A model of car-following behavior at sags

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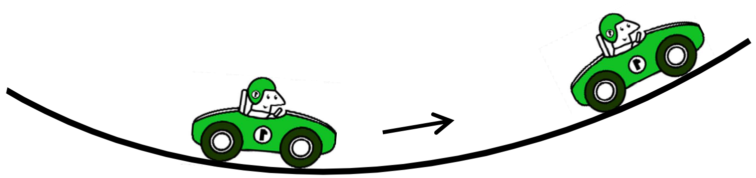

Jülich Supercomputing Centre

Traffic and Granular Flow '13

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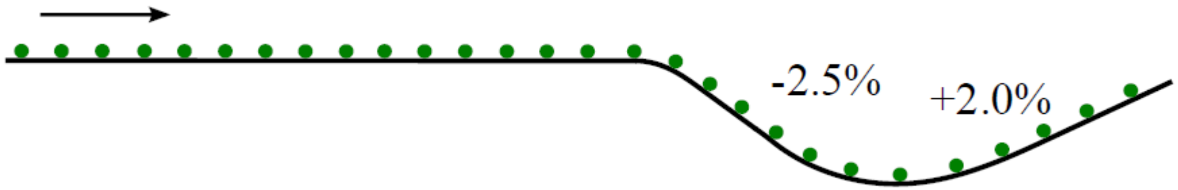
Outline

1. Background
2. Car-following model
3. Empirical data
4. Simulation study
5. Conclusions

Background

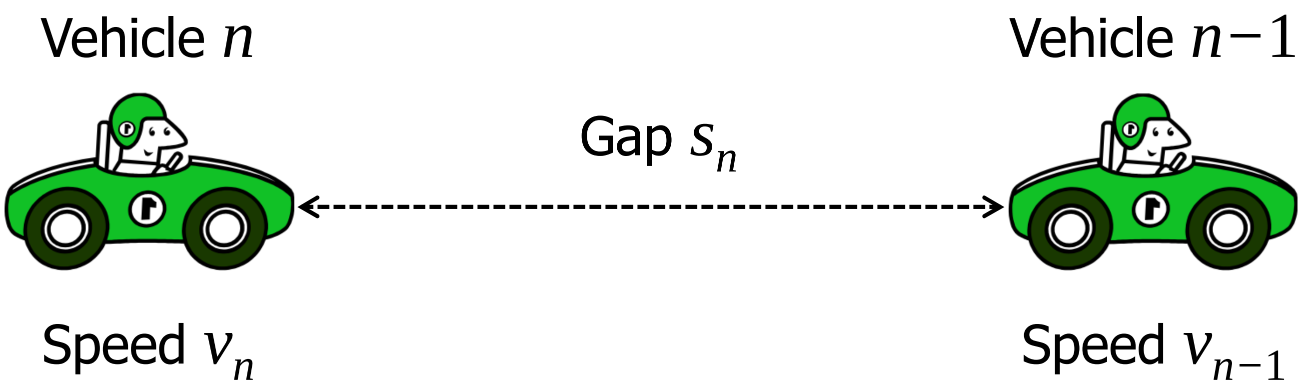
What is a sag?

- **Sag**: freeway section along which the gradient changes significantly from downwards to upwards



Background

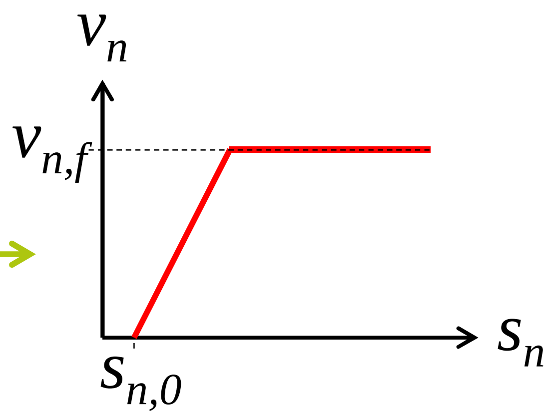
What is car-following behavior?



