Traffic Engineering

Freeway Traffic: Merges, Bottlenecks, Ramp metering

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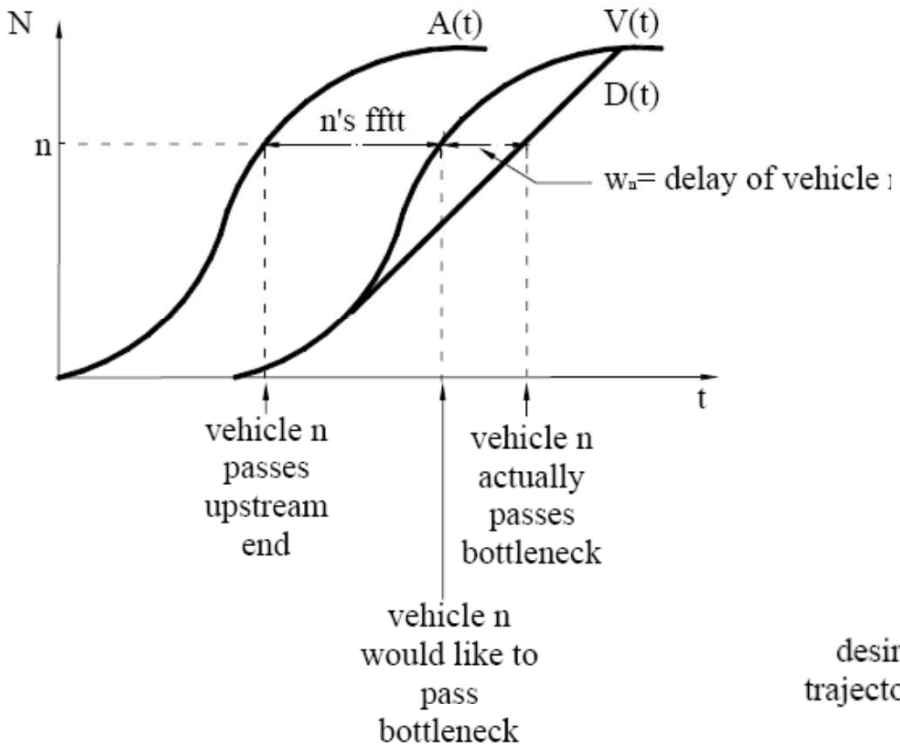
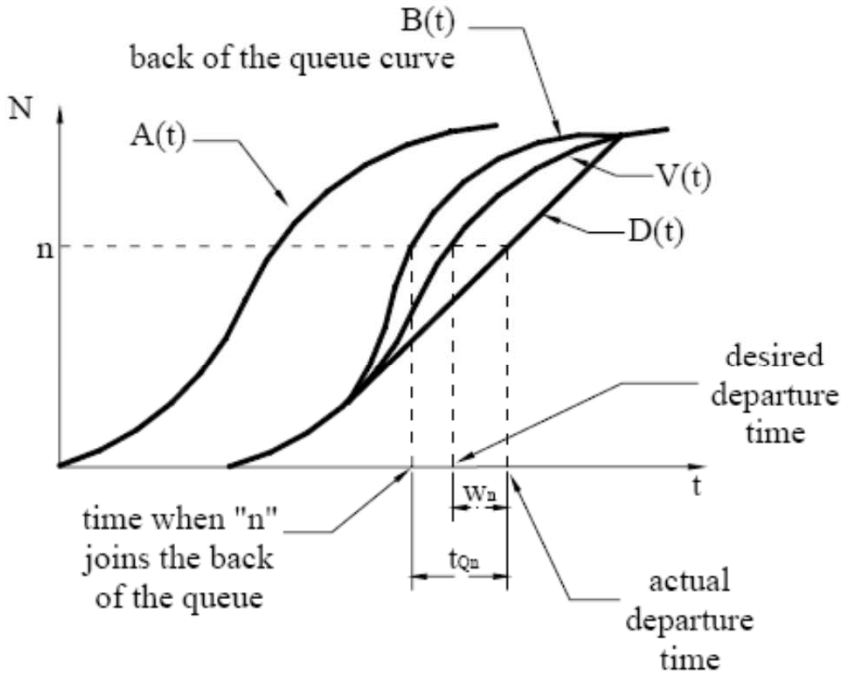
EPFL

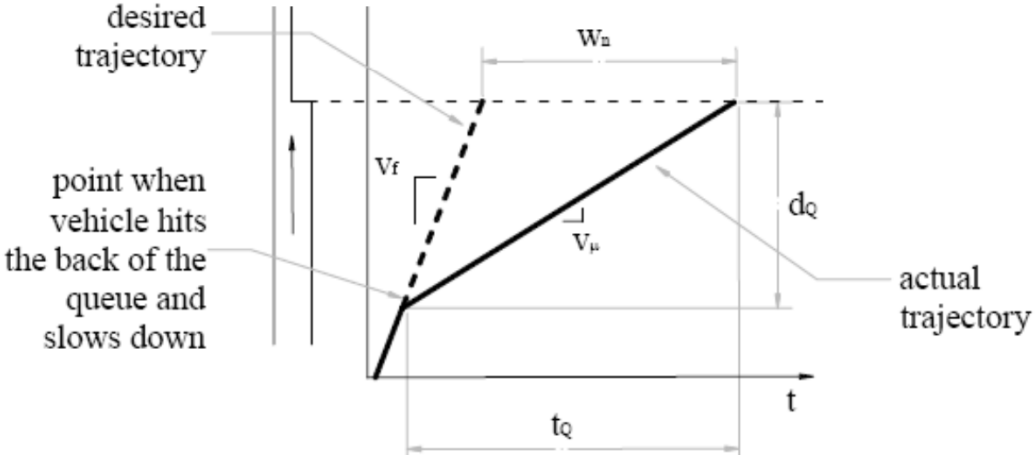
Outline

- Back of the queue (BOQ) estimation
- Merge Dynamics
- Ramp Metering (RM)
- A Swiss experiment in RM

Back of the queue estimation (BOQ)







BOQ (…)

- Time spent in queue

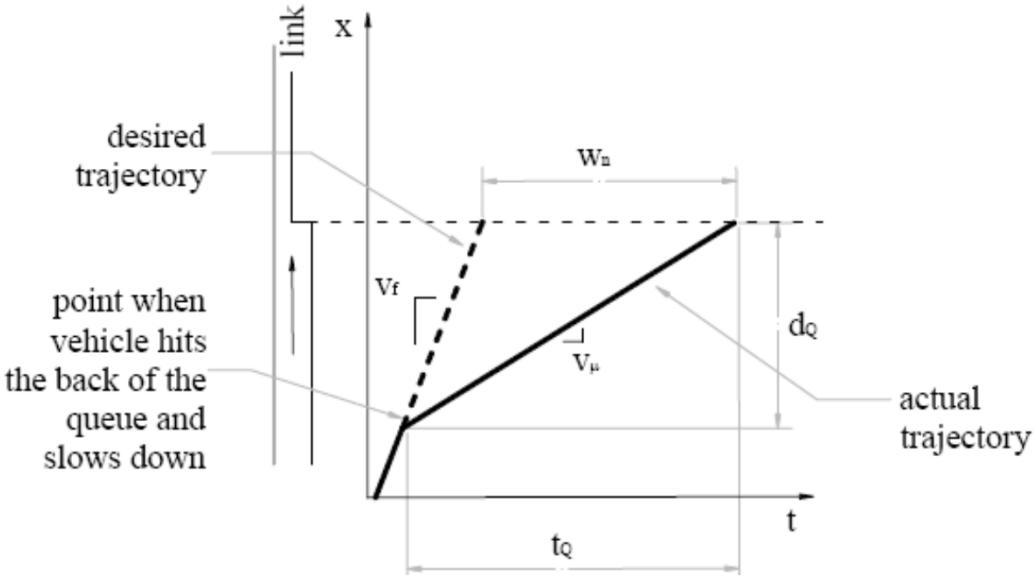
$$t_Q = \frac{d_Q}{v_\mu} = \frac{d_Q}{v_f} + w$$

- Distance traveled while in queue

$$d_Q = \frac{w}{\frac{1}{v_\mu} - \frac{1}{v_f}}$$

- From (1) and (2)

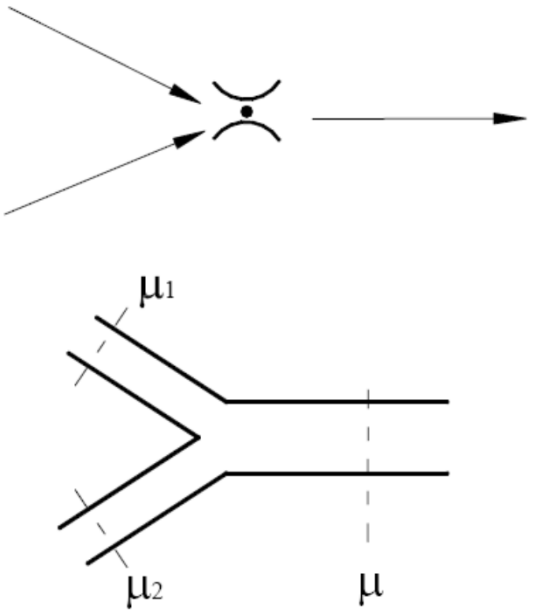
$$t_Q = \frac{w}{1 - \frac{v_\mu}{v_f}}$$

