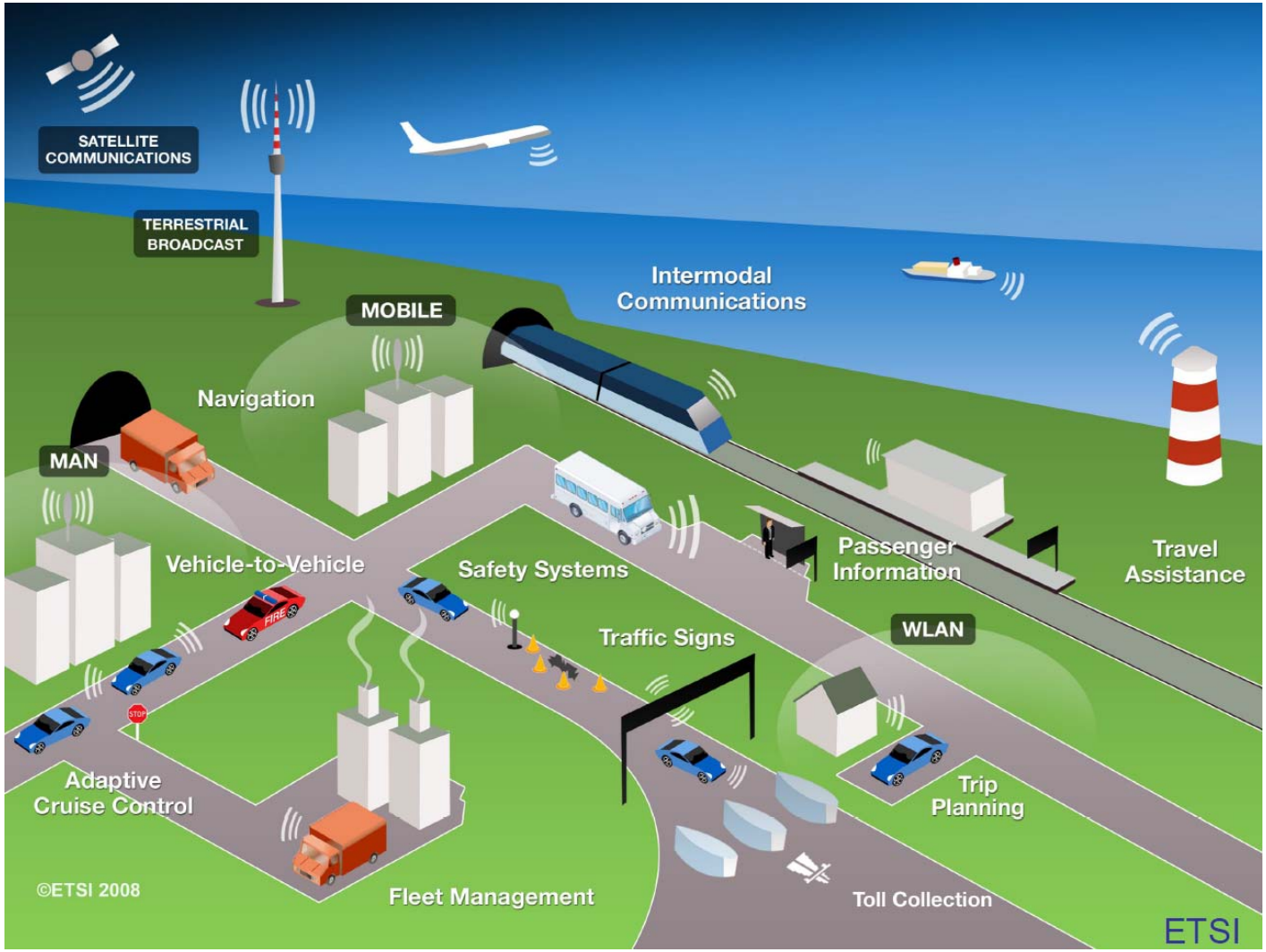
Emerging Technologies