Relative speed $\Delta v_n = v_{n-1} - v_n$

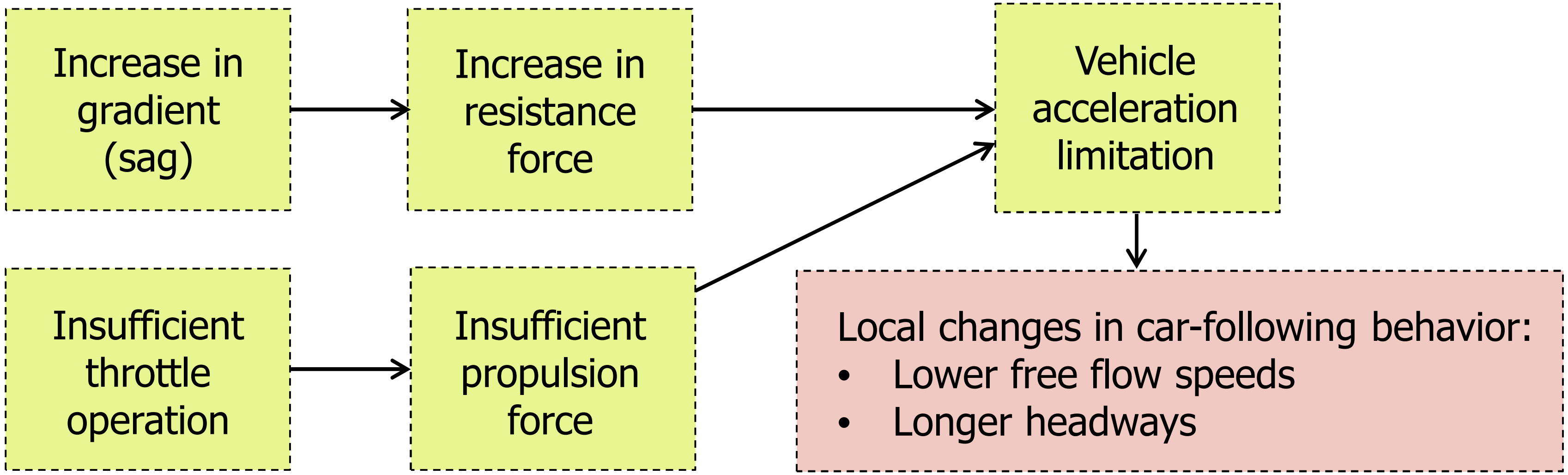
Acceleration $dv_n/dt = f\,(s_n, v_n, \Delta v_n, \ldots)$