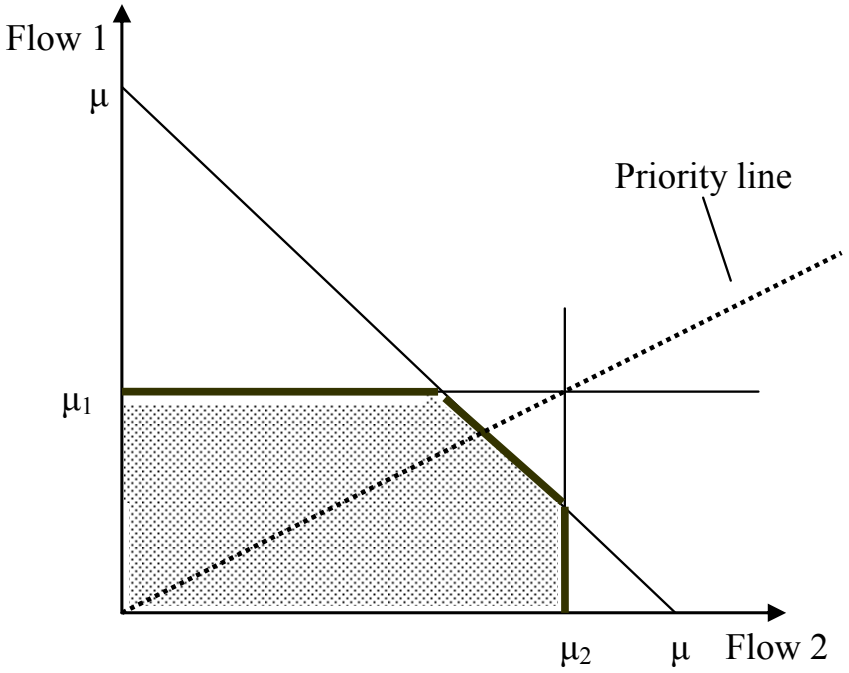


Merge Dynamics

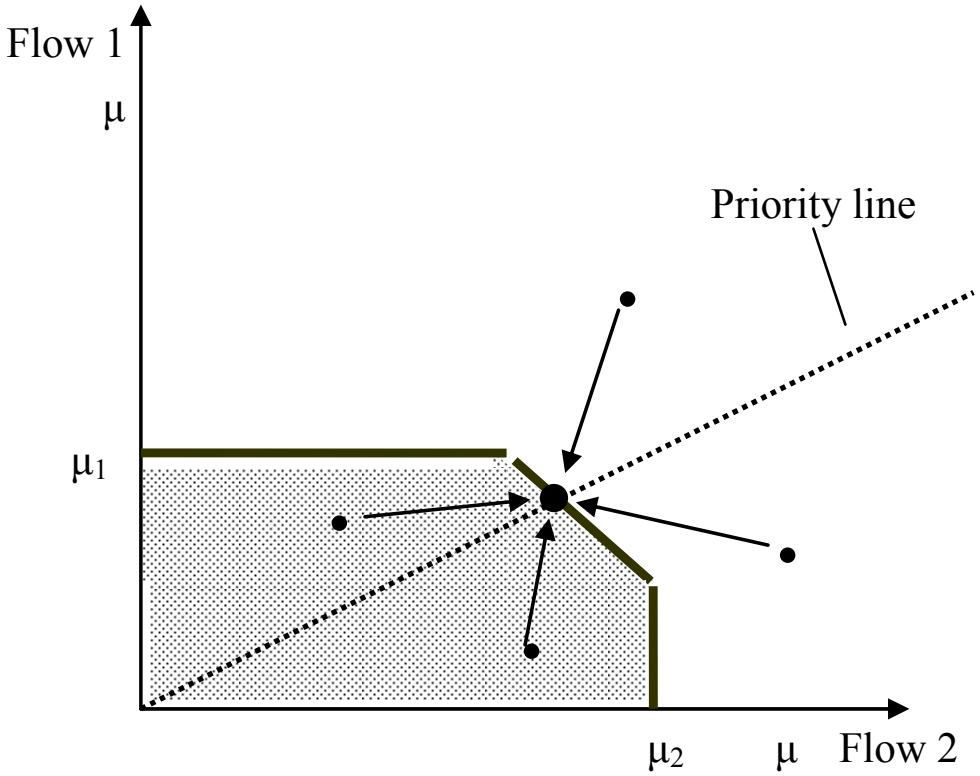
Merge Dynamics

- Given $V_1(t)$, $V_2(t)$, and μ, μ_1, and μ_2, what are $D_1(t)$, and $D_2(t)$?

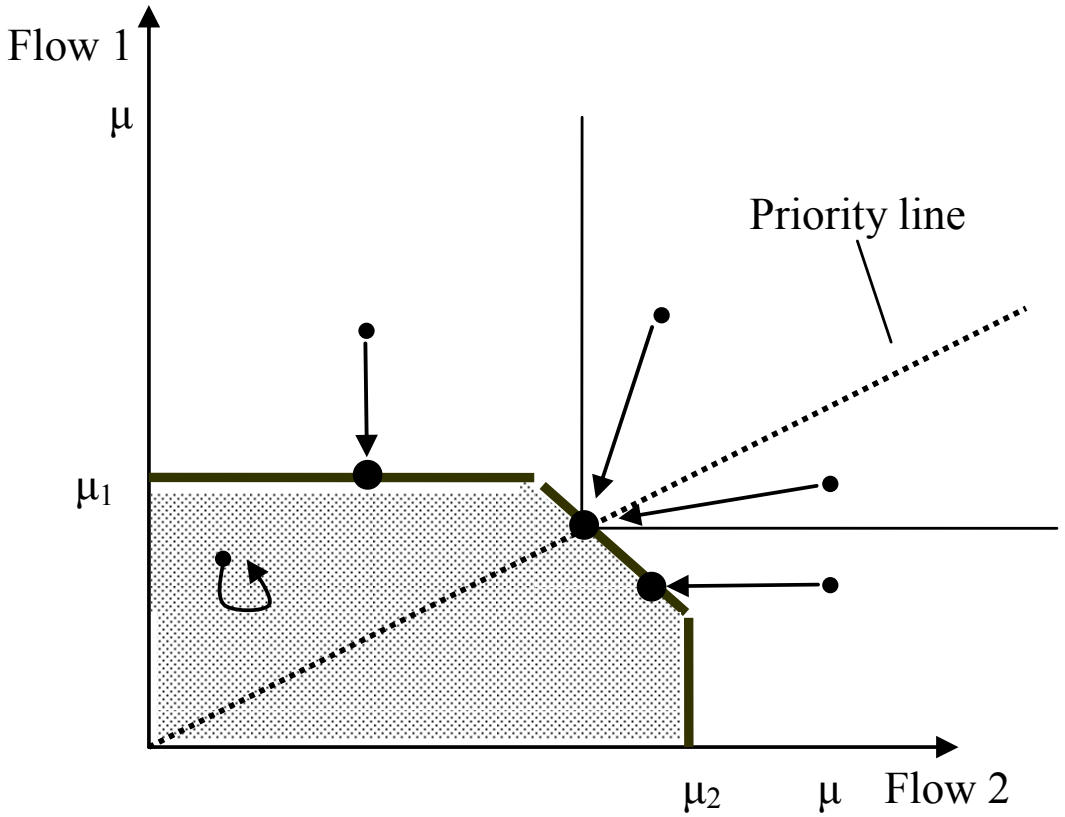




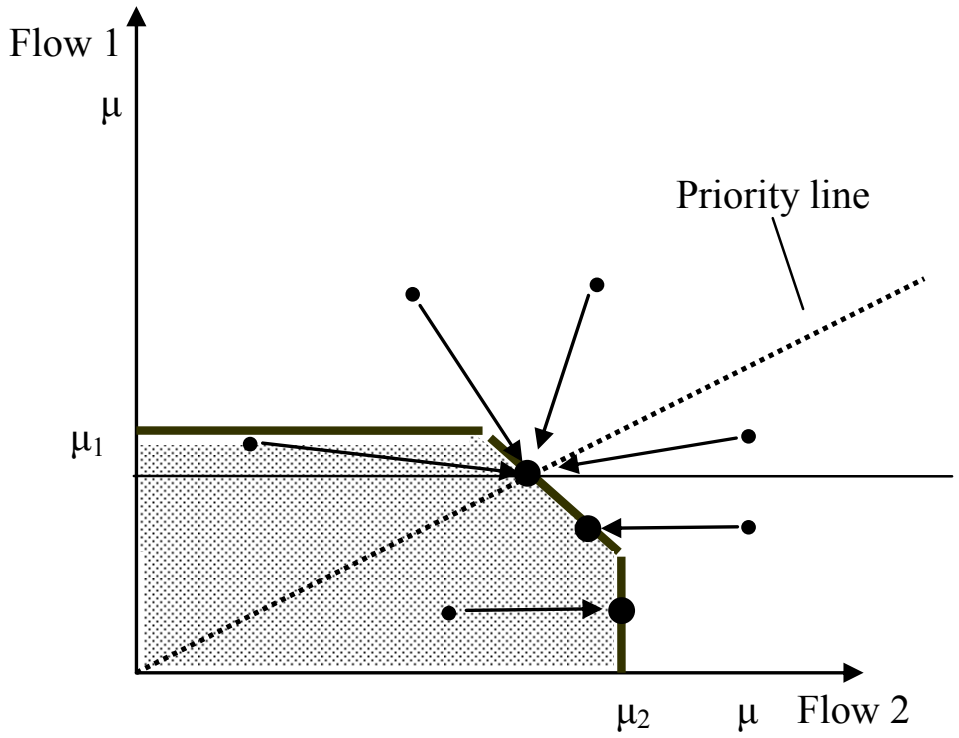
Queues in both approaches



No queue



Queue only in approach 2



Traffic Engineering

Ramp metering

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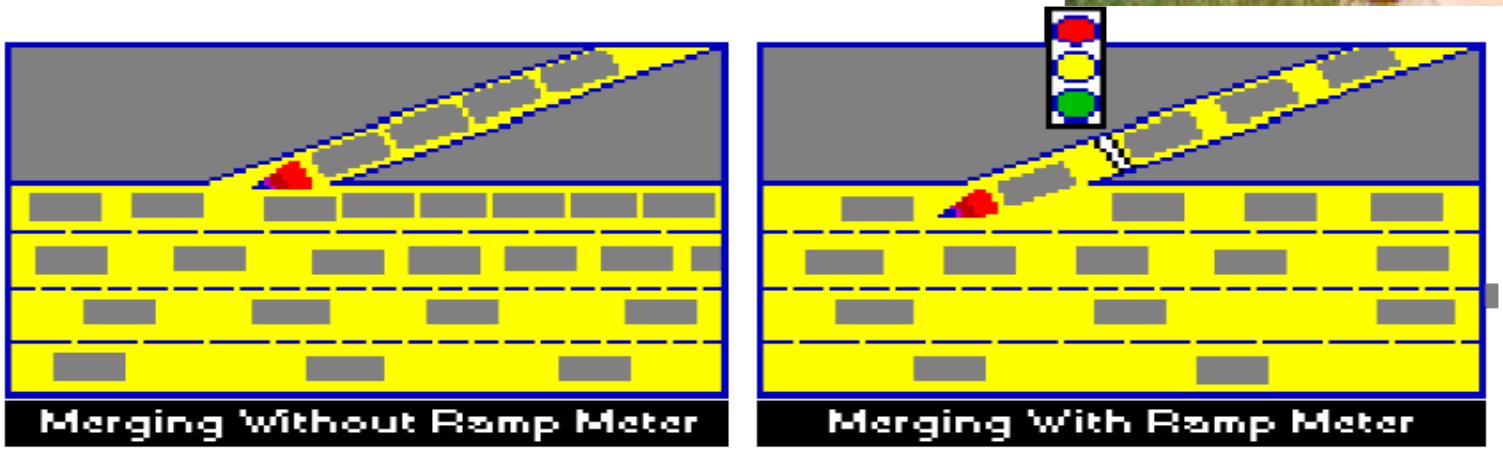
Ramp metering

