Modeling Acceleration Behavior in A Connected Environment

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Why Connectivity and Automation?
Connected vs. Autonomous

Vehicle Operation

No Automation
Function Specific Automation
Combined Function Automation
Limited Self-Driving Automation
Full Self-Driving Automation
Connected vs. Autonomous

- Improve drivers’ strategic and operational decisions.

**V2V Communications**
- Increase drivers’ situational awareness.
- Improve drivers’ operational decisions.

**V2I Communications**
- Improve drivers’ strategic decisions.
Connected vs. Autonomous

- Enhance self-contained sensing capabilities through real-time messaging.

**V2V Communications**
- Improve vehicles’ operational decisions.

**V2I Communications**
- Improve vehicles’ strategic decisions.

CONNECTIVITY

Vehicle Operation

- No Automation
- Function Specific Automation
- Combined Function Automation
- Limited Self-Driving Automation
- Full Self-Driving Automation
Acceleration Framework

- No Automation
  - Not Connected

- No Automation
  - Connected

- Self-Driving
  - Not Connected
Acceleration Framework

<table>
<thead>
<tr>
<th>No Automation Not Connected</th>
<th>No Automation Connected</th>
<th>Self-Driving Not Connected</th>
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- Acceleration Behavior: Probabilistic
- Perception of Surrounding Traffic Condition: Subjective
- Reaction Time: High
- Safe Spacing: High
- High-Risk maneuvers: Possible

- The car-following model of Talebpour, Hamdar, and Mahmassani (2011) is used.
  - Probabilistic
  - Recognizes two different driving regimes:
    - congested
    - uncongested
  - Consider crashes endogenously
Acceleration Framework

No Automation Not Connected

No Automation Connected

Self-Driving Not Connected

Active V2V Communications  Inactive V2V Communications

Active V2I Communications  Inactive V2I Communications
The Intelligent Driver Model (Treiber, Hennecke, and Helbing, 2000) is used.

- Acceleration Behavior: Deterministic
- Perception of Surrounding Traffic Condition: Accurate
- Reaction Time: Low
- Safe Spacing: Low
- High-Risk maneuvers: Very Unlikely
Acceleration Framework

- Sources of information: drivers’ perception and road signs
- Behavior is modeled similarly to the “No Automation Not Connected”.
**Acceleration Framework**

- TMC can detect individual vehicle trajectories
  - Speed harmonization
  - Queue warning

- Depending on the availability of V2V Communications:
  - Active V2V Communications: IDM
  - Inactive V2V Communication: Talebpour, Hamdar, and Mahmassani.
Acceleration Framework

- No communication between vehicle and TMC

- Depending on the availability of V2V Communications:
  - Active V2V Communications: IDM
  - Inactive V2V Communication: Talebpour, Hamdar, and Mahmassani
Acceleration Framework

- On-board sensors are simulated: SMS Automation Radars (UMRR-00 Type 30) with 90m±2.5% detection range and ±35 degrees horizontal FOV.
Speed should be low enough so that the vehicle can react to any event outside of the sensor range \( v_{\text{max}} \) (Reece and Shafer, 1993).

\[
a_i(t) = \min(a_i^d(t), k(v_{\text{max}} - v_i(t))) \quad (\text{Arem, Driel, and Visser, 2006})
\]

\[
a_i^d(t) = k_a a_{i-1}(t - \tau) + k_v(v_{i-1}(t - \tau) - v_i(t - \tau)) + k_d(s_i(t - \tau) - s_{\text{ref}})
\]
Stability Analysis

Local Stability vs. String Stability
200 vehicles with 40 meters initial spacing.

To create perturbation:
    One vehicle is slowed down to $v = 1 \text{ m/s}$ with maximum deceleration (-8 m/s$^2$).
    Speed is kept at 1 m/s for 50 s.
Stability Analysis
Ring Road Analysis

No Automation
Not Connected

No Automation
Connected

Self-Driving
Not Connected
Sensitivity Analysis
Simulation Segment

1.75 Miles

3.5 Miles

1800 veh/hr

650’

360 veh/hr
Sensitivity Analysis
Market Penetration Rate of Autonomous Vehicles

0% MPR

10% MPR

50% MPR

70% MPR

90% MPR

100% MPR
Sensitivity Analysis
Market Penetration Rate of Connected Vehicles

Density (Veh/km/lane)
0% MPR

Density (Veh/km/lane)
10% MPR

Density (Veh/km/lane)
50% MPR

Density (Veh/km/lane)
70% MPR

Density (Veh/km/lane)
90% MPR

Density (Veh/km/lane)
100% MPR
Sensitivity Analysis
Simulation Segment

1.75 Miles

3.5 Miles

2200 veh/hr

650'

360 veh/hr
Sensitivity Analysis
Mixed Environment: Regular, Connected and Autonomous Vehicles

10 – 0 – 90
10-20-70
10-40-50
10-50-40
10-70-20
10-90-0
Conclusion

The presented acceleration framework is string stable (more analysis is required).

**Connected Vehicles / Autonomous vehicles:**
- Low penetration rate increase the scatter in fundamental diagram.
- High penetration rate reduce the scatter in fundamental diagram.
- Capacity increases as market penetration rate increases.

From eliminating/delaying breakdown formation stand point:

Autonomous vehicles response more effective in this case at preventing breakdown than human driving enhanced by passive connectivity.
Conclusion

Connected and Autonomous Vehicles:

- Autonomous Vehicles > Connected Vehicles
  
  SCATTER IS NEGLIGIBLE

- (Autonomous Vehicles < Connected Vehicles) and (Autonomous Vehicles > 10%)
  
  SCATTER IS SIGNIFICANT

Scatter decreases as market penetration rate of connected vehicles increases

- (Autonomous Vehicles < Connected Vehicles) and (Autonomous Vehicles < 10%)
  
  SCATTER IS NEGLIGIBLE
THANK YOU!