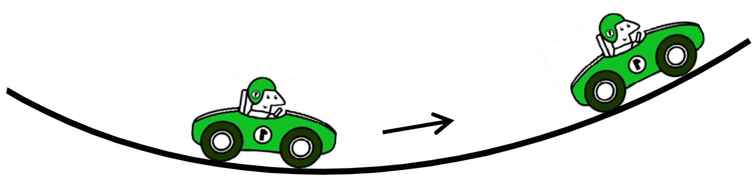
Equilibrium traffic conditions

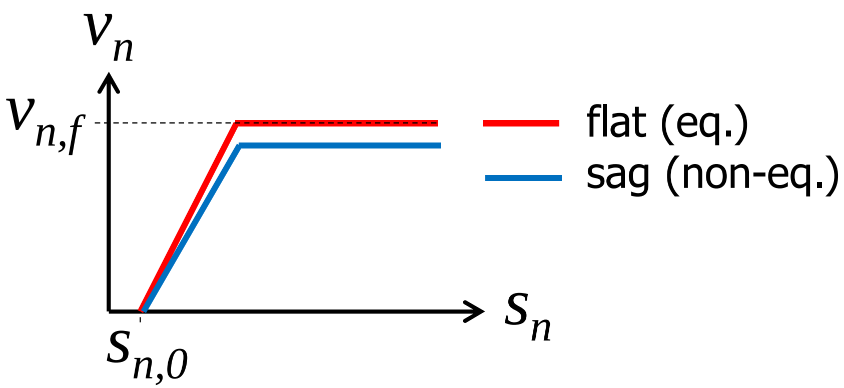


Background

Car-following behavior at sags







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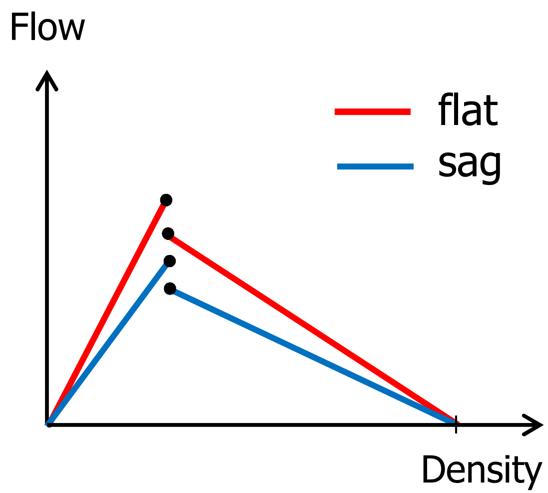
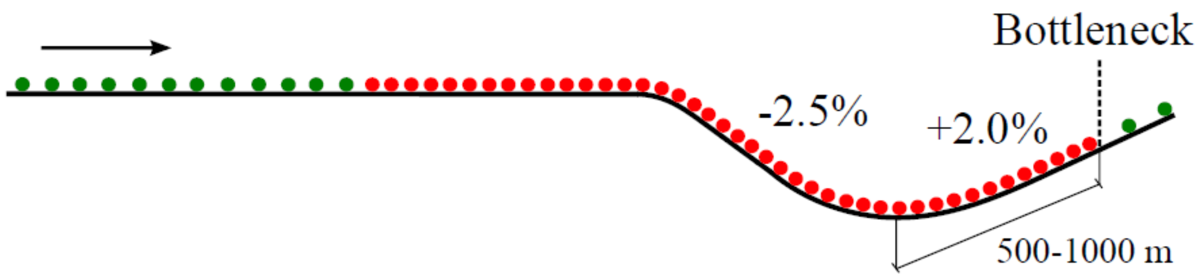
Background

Sags become freeway bottlenecks

- Those changes in car-following behavior have a negative influence on freeway capacity
  - ➢ Capacity is 10-20% lower at sags than at flat sections



- In conditions of high demand, traffic breaks down at sags → capacity drop



Car-following model

Influence of gradient: principles

1. Drivers perceive the change in gradient at sags

2. Drivers are not able to fully compensate for the increase in resistance force at the beginning of the uphill section

    - Limiting effect on vehicle acceleration

3. Along the uphill section, drivers are able to gradually compensate for the increase in resistance force

    - The limiting effect on vehicle acceleration decreases over time/space

Car-following model

Formulation

- Acceleration: $\dot{v}(t) = f_1(t) + f_2(t)$
- **First term**: influence of speed, gap and relative speed (≈ IDM)

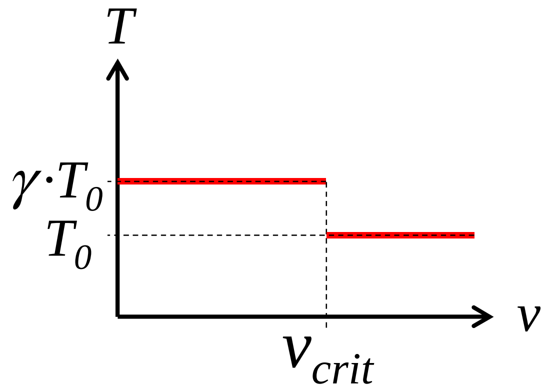
$$f_1(t) = a \cdot \left[1 - \left(\frac{v(t)}{v_{des}(t)} \right)^4 - \left(\frac{s^*(t)}{s(t) - l} \right)^2 \right]$$

where: $s^*(t) = s_0 + v(t) \cdot T(t) + \frac{v(t) \cdot \Delta v(t)}{2 \cdot \sqrt{ab}}$

Safe time gap (s)

$$T(t) = \begin{cases} T_0 & \text{if } v(t) \geq v_{crit} \\ \gamma \cdot T_0 & \text{if } v(t) < v_{crit} \end{cases}$$