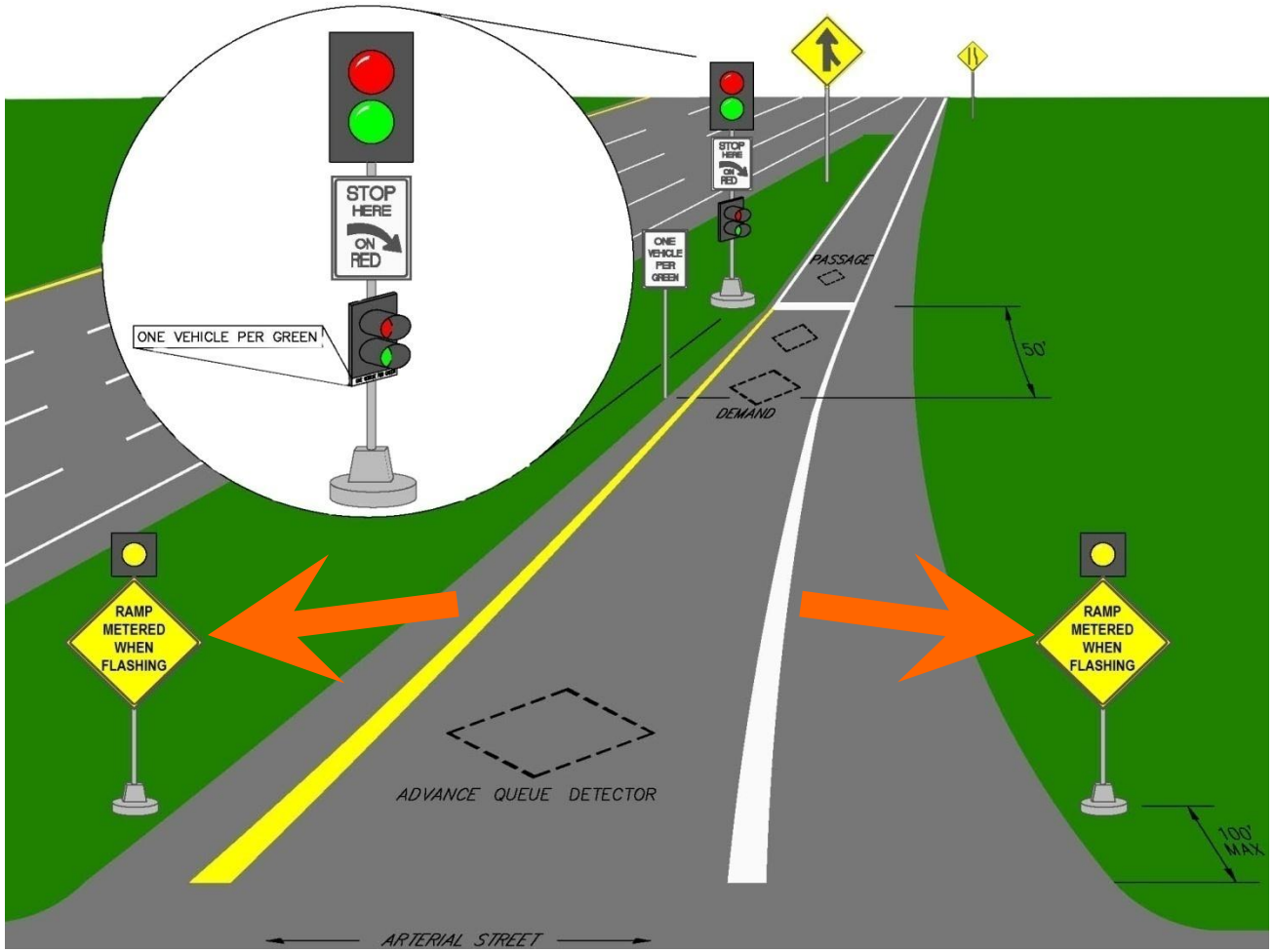
- Stop and go signals located at the entrance ramps of freeways to regulate the amount of vehicles entering. It allows traffic to have higher speed, be more “free flowing”, and cause less traffic jams
- Since 1963 in Chicago, has been operating in 21 metropolitan areas in the US and also many countries in Asia, Europe, Australia

Goals of ramp metering

- Objective
  - balance demand and capacity of the freeway in order to maintain optimum operation and prevent operational breakdowns
- Safety considerations
  - Increase gaps for on-ramp vehicles to freeway

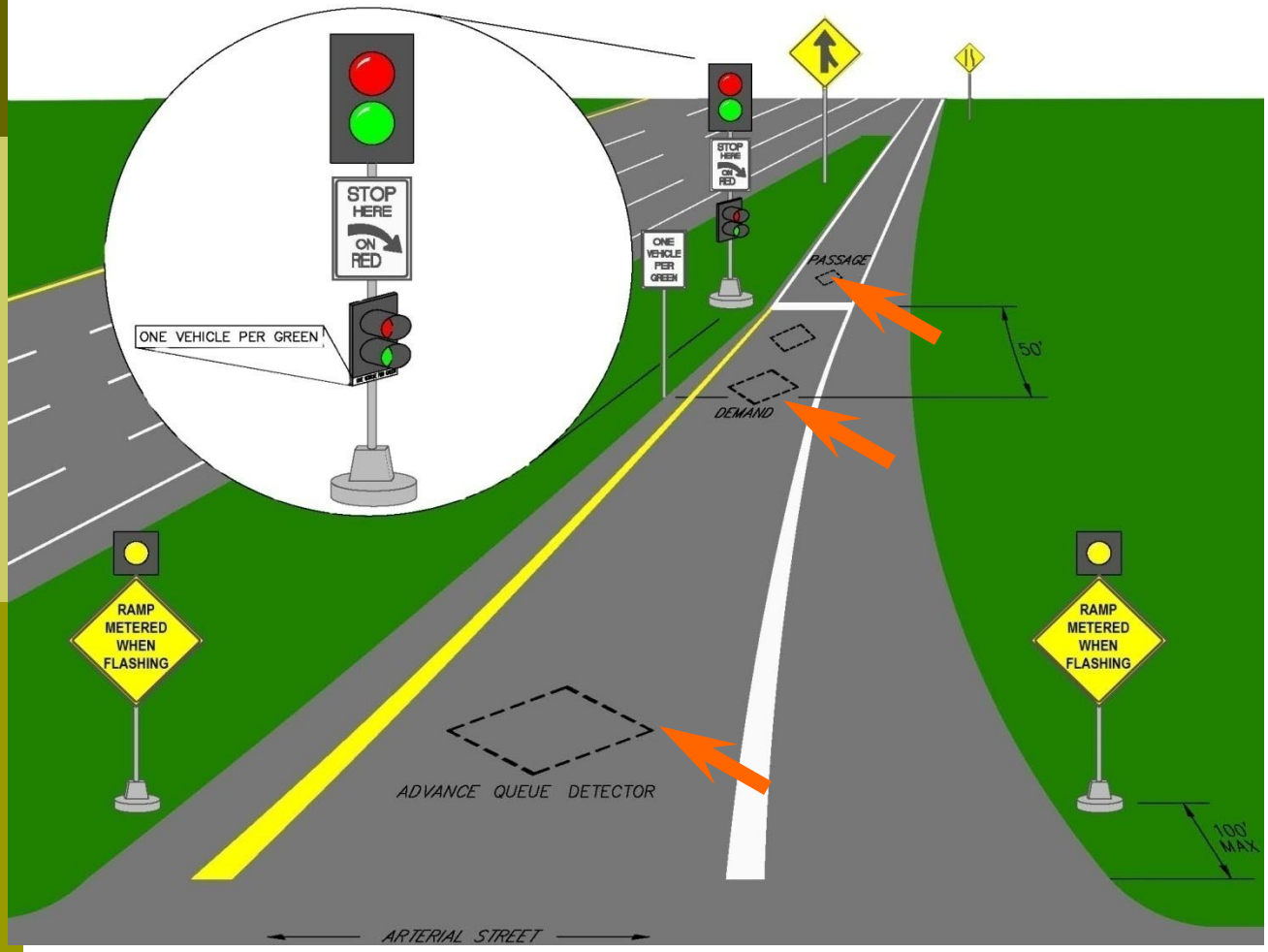


One-Lane Ramp, One Vehicle Per Green



- Advance Warning
  - 'Ramp Metered When Flashing' sign
  - Flashing yellow indication
  - Located on both sides of ramp
  - Clear Messages
  - Flashing beacons dark when not in operation

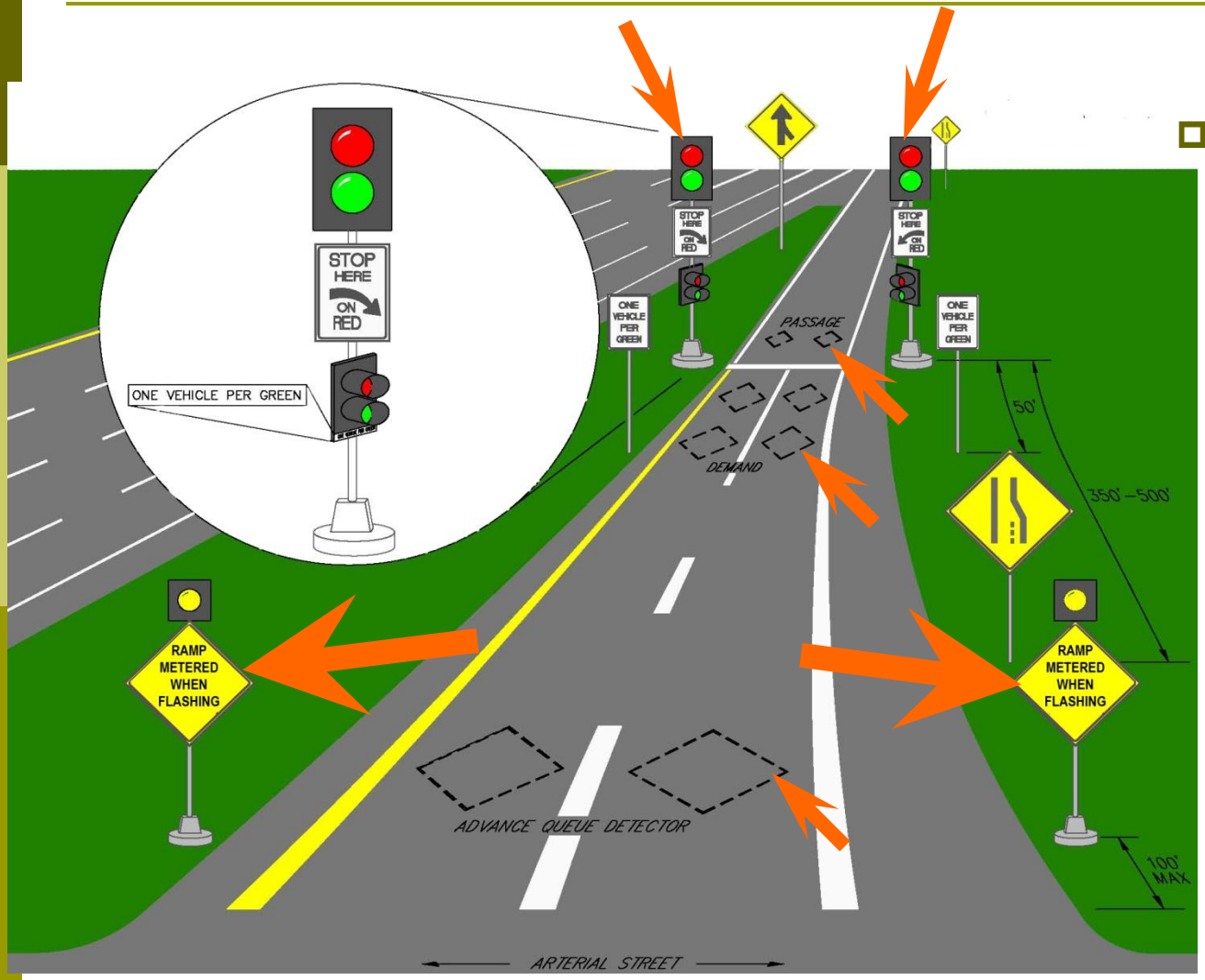
Loop Detection



- Demand loops
- Passage loop
- Advance queue detection loop
- AQ loop impacts meter rate
- No backups onto arterial street

Real World Look…

Two-Lane Ramp, One Vehicle Per Green



- Ramp Meter Control
  - Same look as single-lane ramp metering
  - Equipment on both sides of ramp
- Merging
  - 'Pavement Width Transition' sign for advance merge warning

Real World Look…

Ramp Metering

- A primary goal of ramp metering is to restrict, if necessary, the outflow from the entry ramp so that the demand at the downstream section does not exceed its capacity.
- In so doing, not all of the ramp demand may be satisfied, possibly resulting in a queue forming on the ramp.
- Should the total upstream + ramp flows be allowed to exceed the capacity downstream, the state of the system downstream will likely become unstable and result in “stop-and-go” conditions and a much reduced flow rate and corresponding speed.

Metering Strategies

	Pre-timed	Traffic Responsive
Local	▶ Appropriate for localized problems. ▶ Detection in the field is not needed. ▶ Requires periodic manual updates. ▶ Not effective for non-static conditions. ▶ Higher operations costs compared to traffic responsive systems.	▶ Appropriate for localized problems. ▶ Detection in the field is needed. ▶ Higher capital and maintenance costs compared to pre-timed systems. ▶ Yields greater benefits because it responds to conditions in the field.
System-wide	▶ Appropriate for widespread problems. ▶ Detection in the field is not needed. ▶ Rarely used compared to system-wide, traffic responsive systems.	▶ Appropriate for widespread problems. ▶ Detection in the field is needed. ▶ Most useful for corridor, system-wide applications. ▶ Greatest capital and maintenance costs, but yields most benefits.

