Reducing travel delay at sags: Implementable controllers

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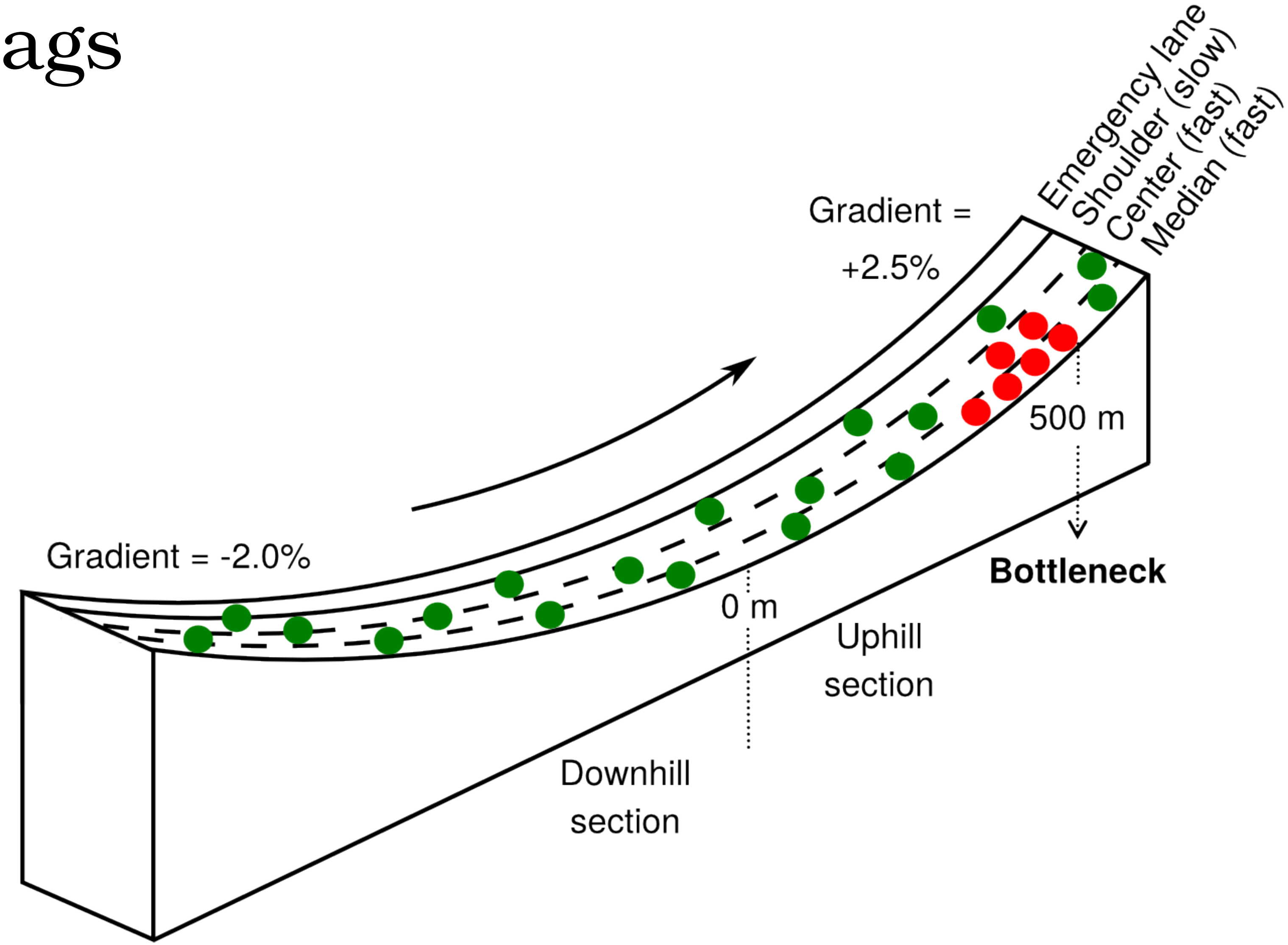
Challenge the future

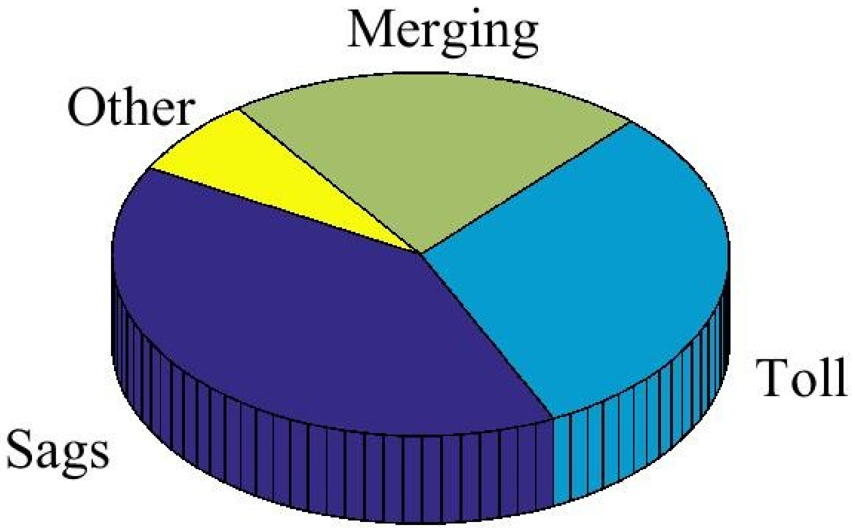
Japan vs the Netherlands

Sags


Emergency lane
Shoulder (slow)
Center (fast)
Median (fast)
Gradient =
+2.5%
500 m
Bottleneck
Gradient = -2.0%
0 m
Uphill
section
Downhill
section