… to model the capacity drop



Car-following model

Formulation

- Acceleration: $\dot{v}(t) = f_1(t) + f_2(t)$
- **Second term**: influence of gradient

$$f_2(t) = -g \cdot [G(t) - G_c(t)]$$

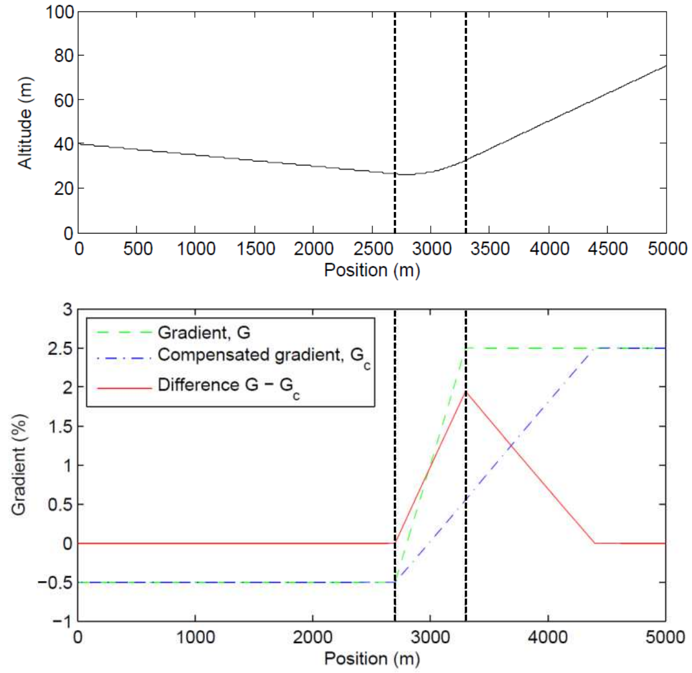
Compensated gradient

where:

$$G_c(t) = \begin{cases} G(t) & \text{if } G(t) \leq G(t_c) + c \cdot (t - t_c) \\ G(t_c) + c \cdot (t - t_c) & \text{if } G(t) > G(t_c) + c \cdot (t - t_c) \end{cases}$$

Maximum gradient compensation rate (s^{-1})