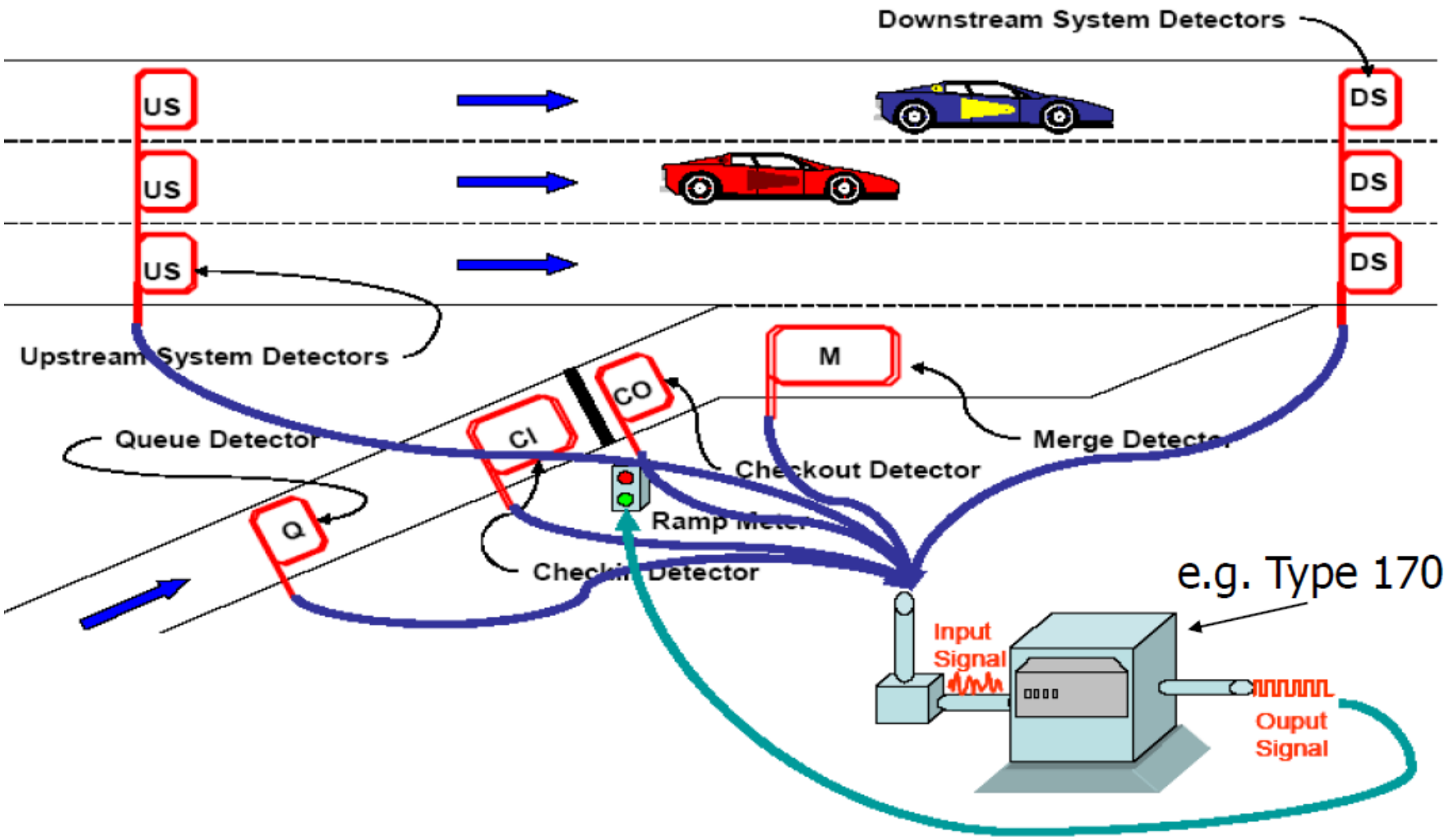
Metering Approach	Advantages	Disadvantages
Pre-Timed (Local & System-Wide)	▶ No mainline detection devices are needed. ▶ No communication with a TMC is required. ▶ Simple hardware configuration compared to other approaches. ▶ Provides safety benefit by breaking up platoon of vehicles entering the freeway. ▶ Can effectively relieve recurring congestion if it is fairly constant day-after-day.	▶ Requires frequent observations so rates can be adjusted to changing traffic conditions. ▶ Often results in over restrictive metering rates leading to unneeded ramp queuing and delays (unless metering at demand is employed), which could affect arterial operations as well. ▶ Not responsive to unusual conditions, such as non-recurring congestion, which in turn can lead to public dissatisfaction.
Local Traffic Responsive	▶ Ability to better manage freeway congestion than pre-timed metering approaches (especially for non-recurring congestion). ▶ Operating costs are lower than pre-timed (due to automatic, rather than manual, meter adjustments), so the extra investment upfront may pay itself off over time.	▶ Higher capital and maintenance costs than pre-timed. ▶ Increased maintenance needs because of mainline detection. ▶ Reactive versus proactive. In other words, improvements are made after the fact, rather than before problems occur. ▶ Doesn't consider conditions beyond the adjacent freeway section, making it difficult to optimize conditions for a downstream bottleneck.
System-Wide Traffic Responsive	▶ Provides optimal metering rates based on real-time conditions throughout the system or corridor. ▶ Some algorithms, such as the fuzzy logic algorithm, have the ability to address multiple objectives (e.g., freeway congestion and ramp queues).	▶ Requires mainline detection (both downstream and upstream detectors). ▶ Requires communication to central computer. ▶ Requires technical expertise for calibrating and implementing system. ▶ More expensive than local traffic responsive in implementation resources needed and communications maintenance.

Installations
Real Benefits

Metropolitan Area	No. of Meters*
Los Angeles – Anaheim – Riverside, CA	1,316
Minneapolis – St. Paul, MN	419
San Diego, CA	288
San Francisco – Oakland – San Jose, CA	191
Houston – Galveston – Brazoria, TX	128
Phoenix, AZ	122
Seattle – Tacoma, WA	120
Milwaukee – Racine, WI	118
Chicago, IL – Gary, IN – Lake County, IL	113
Portland, OR – Vancouver, WA	110

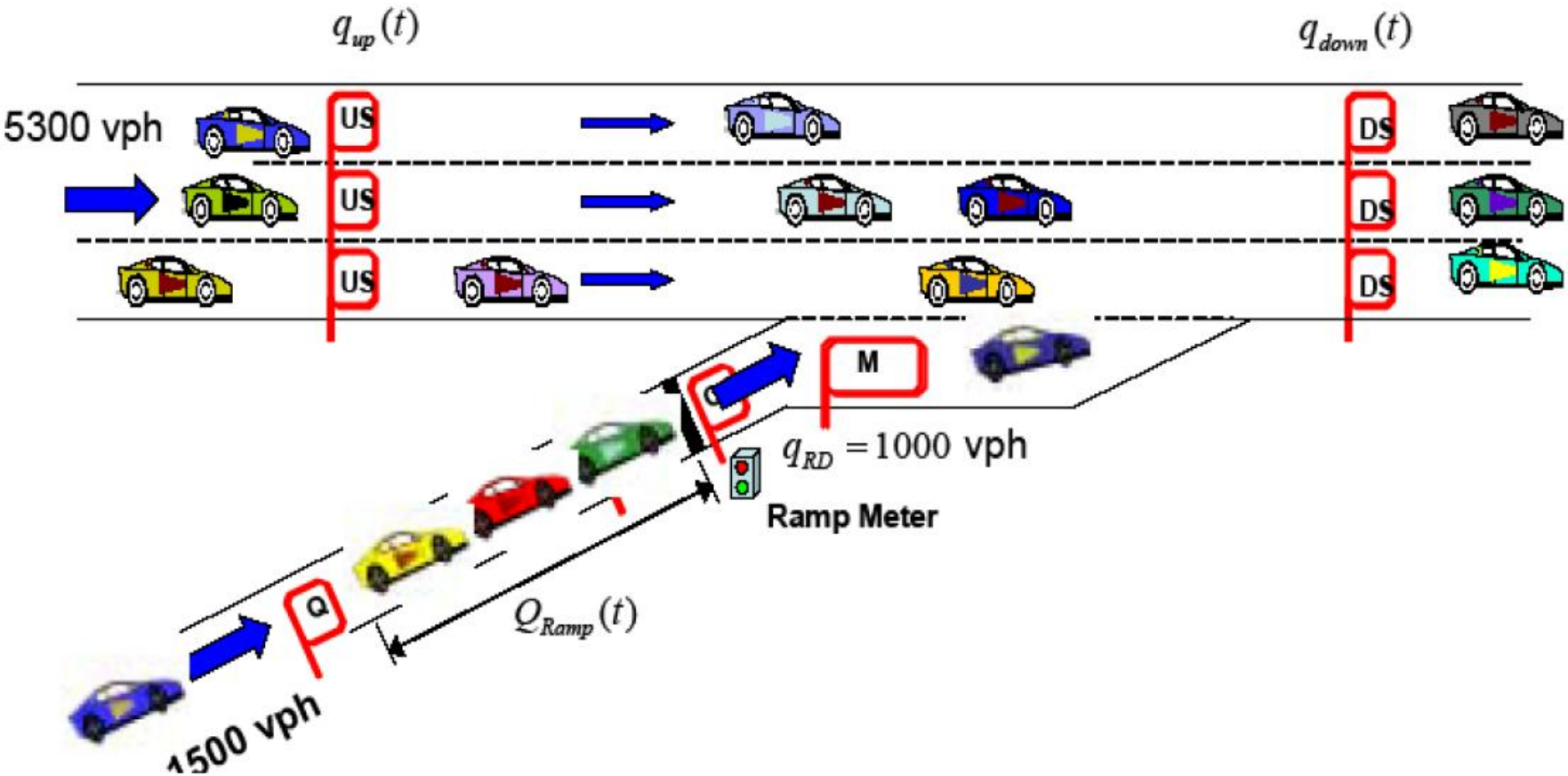
Measure	Location	Benefits
Safety	Minneapolis, MN	26% reduction in peak period collisions and 38% decrease in peak period collision rate.
	Seattle, WA	34% decrease in collision rate.
	Denver, CO	50% reduction in rear-end and side swipe collisions.
	Detroit, MI	50% reduction in total collisions, 71% reduction in injury collisions.
	Portland, OR	43% reduction in peak collisions.
	Long Island, NY	15% reduction in collision rate.
Travel Time and Speed	Long Island, NY	9% increase in average vehicle speed.
	Portland, OR	26 to 66 km/h increase in average vehicle speeds (16 to 41 mi/h).
	Denver, CO	69 to 80 km/h improvement in average vehicle speeds (43 to 50 mi/h).
	Seattle, WA	Decrease in average travel time from 22 to 11.5 minutes.
	Minneapolis, MN	64 to 69 km/h improvement in average peak hour speeds (40 to 43 mi/h).
Throughput	Minneapolis, MN	25% increase in peak volume.
	Seattle, WA	74% increase in peak volume.
	Denver, CO	18% increase in peak volume.
	Long Island, NY	2% increase in throughput.
Environmental	Minneapolis, MN	2 to 55% reduction in fuel consumption.
		Savings of 1,160 tons of emissions.