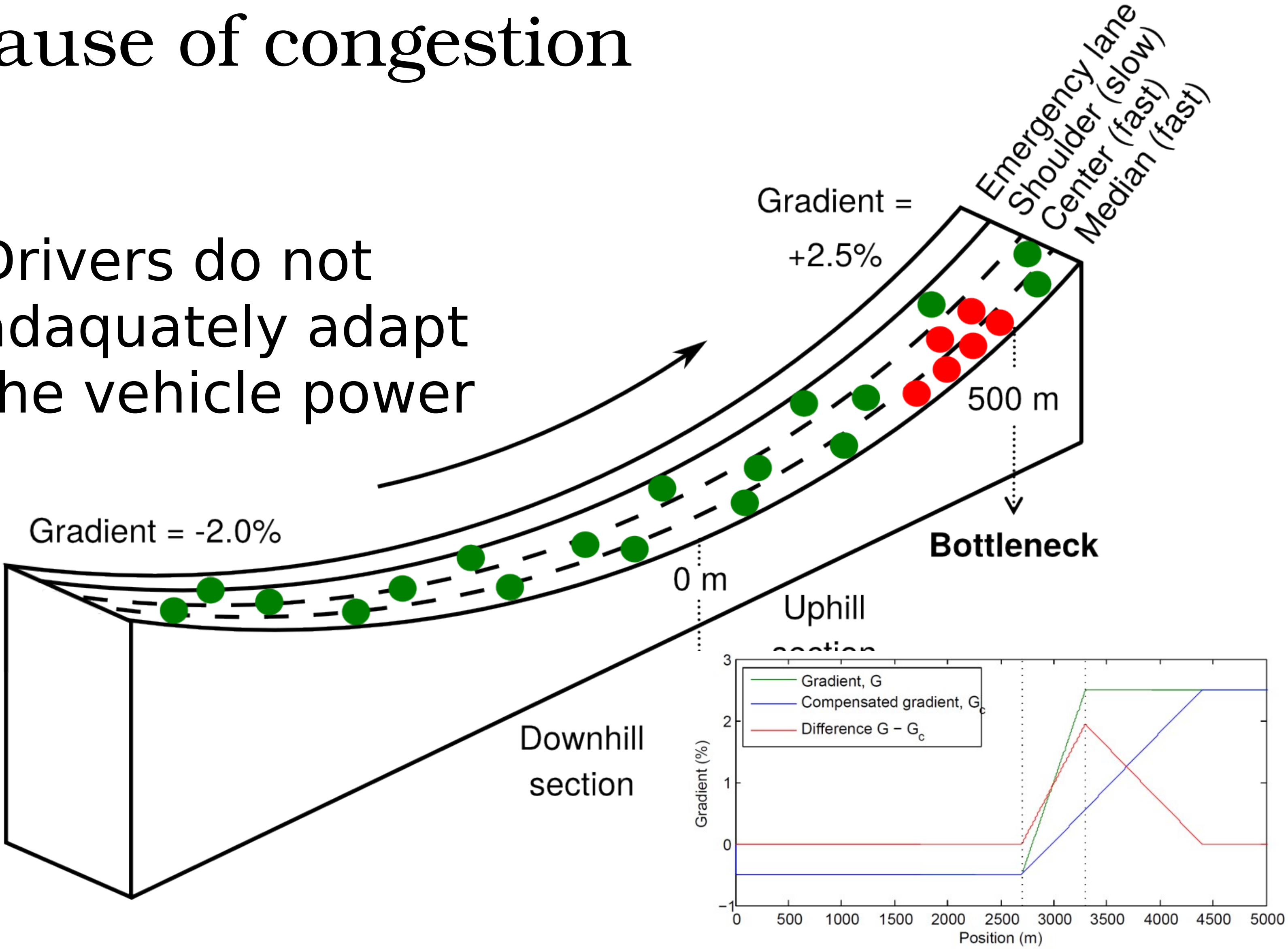
Relevance of congestion at sags

- In Japan, sags are the cause of most of the congestion
- Toll will reduce due to electronic toll collection



Cause of congestion

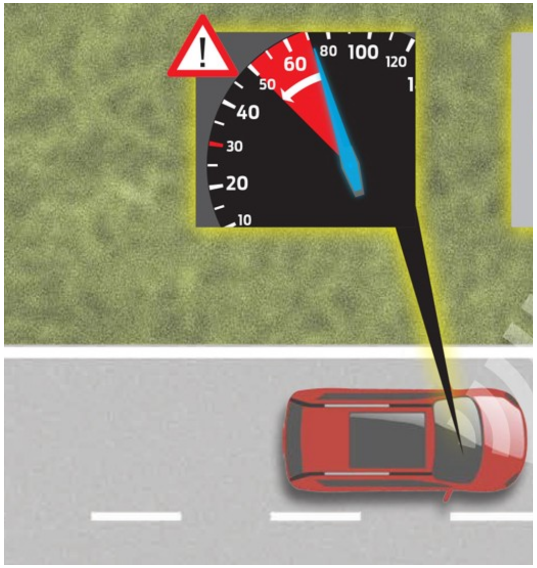
- Drivers do not adaquately adapt the vehicle power