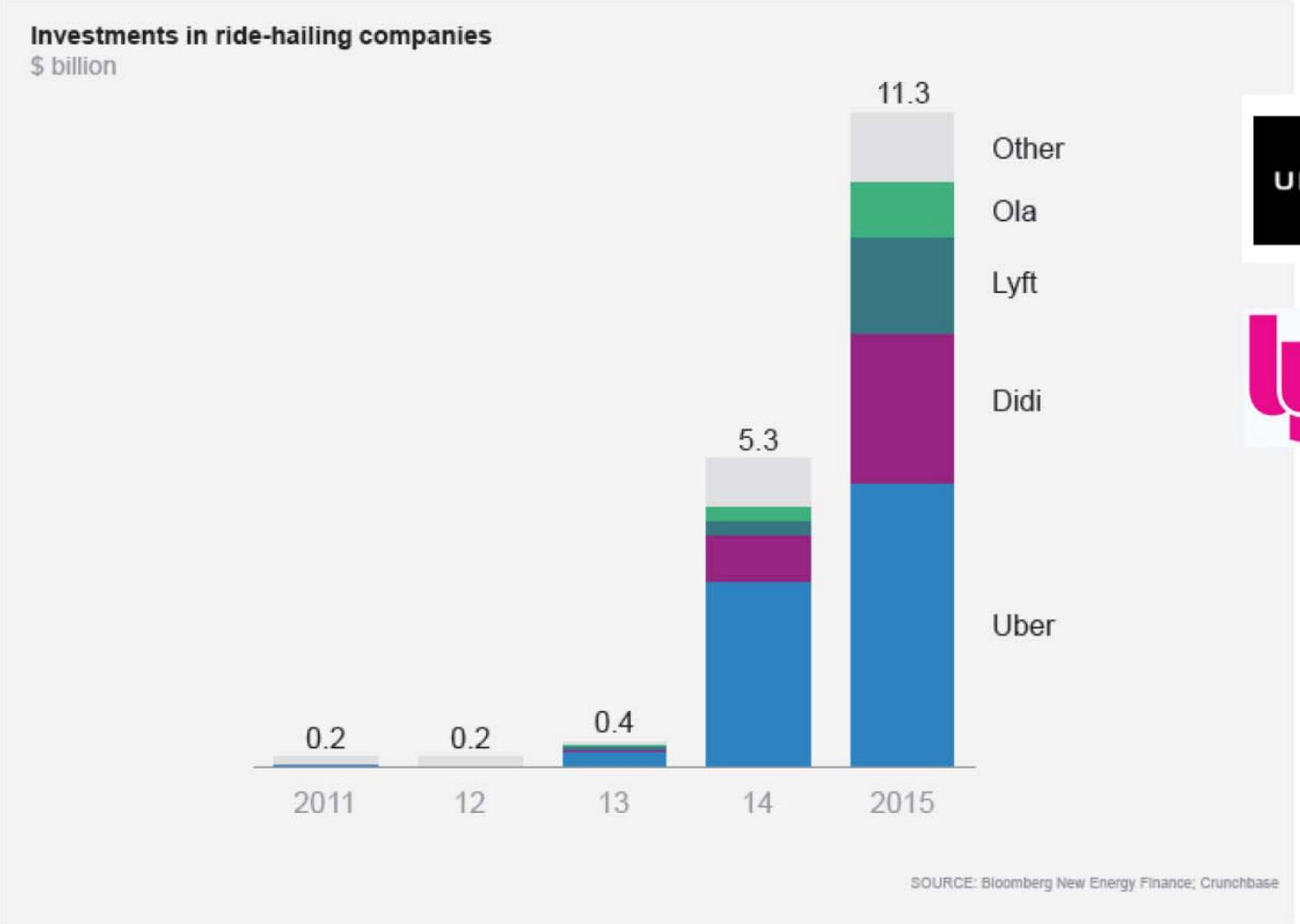
City of Zurich: Roadmap V2X-Pilot