Typical Freeway Configuration

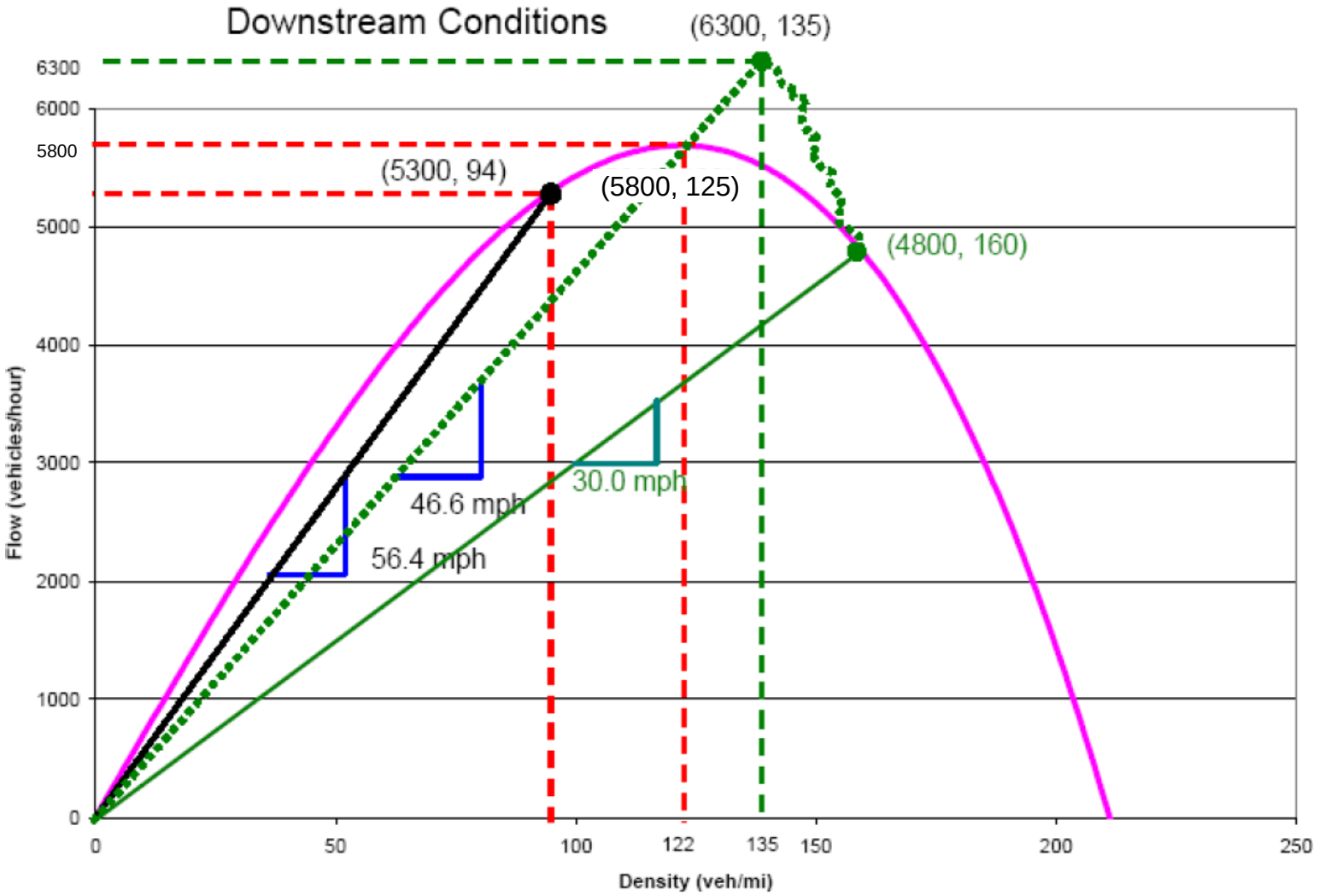


$q_{demand} + q_{meter} > q_{down}(capacity)$

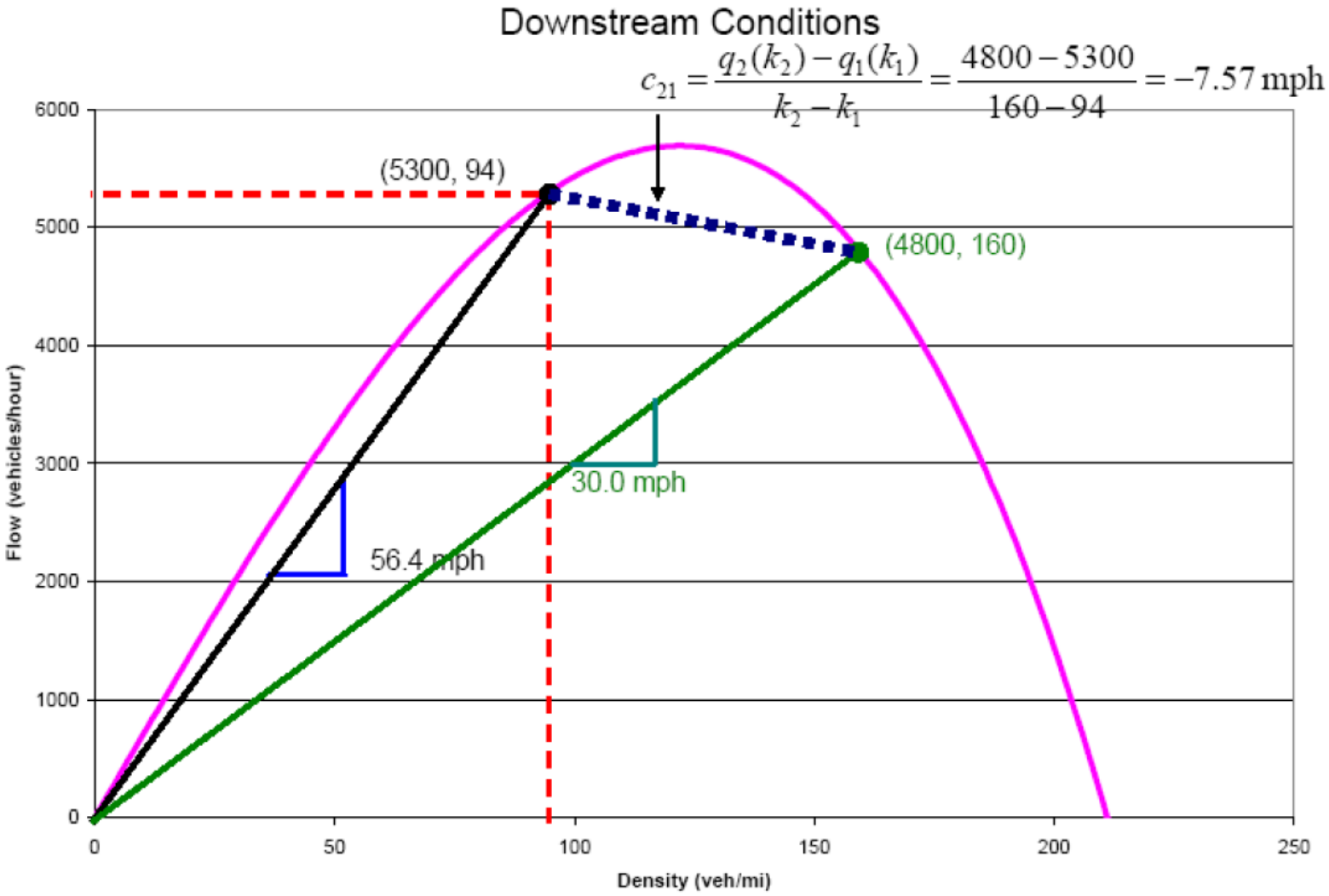
$q_{down}(cap) = 5800$vph



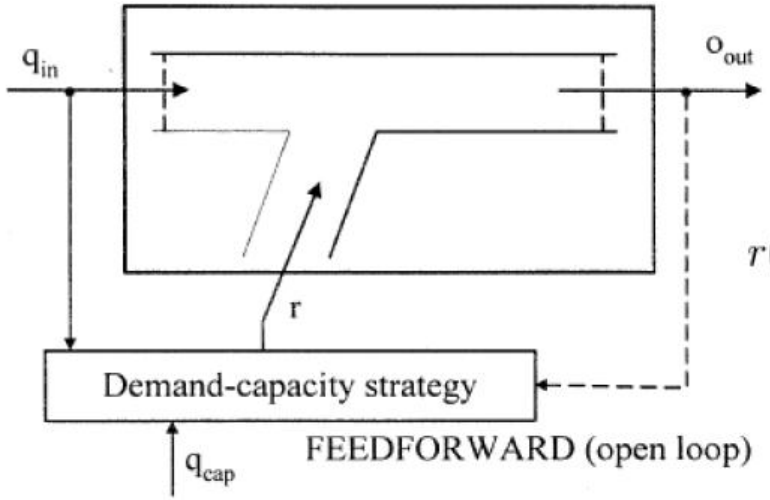
Shockwave moving backward



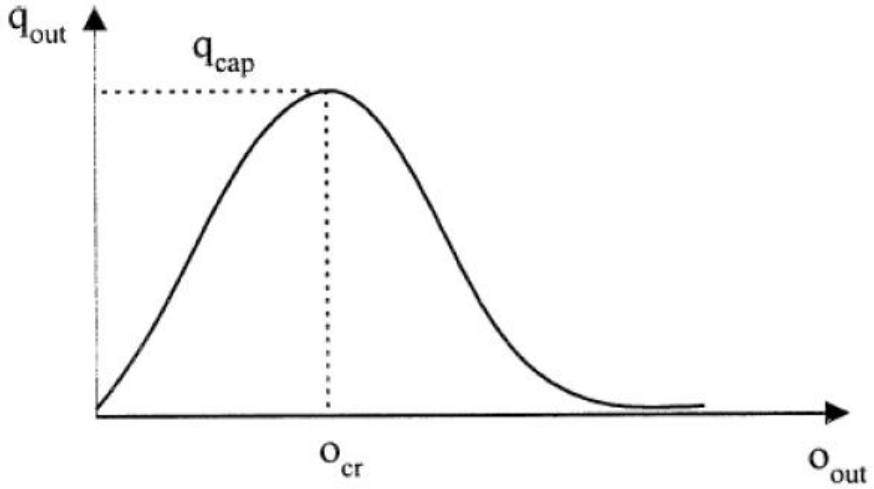
Shockwave moving backward



Traffic Responsive – Demand Strategy



$$r(k) = \begin{cases} q_{\text{cap}} - q_{\text{in}}(k-1), & \text{if } o_{\text{out}}(k) \le o_{\text{cr}} \\ r_{\min}, & \text{else} \end{cases}$$