Implementable Control

1. Main stream traffic flow metering

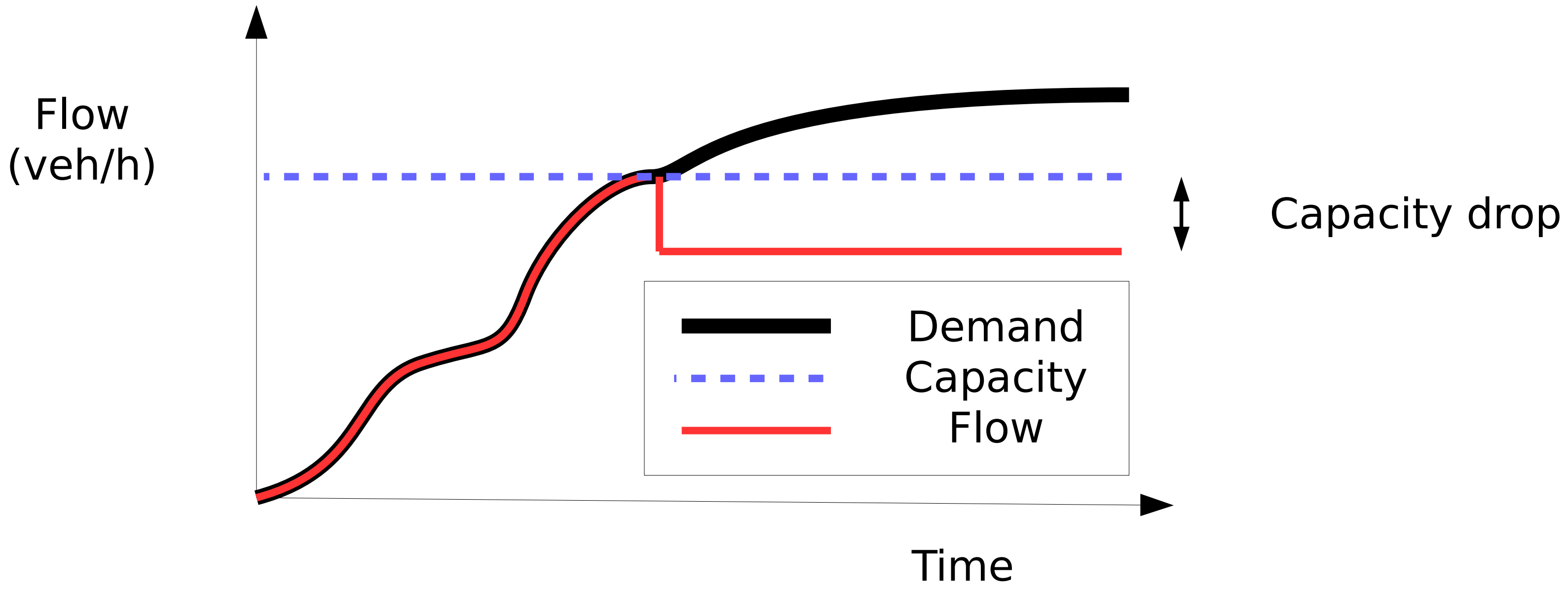
2. Individual control strategies



Background

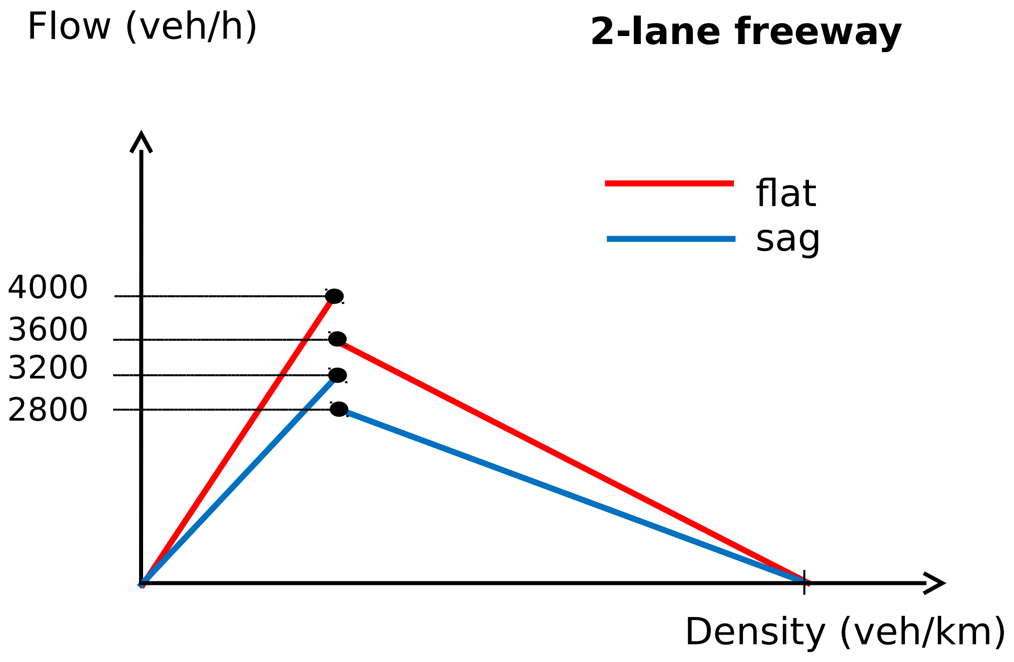
Capacity drop

- Capacity is the maximum flow through a bottleneck section



Background

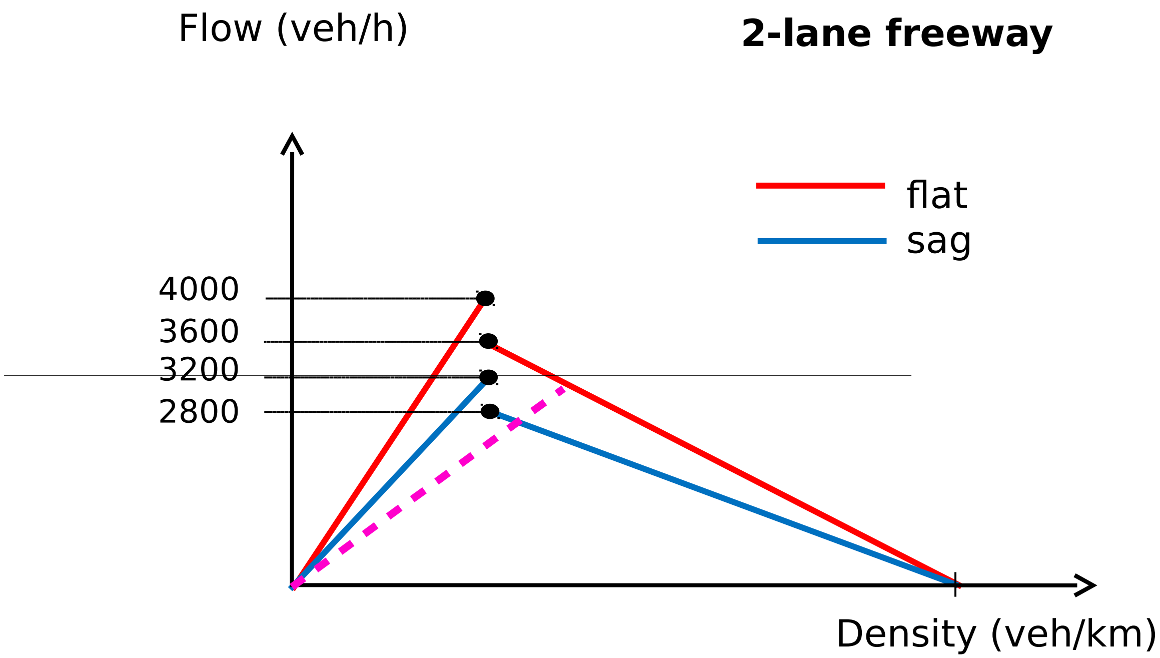
Traffic flow - “fundamental diagram



Goal

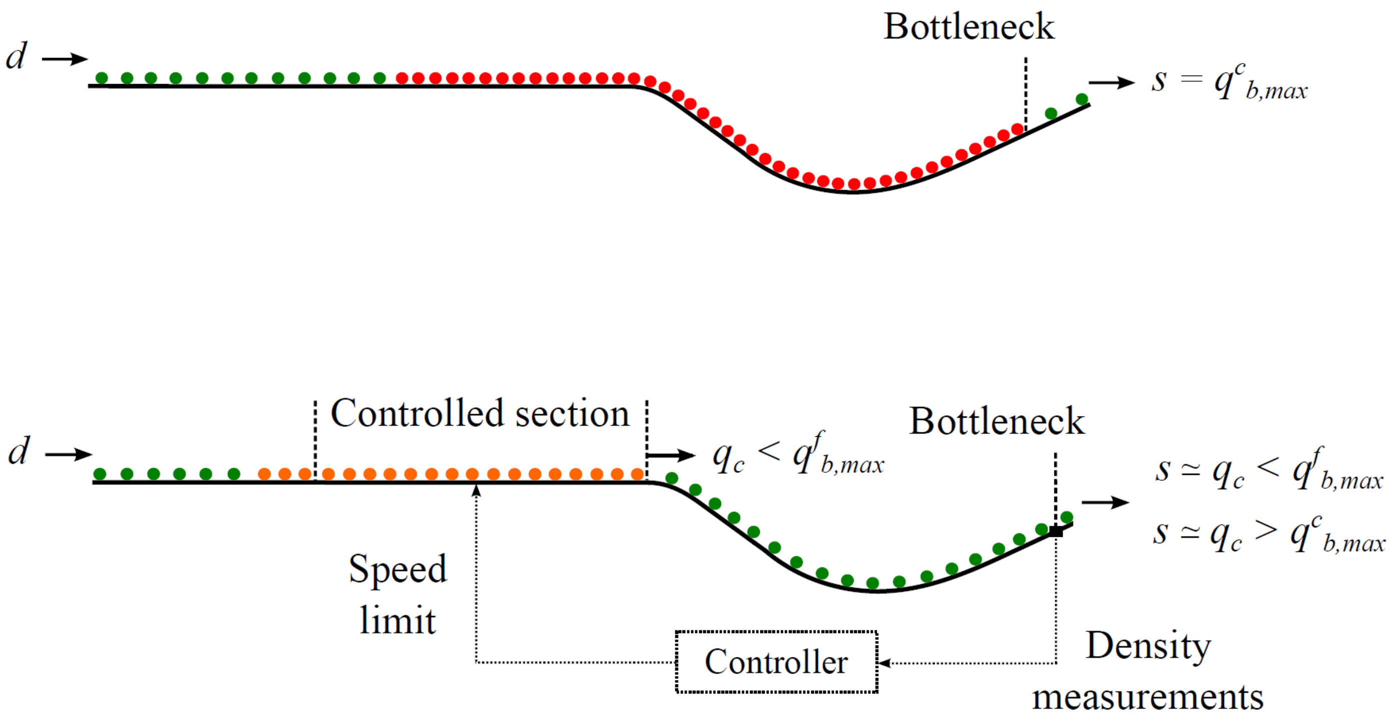
Sags as freeway bottlenecks

- keep the inflow to the bottleneck below its free flow capacity



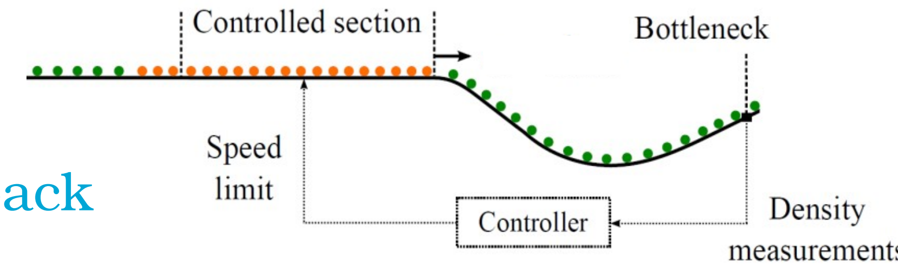
Control strategy

Control concept: mainstream traffic flow control (MTFC)



Control strategy

Control law: proportional feedback

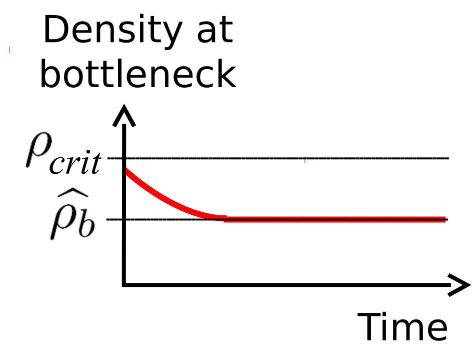


$$v_{\lim}^{\text{VSL}}(k) = v_{\lim,0}^{\text{VSL}} + K_p \cdot [\widehat{\rho}_b - \rho_b(k - r)]$$

- $v_{\lim}^{\text{VSL}}(k)$: Speed limit → Variable
- $v_{\lim,0}^{\text{VSL}}$: Target speed limit → Constant
- K_p: Gain → Constant
- $\widehat{\rho}_b$: Target density → Constant
- $\rho_b(k - r)$: Measured density → Variable
- r: Delay → Constant

