Reducing travel delay at sags: Implementable controllers

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Japan vs the Netherlands
Sags

Gradient = -2.0%

Gradient = +2.5%

300 m

Uphill section

Downhill section

Emergency lane
Shoulder (slow)
Center (fast)
Median (fast)

Bottleneck
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 adequately adapt the vehicle power

![Diagram showing cause of congestion with gradient values of -2.0% and +2.5% at different positions, including bottleneck and uphill/downhill sections.](image)
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

Flow (veh/h) | 2-lane freeway
---|---
4000 | flat
3600 | sag
3200
2800

Density (veh/km)
Goal

Sags as freeway bottlenecks

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

Flow (veh/h) vs Density (veh/km) for a 2-lane freeway

- Flat line
  - Flow: 4000, 3600, 3200, 2800
  - Density: 4000

- Sag line
  - Flow: 4000, 3600, 3200, 2800
  - Density: 4000
Control strategy

Control concept: mainstream traffic flow control (MTFC)
Control strategy

Control law: proportional feedback

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

- **Speed limit**
- **Target speed limit**
- **Gain**
- **Target density**
- **Measured density**
- **Variable**
- **Constant**
- **Delay**

**Constraints**

\[
\begin{align*}
    v_{\text{VSL}}^\text{lim}(k) & \text{is a multiple of 10 km/h} \\
    v_{\text{VSL}}^\text{lim}(k) & \geq 20 \text{ km/h} \\
    |v_{\text{VSL}}^\text{lim}(k) - v_{\text{VSL}}^\text{lim}(k + 1)| & \leq 20 \text{ km/h}
\end{align*}
\]
Evaluation method

Case study

• Microscopic traffic flow model

• Two scenarios:
   No-control scenario
   Control scenario
Results

Average travel time (min)

- **No control**
- **Control**
Results

Average travel time (min)

- 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)
Adaptive cruise control

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

\[ a = k_1 (v_{input,i} - v_i) + k_2 \frac{\Delta v_i}{s_i} \]

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

• 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

• In an equation

\[ a_i^{CACC} = a_i^{ACC} + k_3 \sum_{j=i-2}^{N} \frac{v_j - v_i}{x_j - x_i} \]
Traffic state adaptive cruise control

- In free flow: \( T_{\text{desired}} = T_{\text{default}} \)
- Approaching the jam: \( T_{\text{desired}} > T_{\text{default}} \)
- In congestion: \( T_{\text{desired}} < T_{\text{default}} \)
- Leaving the jam: \( T_{\text{desired}} < T_{\text{default}} \)
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

Bar chart showing the average travel time (min) against the penetration rate. The chart compares different control strategies:
- No-Control
- ACC
- TSA-ACC
- I2V-ACC
- CACC
- Free flow

The y-axis represents the average travel time in minutes, ranging from 3.8 to 4.8. The x-axis represents the penetration rate, ranging from 0 to 100.
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

*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