Demand>Capacity

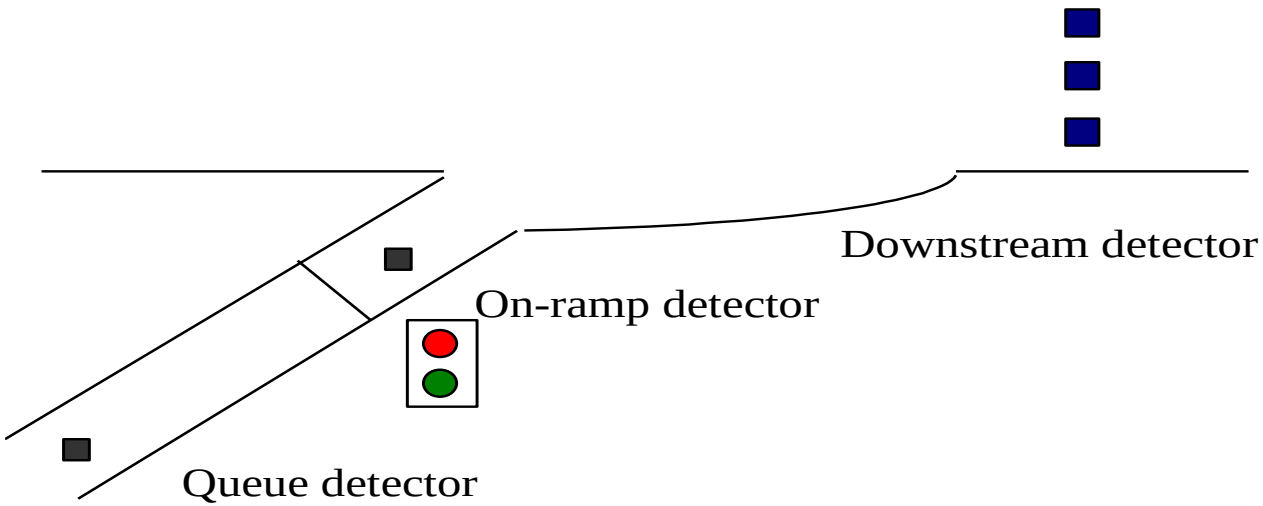
- when demand exceeds capacity:
  - flow breakdown occurs
  - travel times increase significantly
  - total system throughput is reduced
- to avoid this situation, limit demand onto freeway to:
  - maintain acceptable level of service
  - maintain higher throughput
- impacts of demand control:
  - freeway: speeds remain higher as no longer operating in the congested regime
  - ramps : higher delay as vehicles queued on ramp
  - surface streets: more traffic on surface streets as some drivers will re-route to avoid Freeway

Ramp metering

- ALINEA, proposed by Papageorgiou in 1990s (based on density, not on flow)
- A local feedback ramp-metering strategy
- Remarkably simple, highly efficient and easily implemented and calibrated
- Good performance
  - Field tests
  - Simulation-based studies
- Queue override feature can be incorporated in the algorithm if required

Background: ALINEA

$$r(t) = \tilde{r}(t - \Delta t) + K_R \bullet (O^* - O(t))$$



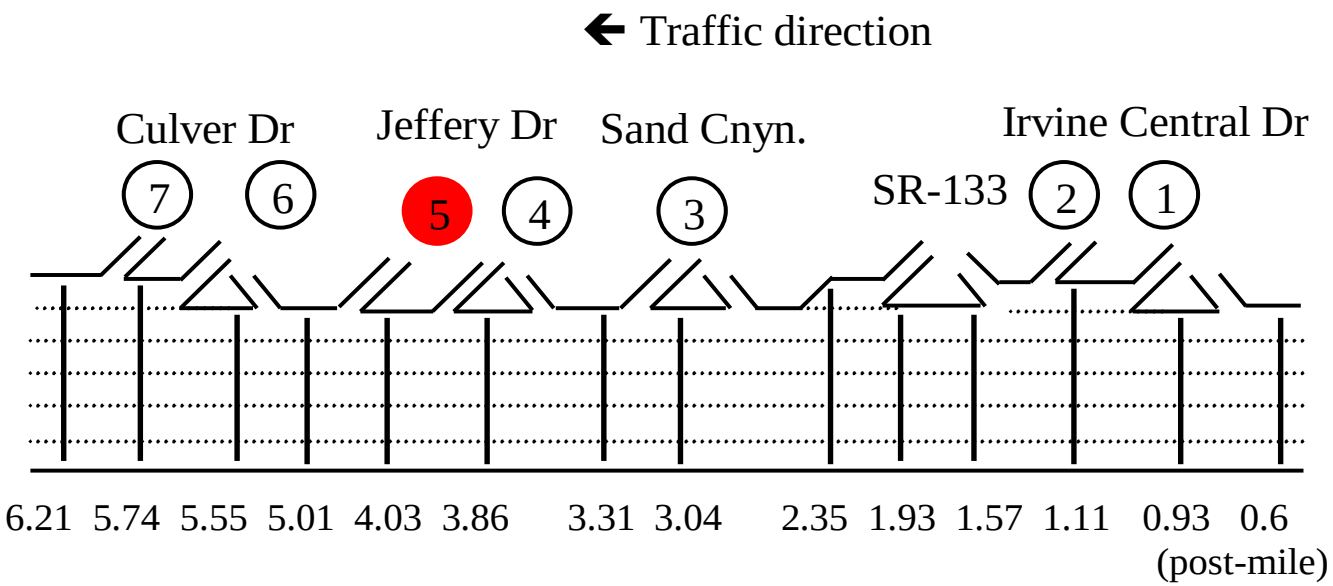
- The feedback control logic dynamically maintains the mainline occupancy level below a target occupancy level by restricting the inflow from on-ramps.

Background : ALINEA

- Parameter values in field tests:
  - Desired occupancy O* : 0.18 -- 0.31
  - K_R =70, in real-world experiments
  - Downstream detector location: 40 m -- 500 m downstream
  - Update cycle *t:* 20 seconds -- 2 minutes

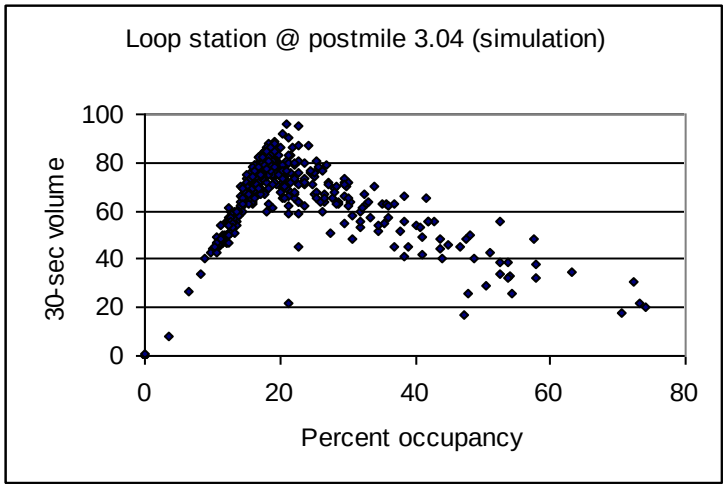
Simulation Modeling

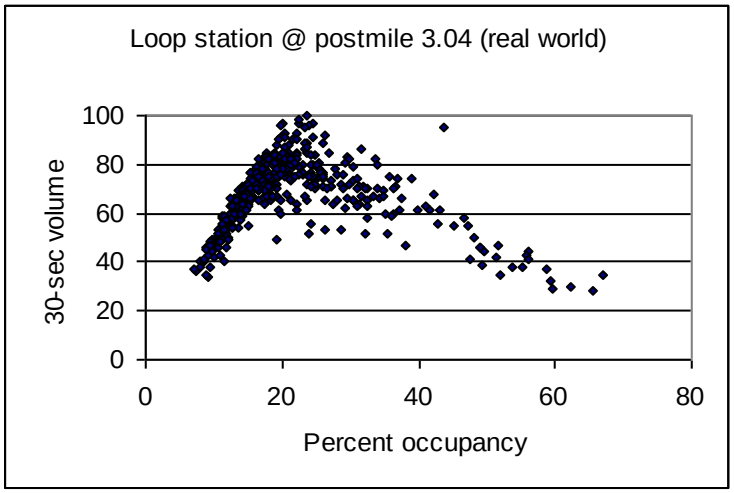
- Study site



Simulation Modeling

- Model Calibration

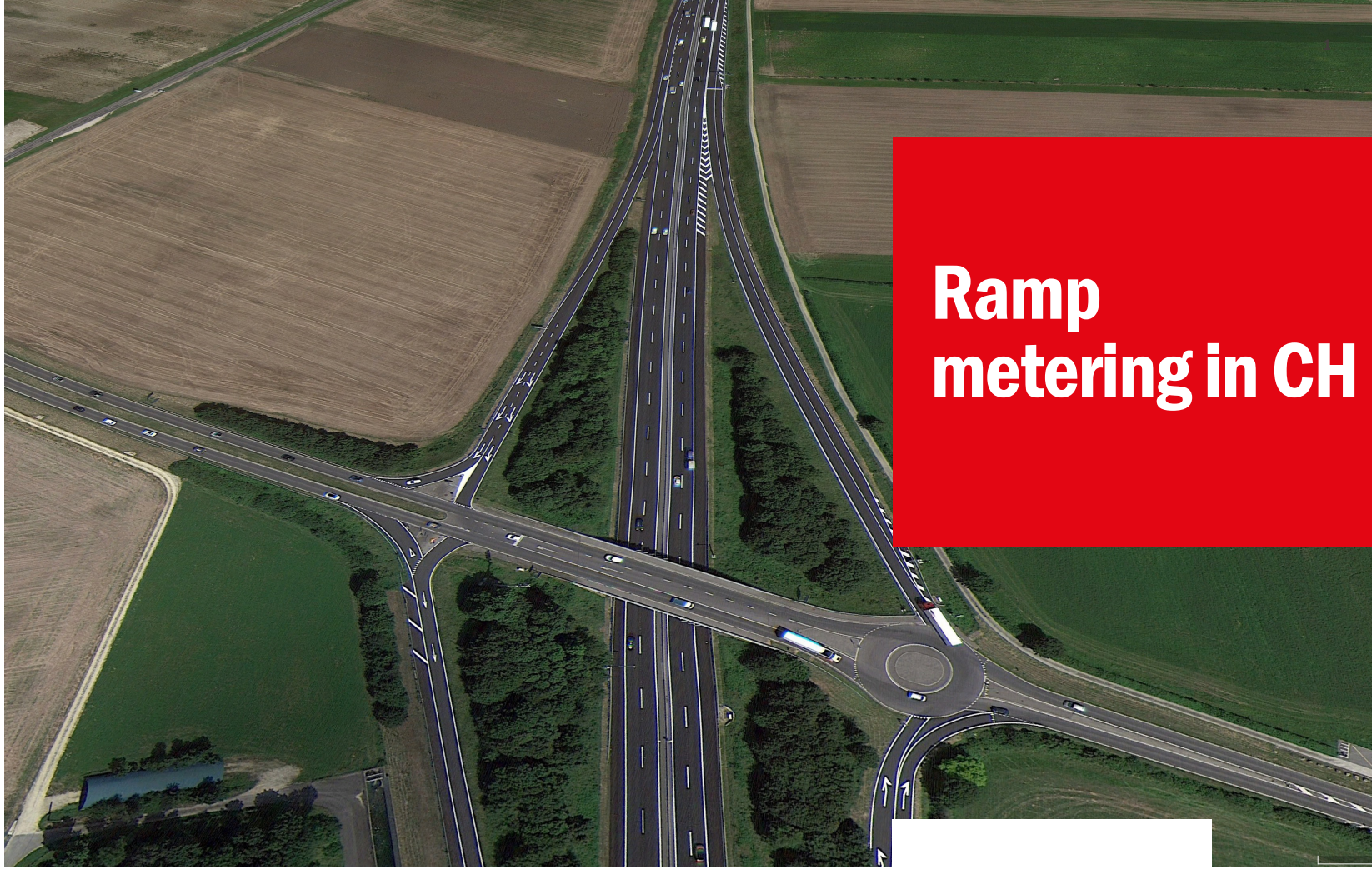




Issues

- Diversion
- Equity
- On-ramp emissions
- Ramp delay and spillback effects
- Installation and maintenance
- Enforcement
- Sensitivity of results to algorithm and strategy