Constraints

- $v_{\lim}^{\text{VSL}}(k)$ is a multiple of 10 km/h
- $v_{\lim}^{\text{VSL}}(k) \geq$ 20 km/h
- $|v_{\lim}^{\text{VSL}}(k) - v_{\lim}^{\text{VSL}}(k+1)| \leq$ 20 km/h



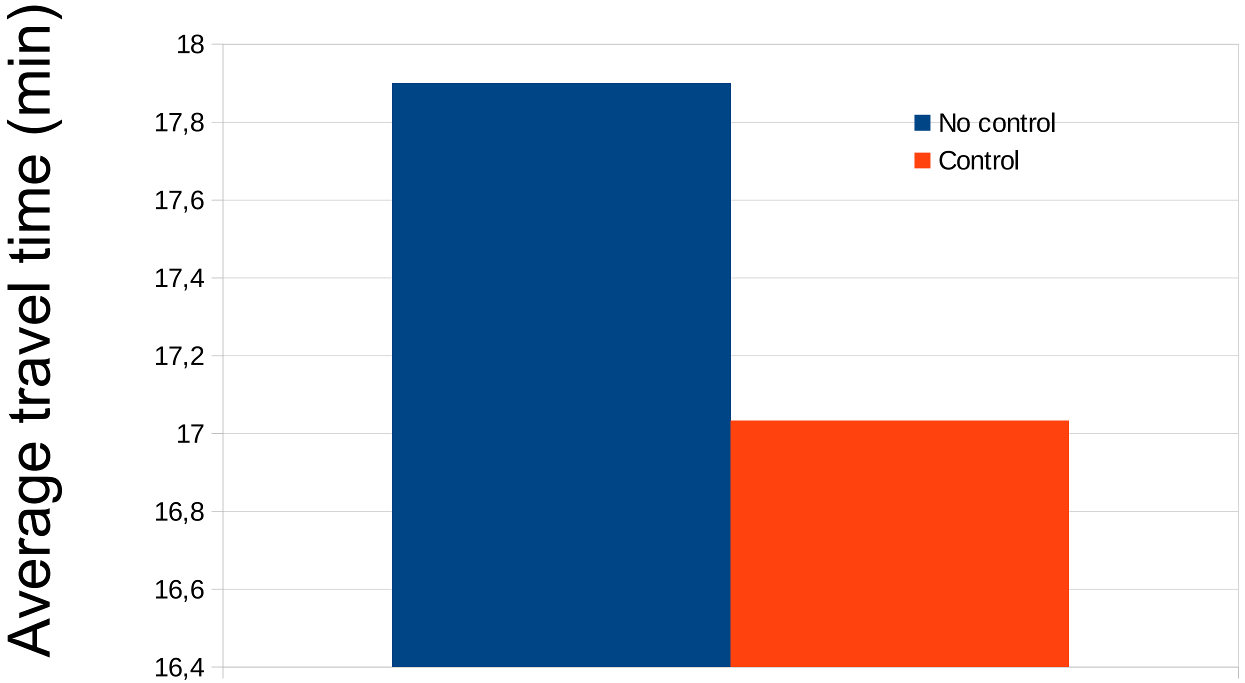
Evaluation method

Case study

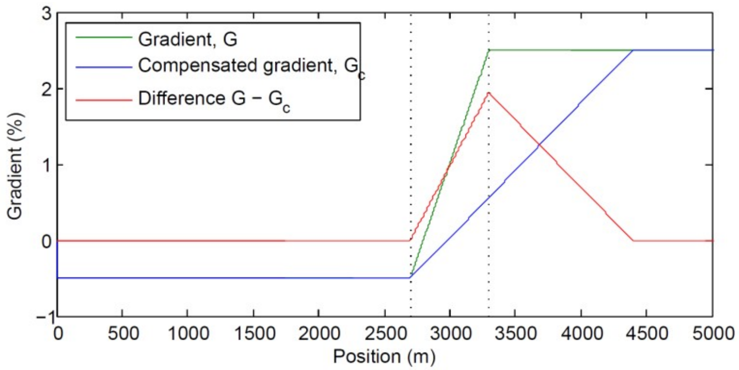
- Microscopic traffic flow model

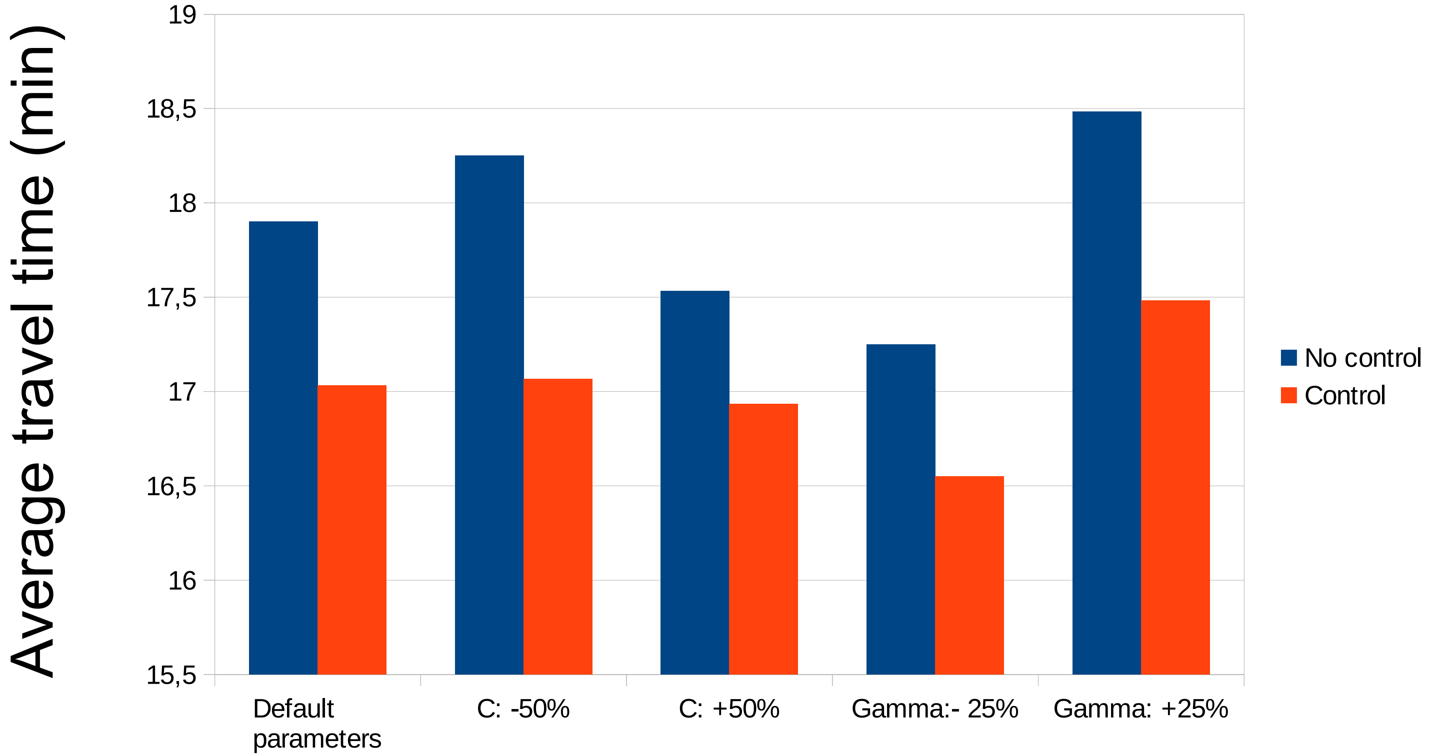
- Two scenarios:
  - No-control scenario
  - Control scenario