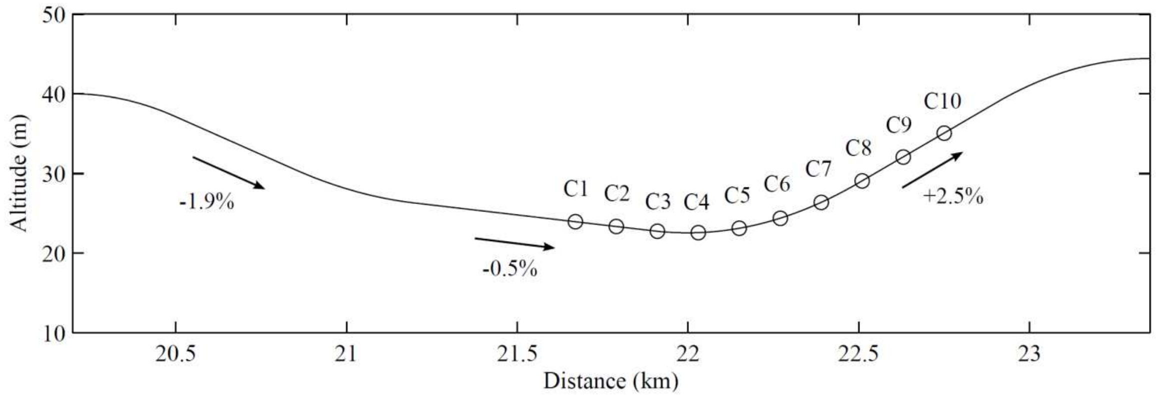
$$t_c = \max(t \mid G_c(t) = G(t))$$

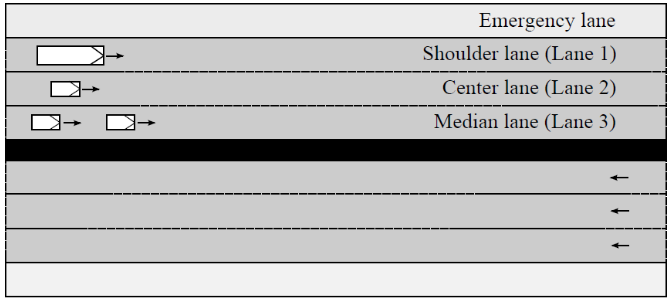


Empirical data

Study site

- Yamato sag, Tomei Expressway (Japan)
- 3 lanes

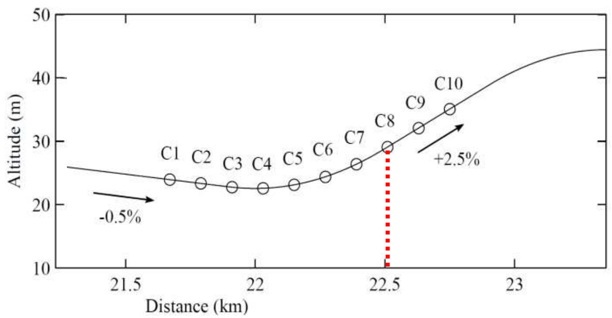




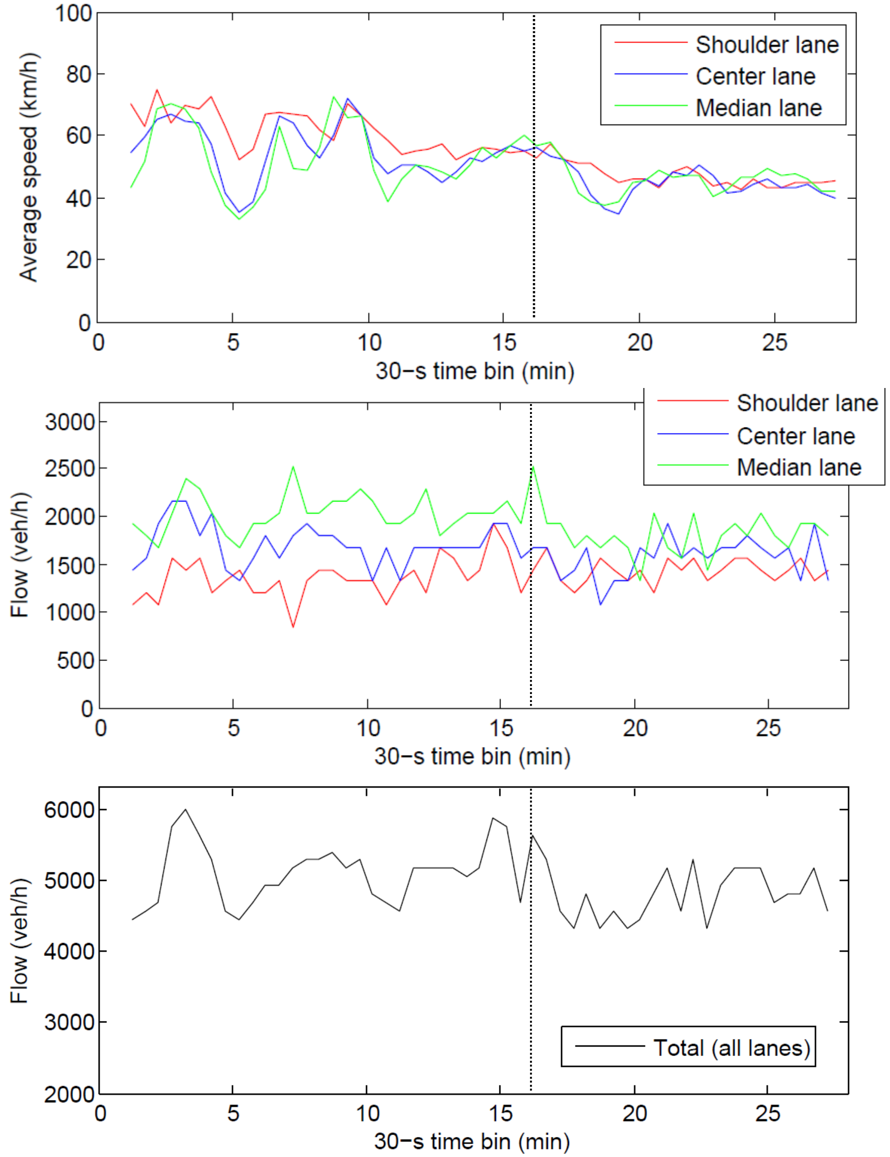
Empirical data

Speed and flow data

- Bottleneck location (head of the queue):
  - x ≈ 22.5 km,
    500 m downstream of the bottleneck (camera 8)