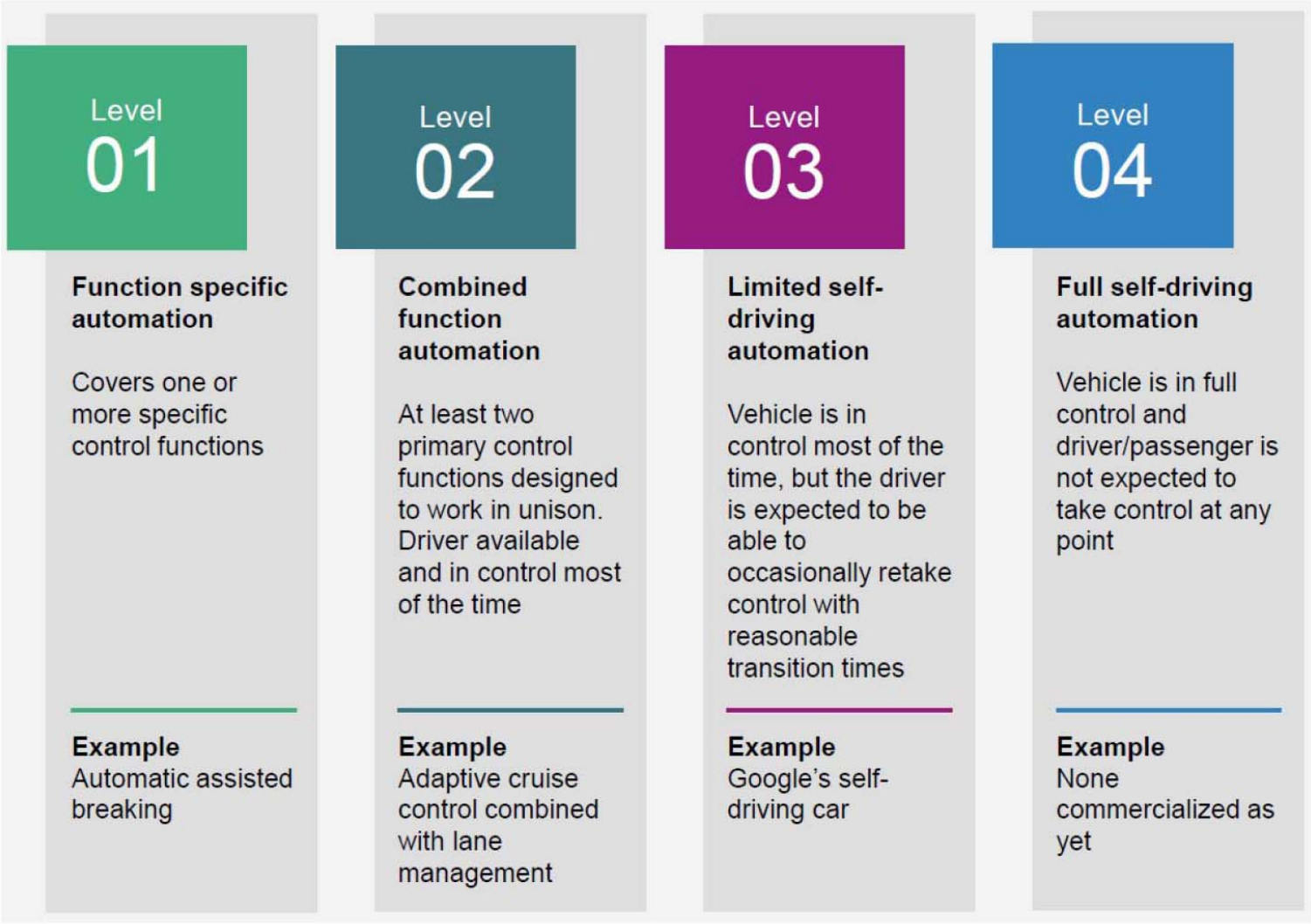
EU Telecommunications Standards Institute