Results


Average travel time (min)
18
17,8
17,6
17,4
17,2
17
16,8
16,6
16,4
No control
Control

Results

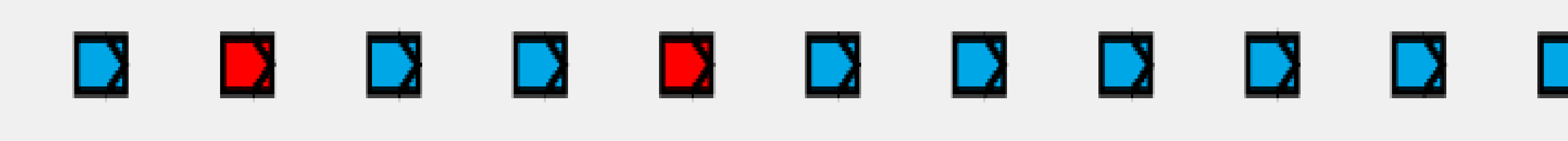

Gradient, G
Compensated gradient, G_c
Difference $G - G_c$
Gradient (%)
Position (m)
3
2
1
0
−1
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000


Average travel time (min)
19
18,5
18
17,5
17
16,5
16
15,5
Default parameters
C: -50%
C: +50%
Gamma:- 25%
Gamma: +25%
No control
Control

Vehicle-based controllers

Main idea

- Let individual vehicles solve the congestion
- Derive actions from the optimal control:
  1) Adaptive cruise control
     no influence of sag?
  2) Cooperative adaptive cruise control
     Forward information
  3) Traffic State Adaptive CACC
     vary the algorithm of the CC
  4) I2V: 4 vehicles
- Test outcomes in simulations



Adaptive cruise control

- Desired speed set, cruise control adapts speed to leader if needed
(not affected by gradient)

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$$a = \boxed{k_1(v_{\text{input},i} - v_i)} + \boxed{k_2 \frac{\Delta v_i}{s_i}}$$

ACC formulation

Coordination: speed adaptation (depends on distance)

Cooperative adaptive cruise control

- The CACC controller receives information of speed and position from vehicles downstream
- CACC is ACC+*vehicle communication*
  - No vehicle in range: ACC
  - Vehicle in range: CACC

Cooperative adaptive cruise control

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- CACC is ACC+*vehicle communication*
  - No vehicle in range: ACC
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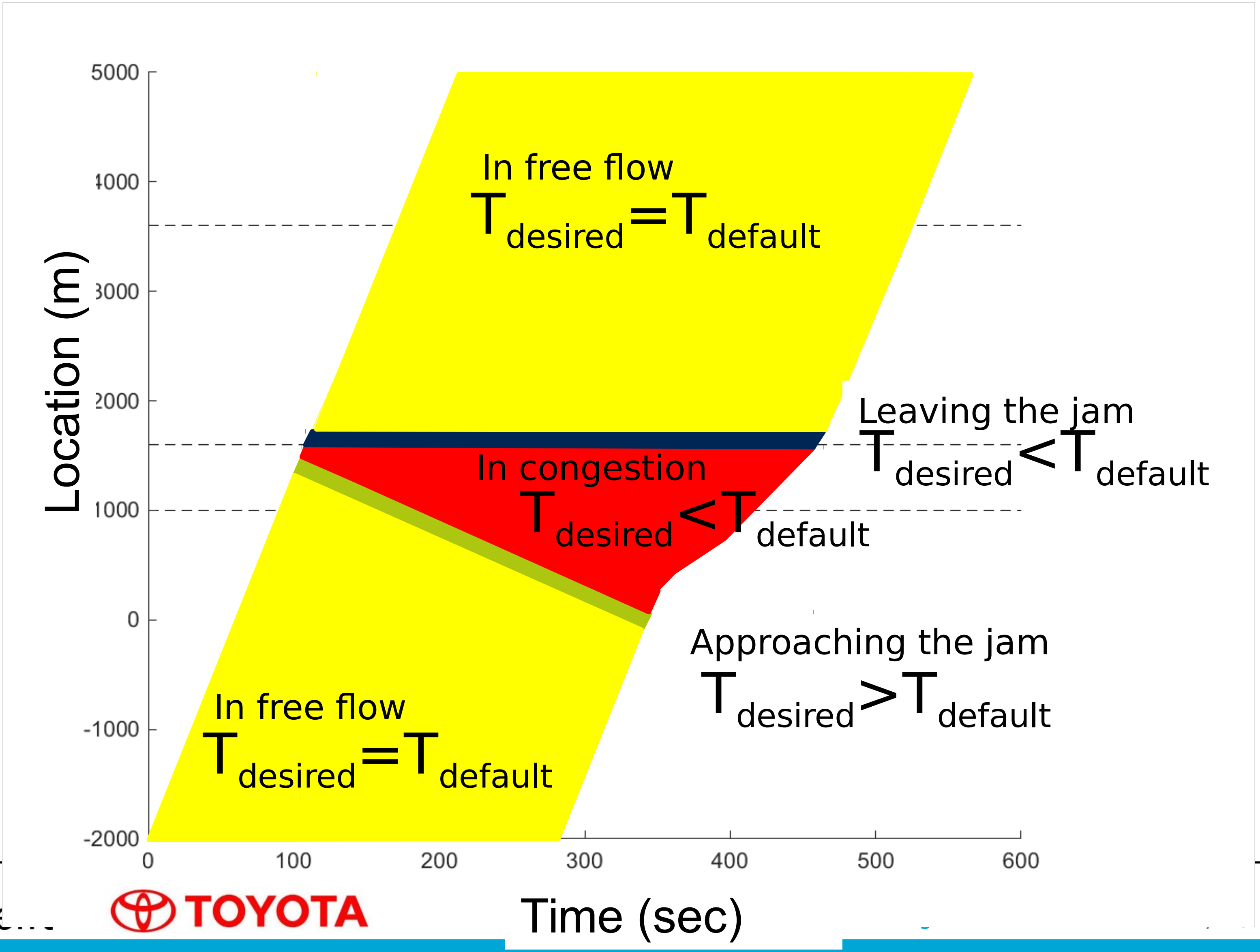
- In an equation