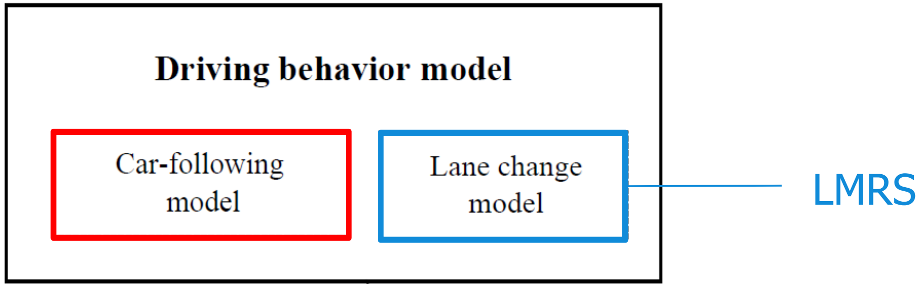


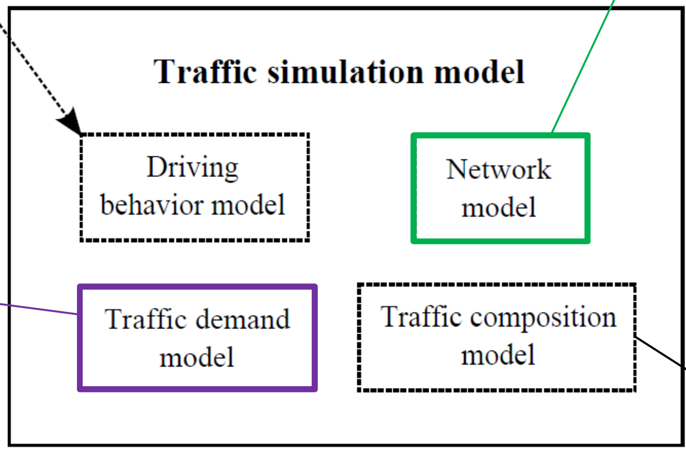
x = 22.5 km (bottleneck)