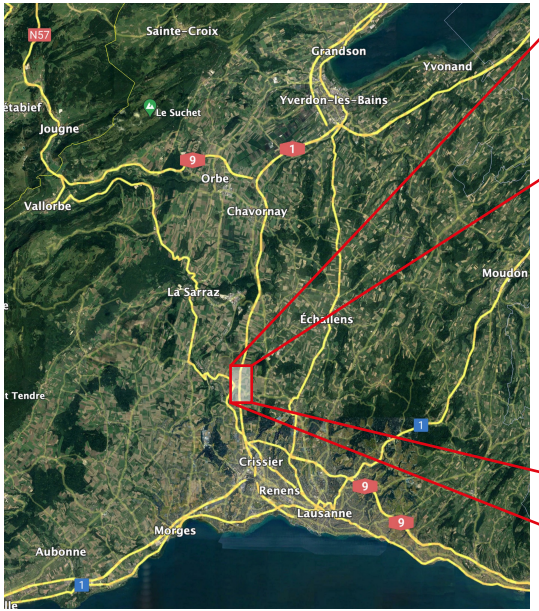
EPFL
LUTS

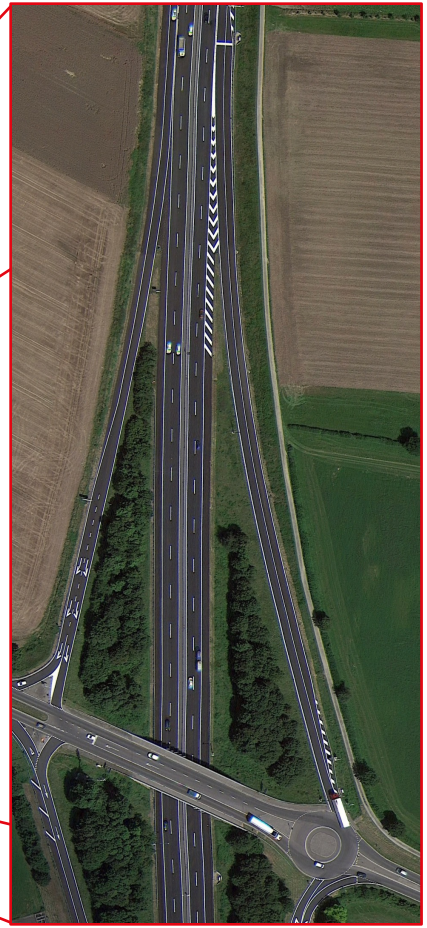


Ramp metering in CH

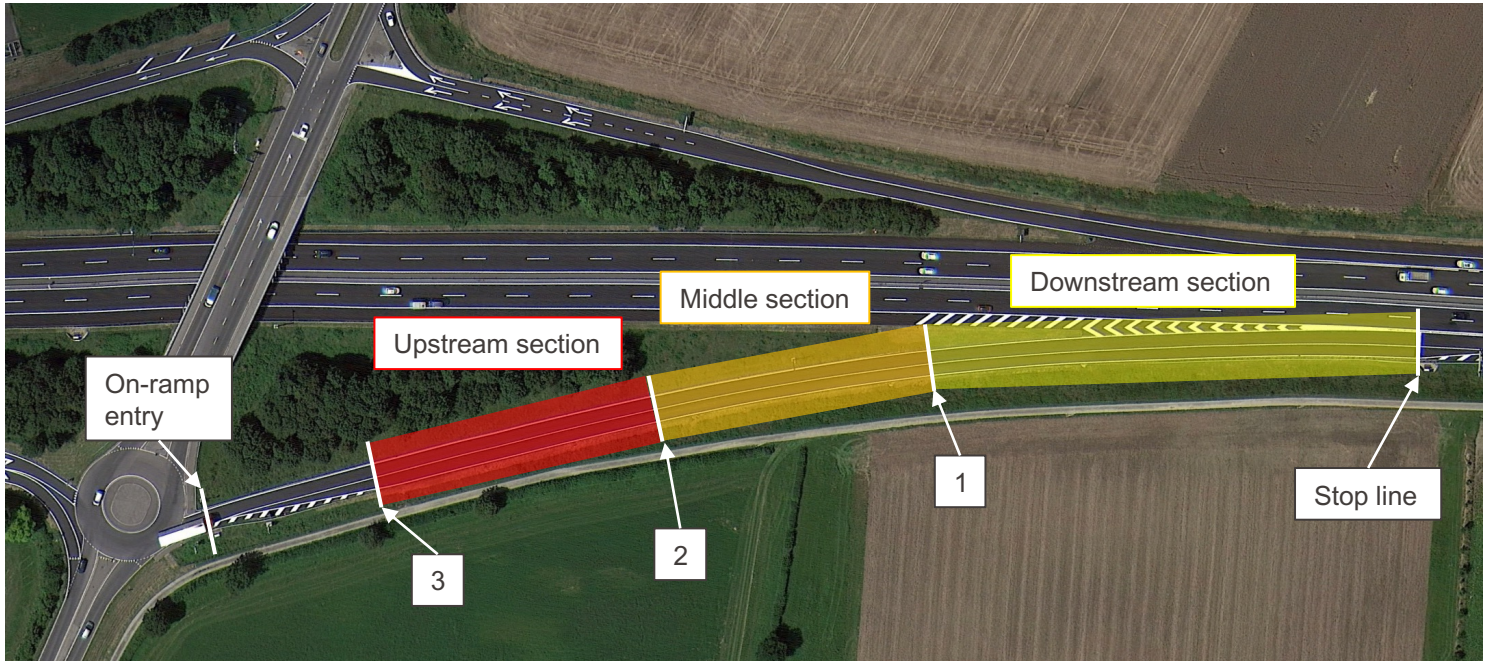
École polytechnique fédérale de Lausanne