$$a_i^{\text{CACC}} = a_i^{\text{ACC}} + k_3 \sum_{j=i-2}^{N} \frac{v_j - v_i}{x_j - x_i}$$

Traffic state adaptive cruise control

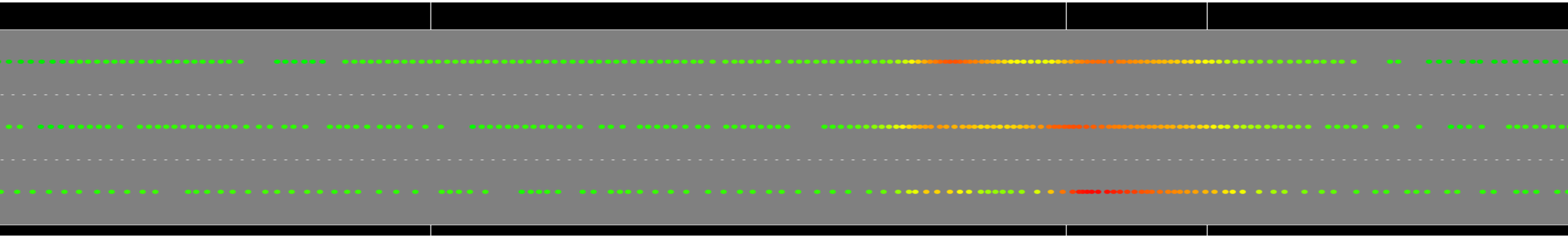


Infrastructure to vehicle

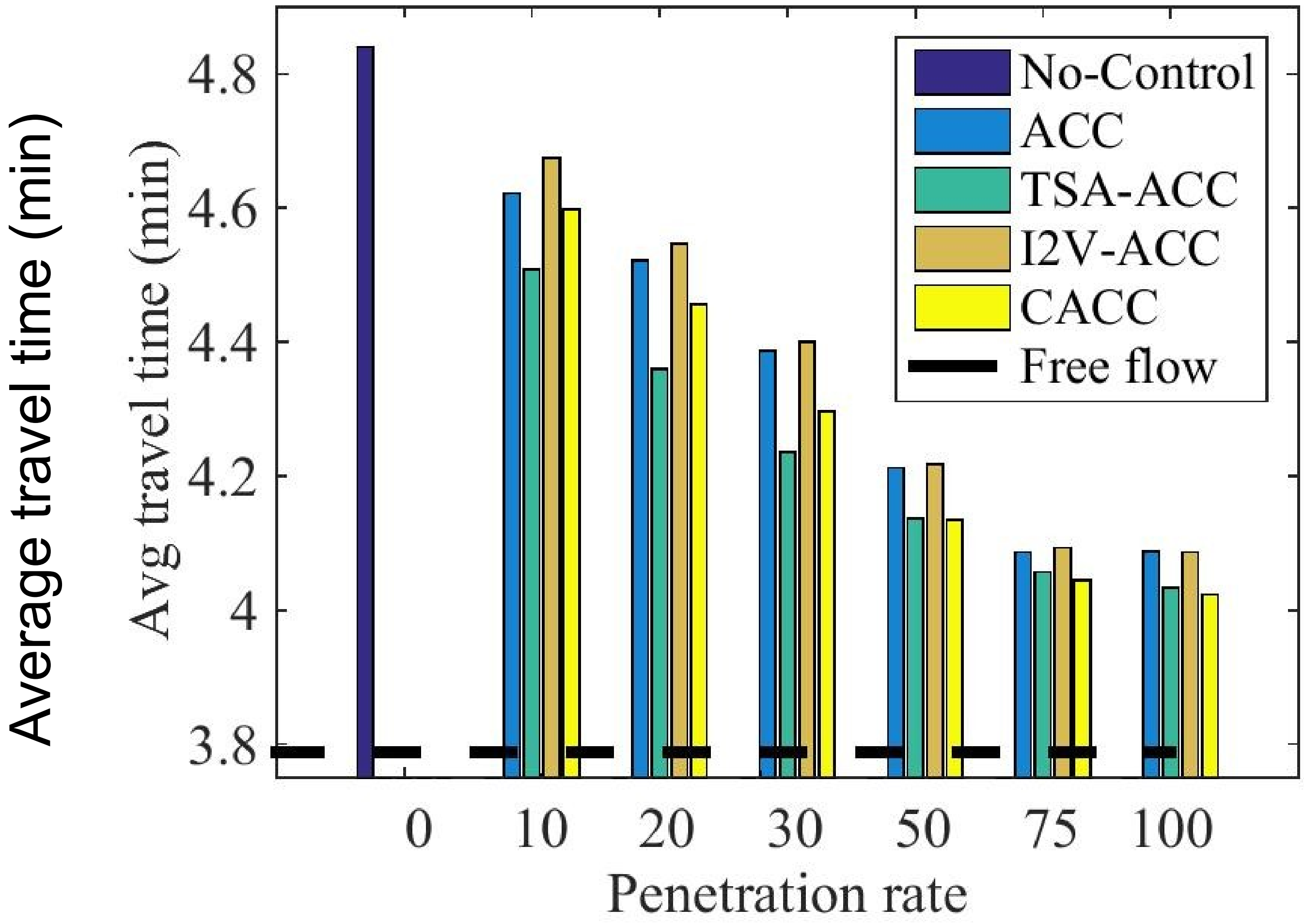
- Apart from the ACC vehicles, there are 4 I2V vehicles
- Low detector speeds => high desired headway (gradual change)