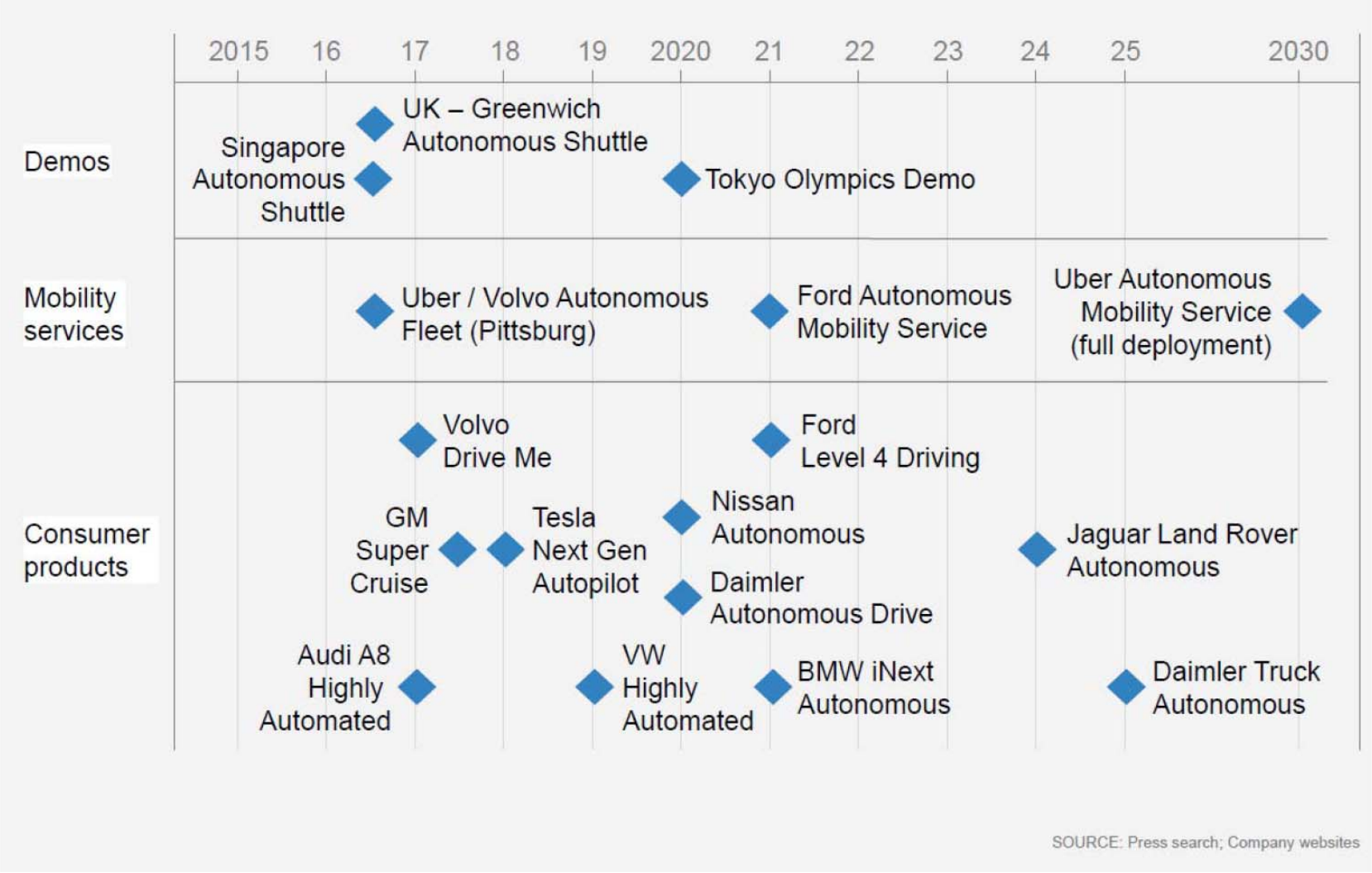
Car sharing market growth



Levels of automation

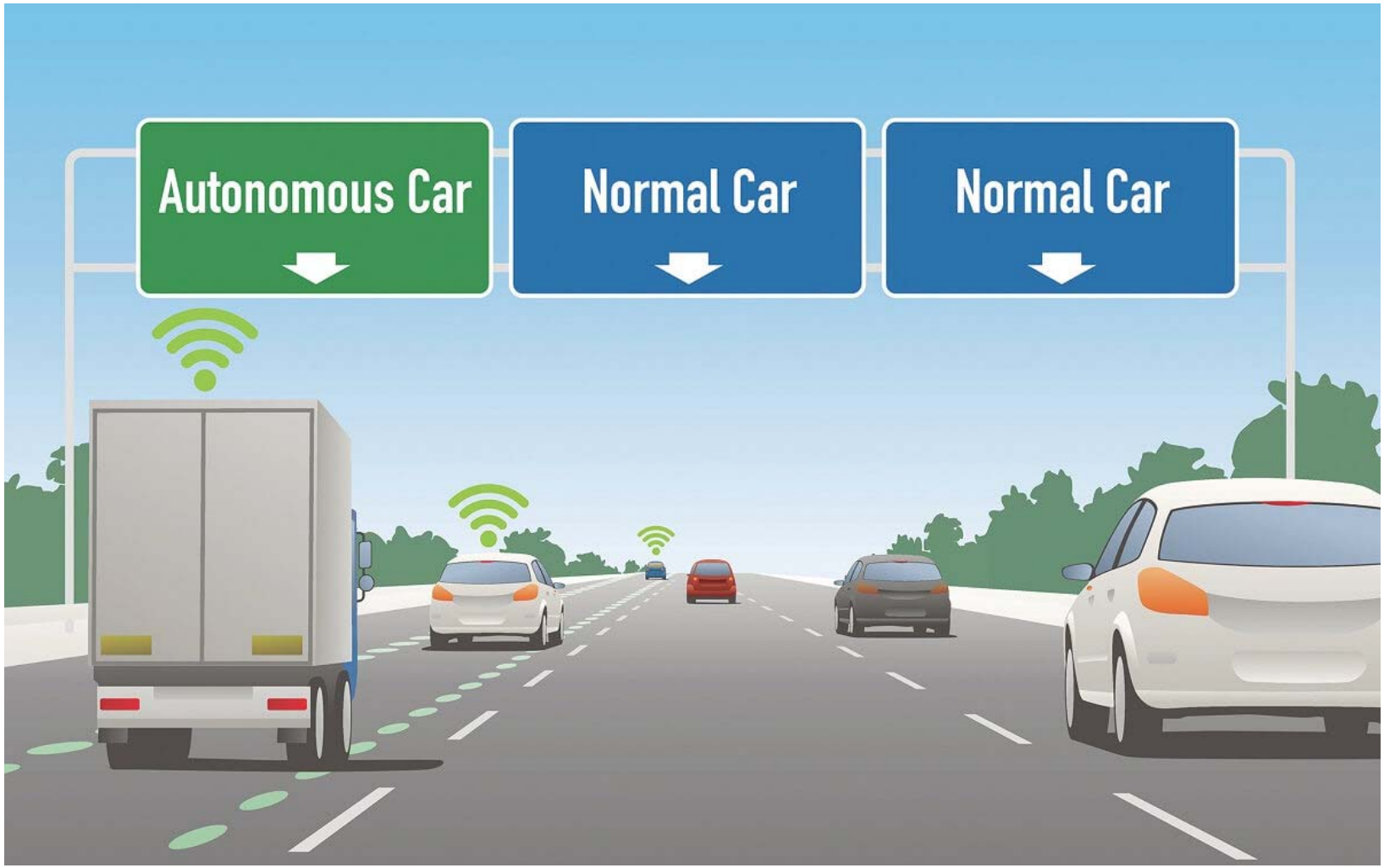


Autonomous vehicles



Road signs already exist in many countries

Intermediate state: Mixed traffic



Autonomous mobility and traffic as a fluid

- Capacity
- Anisotropy
  - Does traffic only propagate backwards?
- Safety
  - Protected environments
  - Mixed traffic
  - Dedicated lanes
- Traffic flow as an artificial fluid
  - Connectivity and cooperation

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Questions and discussion!

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