Ramp metering Cossonay

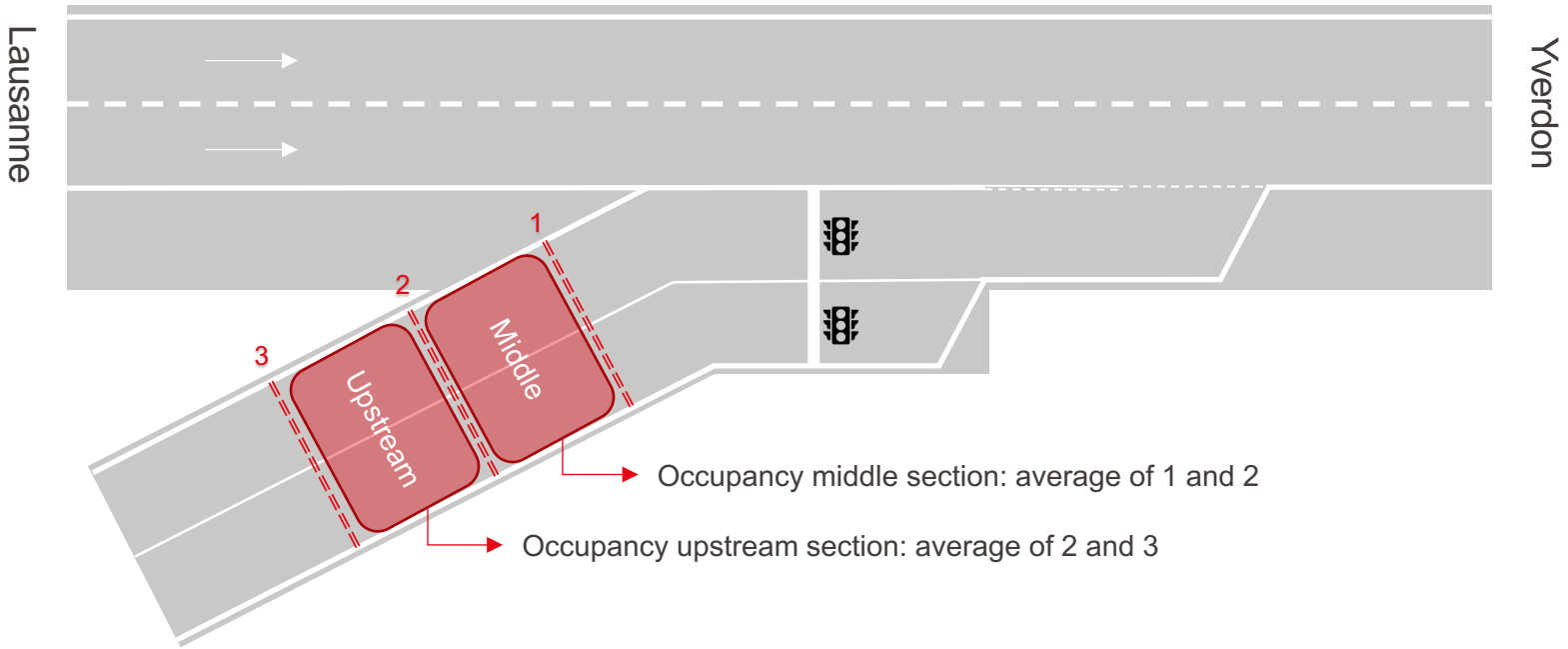




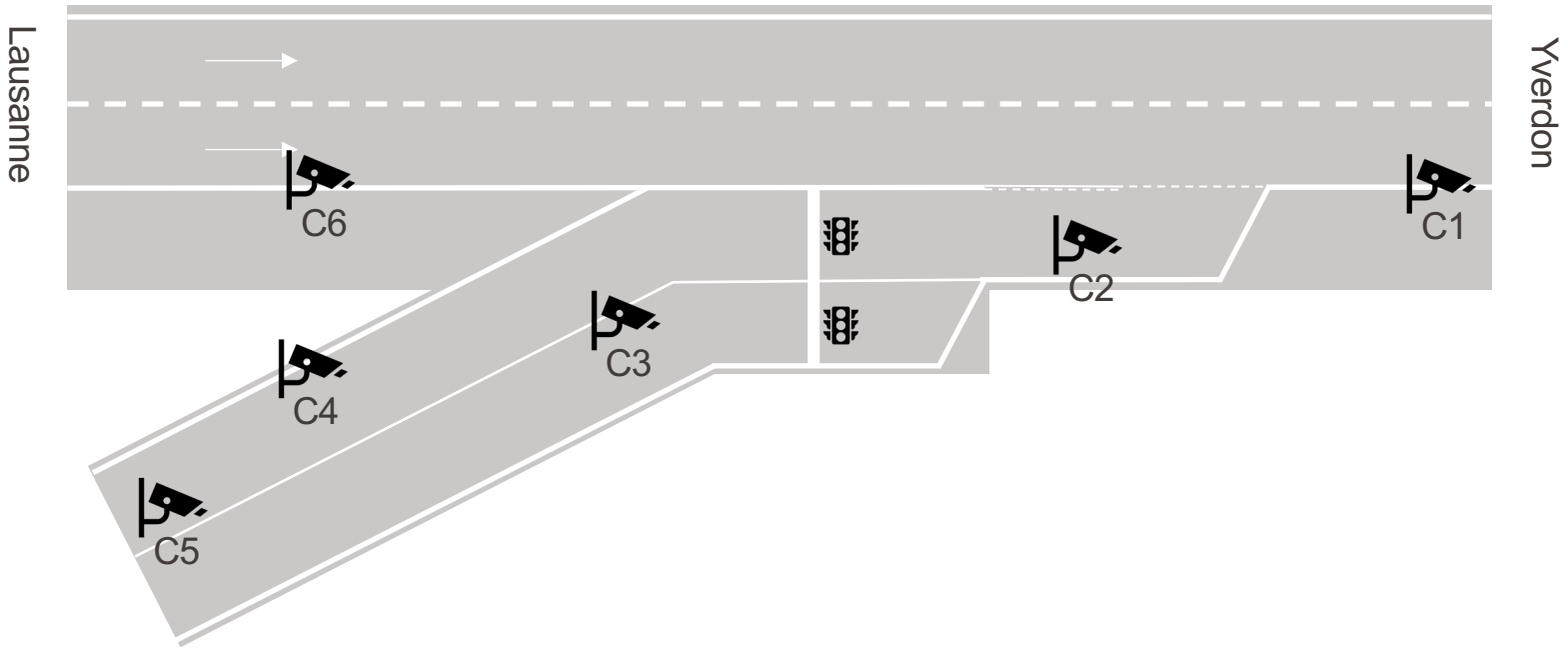
Ramp metering Cossonay



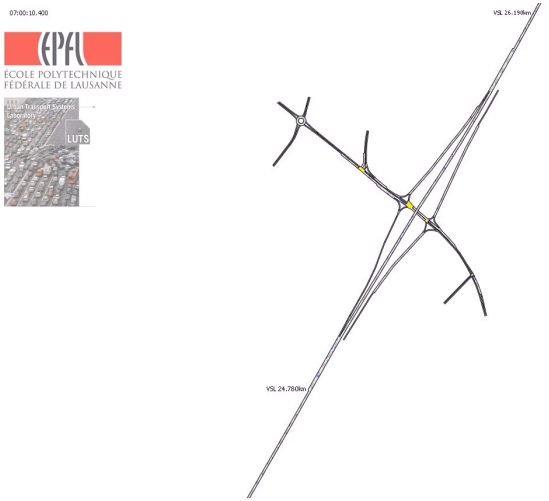
Ramp metering Cossonay



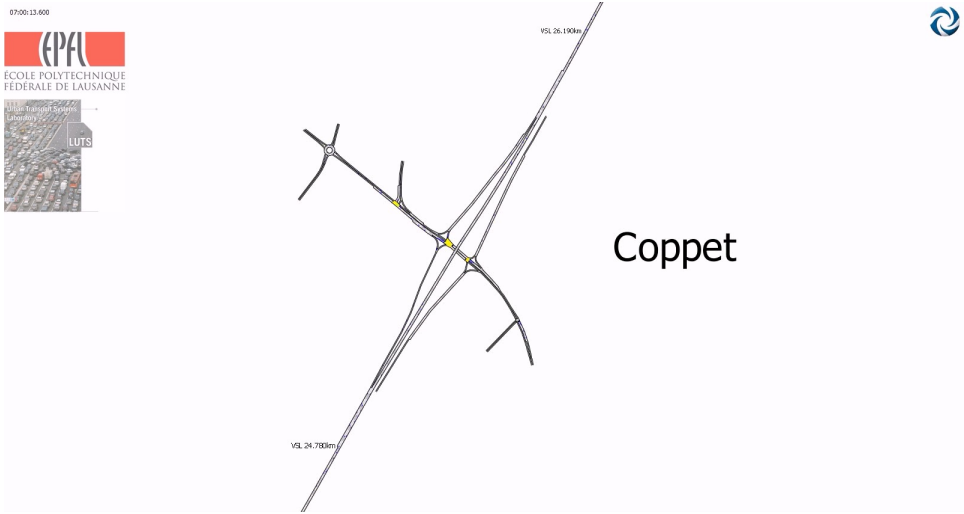
Ramp metering Cossonay



Simulation results



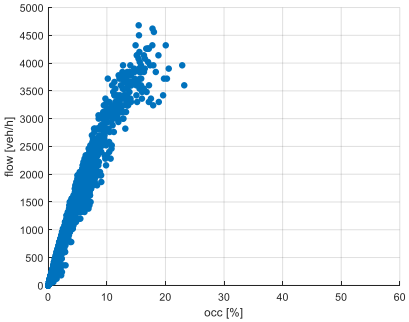
Coppet



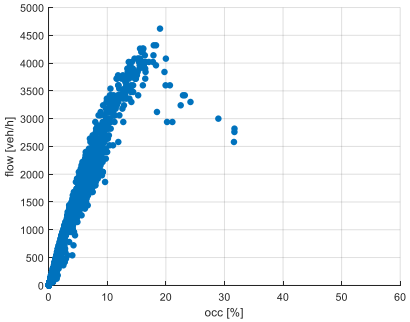
Coppet

Fundamental Diagram, Section 13
During RM

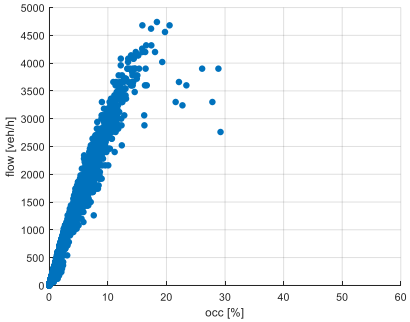
05/10, Tuesday



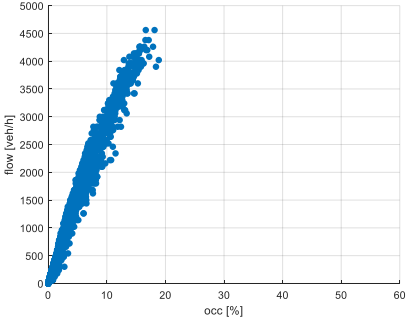
06/10, Wednesday



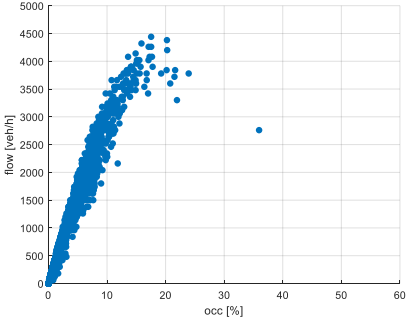
07/10, Thursday



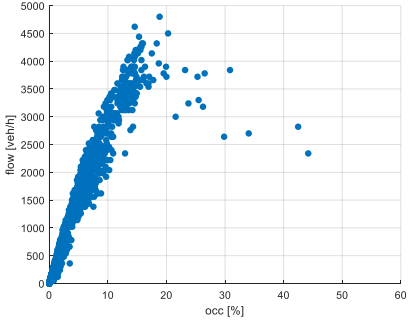
08/10, Friday



11/10, Monday

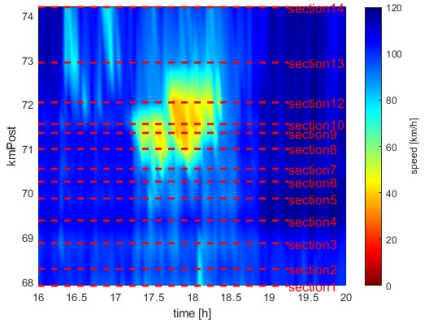


12/10, Tuesday

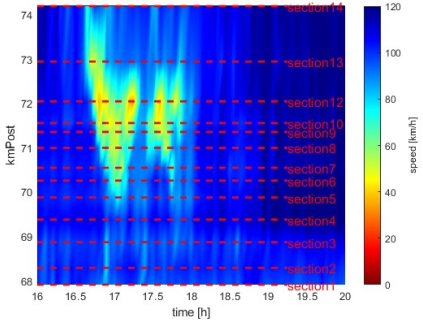


Before-After Comparison

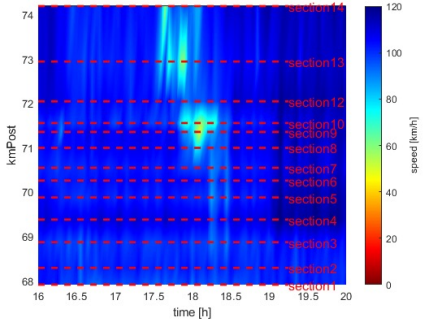
05/10, Tue



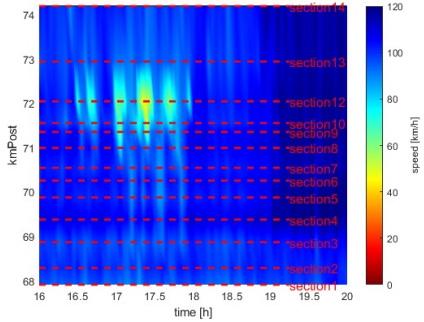
06/10, Wed



07/10, Thu



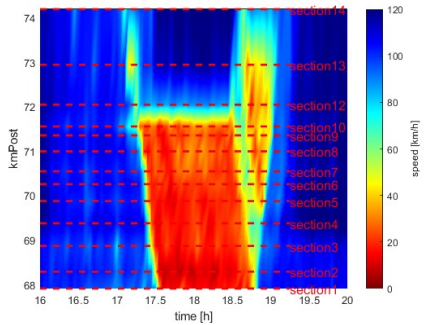
08/10, Fri



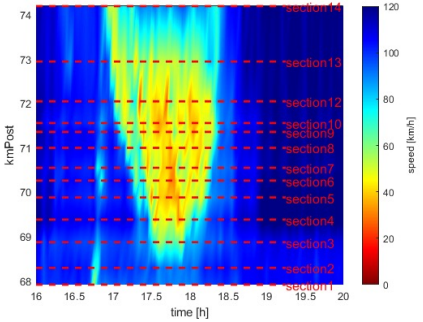
After RM

Before RM

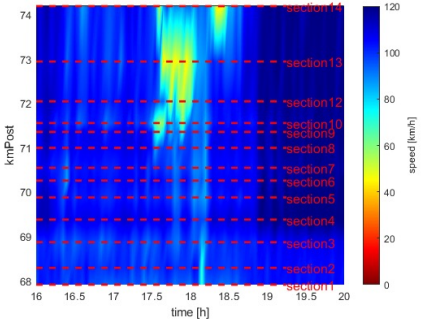
06/09, Mon



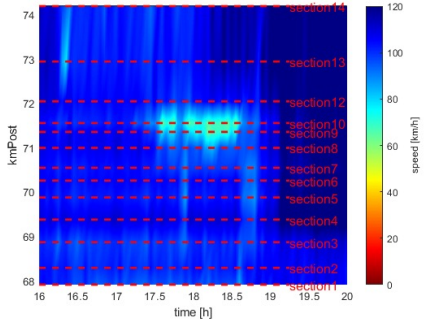
07/09, Tue



08/09, Wed



09/09, Thu



Activation


N01+720:940 1
Bern 92 km
Neuchâtel 59 km
Yverdon 23 km
Besançon 111 km
Vallorbe 32 km
C1


N01+720:620 1
C2


N01+720:215 1
C3

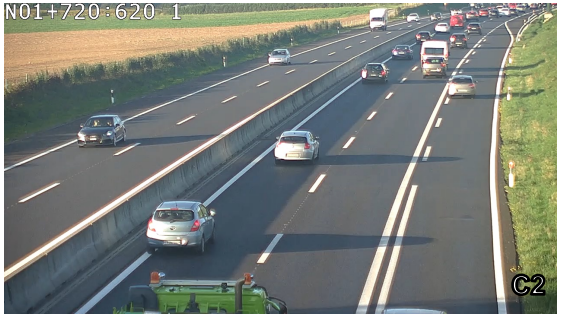

N01+720:062 1
C4


N01+720:062 2
C5


N01+720:065 1
C6

Small queue


N01+720:940 1
C1


N01+720:620 1
C2


N01+720:215 1
C3


N01+720:062 1
C4


N01+720:062 2
C5

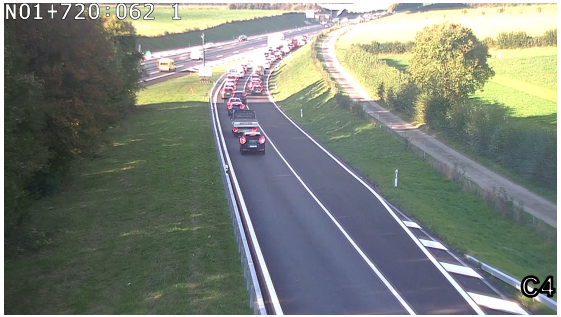

N01+720:065 1
C6

Long queue


N01+720+940 1
Bern 92 km
Neuchâtel 59 km
Yverdon 23 km
Besancon 111 km
Vallorbe 32 km
C1


N01+720:620 1
C2


N01+720:215 1
C3


N01+720:062 1
C4


N01+720:062 2
C5


N01+720:065 1
C6

Queue override