Testing extensions

- Microscopic simulation:
  - Multi-lane
  - Trucks
    (base 16%, also 10&20%)
  - Speed classes
  - Speed variation

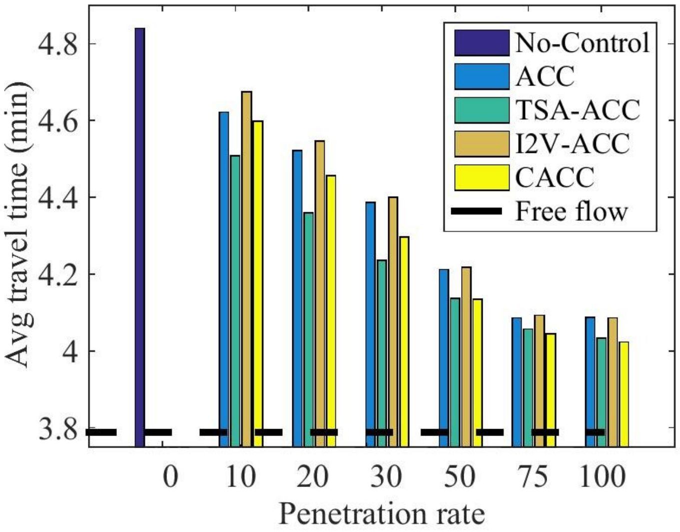


Results


Average travel time (min)
Avg travel time (min)
4.8
4.6
4.4
4.2
4
3.8
No-Control
ACC
TSA-ACC
I2V-ACC
CACC
Free flow
0
10
20
30
50
75
100
Penetration rate

Results

Average travel time (min)

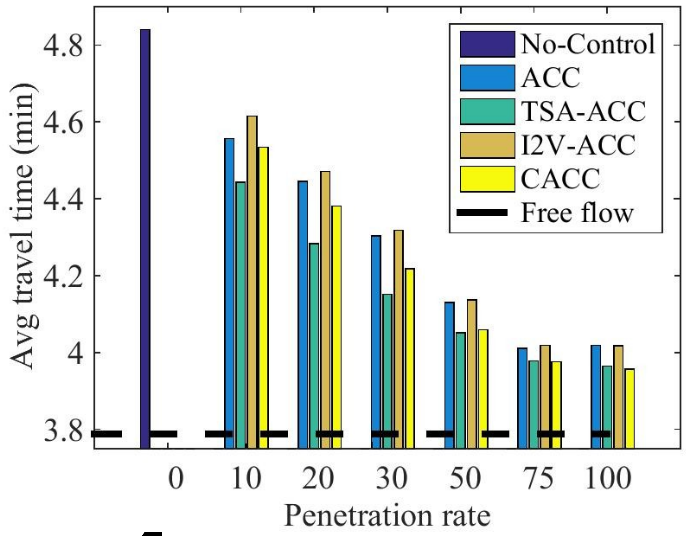


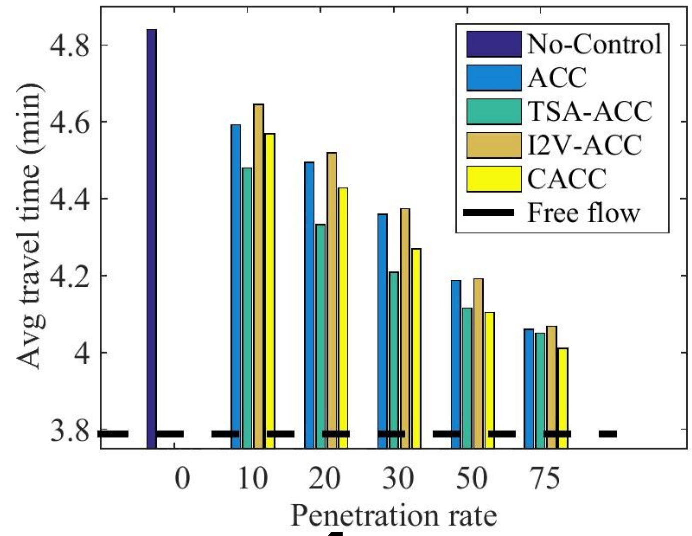
Penetration rate

- The higher the penetration rate, the better
- Traffic state adaptation and CACC leads to the best results
- CACC needs higher penetration rate

Results

Average travel time (min)





Penetration rate

- Equipped vehicles are better off than non-equipped vehicles (slightly, trucks excluded)
- All improve

Conclusions

- Two strategies:
  - Main stream control using speed limits
    all vehicles reduce speed,
    avoid congestion (but slow down)
  - Individual vehicles controlled

- Outflow increases by strategies
- Travel time depends on penetration rate
- TSA-ACC best for low penetration
- Cooperative ACC best for high penetration