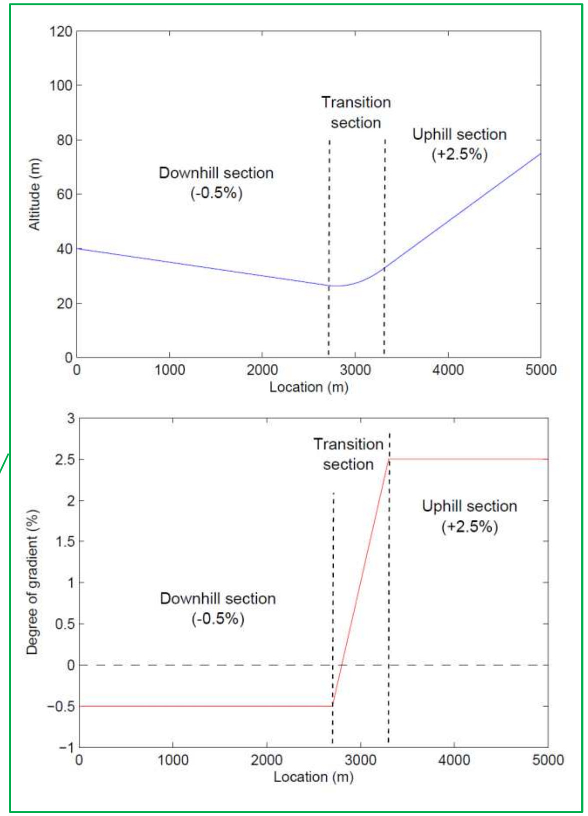


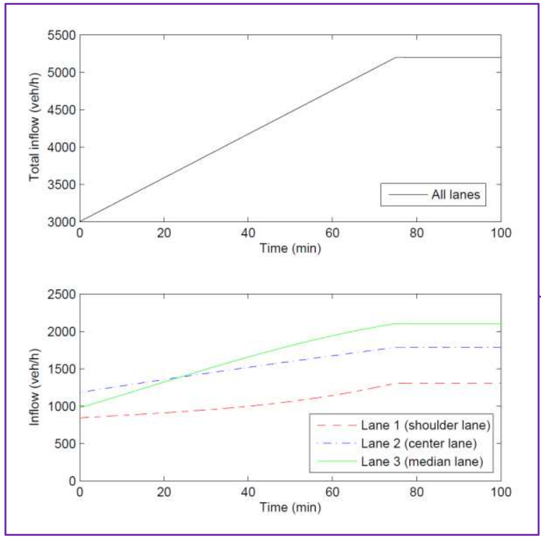
Simulation study

Set-up





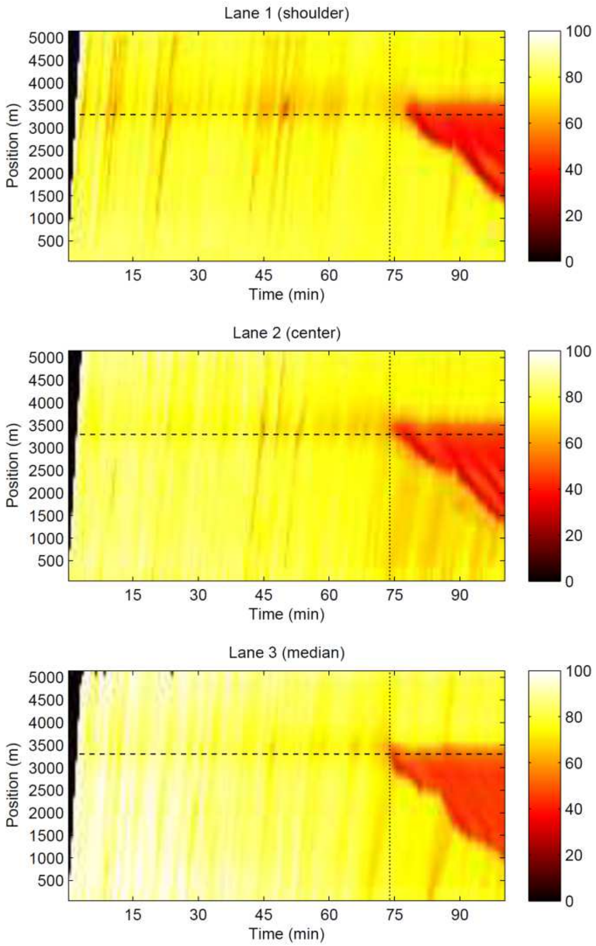




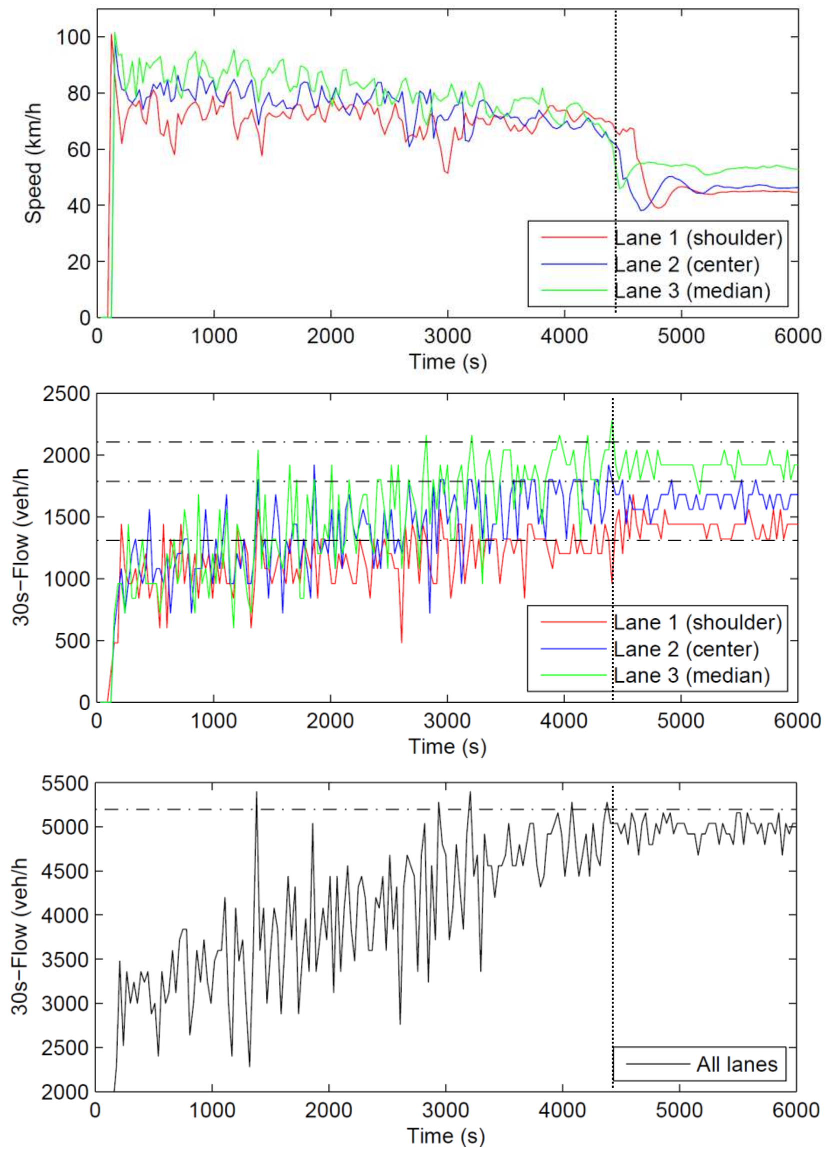
Vehicle type	Car	Car	Car	Truck
Driver type	Car driver 1	Car driver 2	Car driver 3	Truck driver
Shoulder lane	90%	0%	0%	10%
Center lane	0%	95%	0%	5%
Median lane	0%	0%	100%	0%

Simulation study

Results



x =3200 m (bottleneck)



Conclusions

- New **car-following model** that takes into account the influence of gradient on vehicle acceleration

- Formulation: IDM + 1 additional parameter

- Key **phenomena** reproduced by our model:
  - ✓ Vehicle acceleration limitation
  - ✓ Reduced capacity
  - ✓ Bottleneck location
  - ✓ Capacity drop in congestion

- Use of the model to test the effectiveness of **control measures** to mitigate congestion at sags

Any questions?

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Parameters

Vehicle type	Car	Car	Car	Truck
Driver type	Car driver 1	Car driver 2	Car driver 3	Truck driver
l (m)	4	4	4	15
a_0 (m/s^2)	1.25	1.25	1.25	0.50
b_0 (m/s^2)	1.80	1.80	1.80	1.50
T_0 (s)	1.45	1.20	1.15	1.50
s_0 (m)	3	3	3	3
v_{lim} (km/h)	100	100	100	85
v_{max} (km/h)	150	150	150	100
v_{crit} (km/h)	60	60	60	60
c_0 (s^{-1})	0.00042	0.00042	0.00042	0.00042
γ (-)	1.15	1.15	1.15	1.15
$\bar{\delta}$ (-)	0.92	0.97	1.03	1.00
σ_δ (-)	0.03	0.10	0.10	0.00
$\overline{v}_{des,t}$ (km/h)				85
$\sigma_{v_{des,t}}$ (-)				2.5
$T_{min,0}$ (s)	0.56	0.56	0.56	0.56
τ (s)	25	25	25	25
x_0 (m)	200	200	200	200
v_{gain} (km/h)	70	50	50	70
d^{ij}_{free} (-)	0.365	0.365	0.365	0.365
d^{ij}_{sync} (-)	0.577	0.577	0.577	0.577
d^{ij}_{coop} (-)	0.788	0.788	0.788	0.788