TRUCK PLATOONING: AN EARLY APPLICATION OF COOPERATIVE VEHICLE AUTOMATION

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Truck Platooning - Overview

• What is it?
• SAE Levels of Automation
• Why V2V Cooperation is Essential
• Benefits to be gained
• Importance of energy savings
• Cooperative adaptive cruise control system
• Test trucks in action
• Energy saving results
• Main Findings
What is truck platooning?

Operating trucks in close formation under automatic speed control using V2V communication to coordinate their speeds

- **Cooperative adaptive cruise control (CACC)**
  - Ad-hoc combination of trucks
  - Drivers can join or depart at will
  - Constant time-gap separation

- **Tightly-coupled platoon**
  - First truck (or driver) supervises operations
  - Joining and departing authorized by leader
  - Constant clearance-gap (distance) separation
  - Generally enables shorter gaps
Driving automation systems are categorized into levels based on:

1. Whether the driving automation system performs either longitudinal or lateral vehicle motion control → L1
2. Whether the driving automation system performs both longitudinal and lateral vehicle motion control → L2+
3. Whether the driving automation system also performs object and event detection and recognition → L3+
4. Whether the driving automation system also performs dynamic driving task fallback → L4+
5. Whether the driving automation system is limited by an operational design domain (ODD) → below L5
## Example Systems at Each Automation Level

<table>
<thead>
<tr>
<th>Level</th>
<th>Example Systems</th>
<th>Driver Roles</th>
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<tbody>
<tr>
<td>1</td>
<td>Adaptive Cruise Control OR Lane Keeping Assistance</td>
<td>Must drive other function and monitor driving environment</td>
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<td></td>
<td>Traffic Jam Assist (Mercedes, Tesla, Infiniti, Volvo…) Parking with external supervision</td>
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<tr>
<td>2</td>
<td>Adaptive Cruise Control AND Lane Keeping Assistance</td>
<td>Must monitor driving environment (system nags driver to try to ensure it)</td>
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<td>3</td>
<td>Traffic Jam Pilot</td>
<td>May read a book, text, or web surf, but be prepared to intervene when needed</td>
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<td>4</td>
<td>Highway driving pilot “Driverless” following truck in platoon “Driverless” valet parking</td>
<td>May sleep, and system can revert to minimum risk condition if needed</td>
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<tr>
<td>5</td>
<td>Ubiquitous automated taxi Ubiquitous automated truck</td>
<td>No drivers needed</td>
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Communication-Based Cooperation is Essential

- Providing advance information about traffic condition changes and hazards (including beyond sensor line of sight)
- Enabling coordination of vehicle actions for safety, smoothness and traffic flow stability
  - Implications for congestion, travel time, energy, emissions…
  - Shorter gaps for aerodynamic “drafting”
- Supporting broader traffic management functions (speed advisories, rerouting, weather alerts,…)
- Information to support eco-driving (adjusting speed profiles based on upcoming traffic signal changes)
Automotive Example: Adaptive Cruise Control with and without V2V Cooperation

Autonomous (no communication)  Cooperative (with V2V communication)
Comparison of Performance

Autonomous (no communication)  Cooperative (with V2V communication)
Benefits to be Gained at Each Automation Level (assuming use of communication for cooperation)

• Level 1:
  – Some comfort and convenience
  – Substantial energy savings (drafting and smoothing speeds)
  – Safety (from collision warnings)

• Level 2:
  – Some additional comfort and convenience
  – Additional energy savings if shorter gaps are enabled
  – (Possible reduction in safety, if misused by driver)

• Level 3:
  – Potential for driver to do other non-driving tasks
  – (Possible reduction in safety if driver loses vigilance)
Benefits to be Gained at Each Automation Level (assuming use of communication for cooperation)

• Level 4:
  – Significant improvement in driver quality of life, stress reduction
  – Hours of service reforms based on ability for driver to sleep on part of long-haul runs
  – Possibility of driverless platoon followers, saving labor costs
  – Enhanced safety based on system fallback capability

• Level 5 (remote future):
  – No need for drivers
Importance of Heavy Truck Energy Savings

- Heavy trucks consume 20% of U.S. transportation energy
- Heavy trucks consume 14% of all U.S. petroleum
- Fuel represents 39% of long-haul heavy truck operating costs

- Annual saving of 10% in fuel costs for a typical long-haul truck represents $6000 per year (worth $60,000 over the life of the truck)
Development and Testing of Truck Cooperative ACC System

- Project sponsored by Federal Highway Administration, Exploratory Advanced Research Program (EARP), with cost sharing from California Department of Transportation

- Measuring energy saving potential and driver preferences for different gap settings
- Simulating impacts on traffic and energy use in a high-volume freight corridor
Cooperative Adaptive Cruise Control System

- Build on production Volvo ACC system
- Add V2V communication by 5.9 GHz DSRC
  - Vehicle location
  - Speed, acceleration, braking, commands
- Short gap settings enabled:
  - 0.6, 0.9, 1.2, 1.5 s
  - 57, 86, 114, 143 ft @ 65 mph
- Coordinated braking
Supplementary Display for Driver
Testing to Measure Energy Consumption

• **International collaboration with Transport Canada and National Research Council of Canada**

  - Environment and Climate Change Canada
  - Environnement et Changement climatique Canada

• **Testing in Blainville, Quebec on 4-mile oval track**
  - SAE standard test procedure
  - 64-mile continuous drive per run
  - 3 runs repeated and averaged
  - Auxiliary fuel tanks weighed on each run
Testing Procedures
Testing at 0.6 s Time Gap in Blainville
Energy Savings Compared to Single Truck with Standard Trailer

Energy Saving with Standard Trailers, 65 mph

Average Savings, Standard vs. Aerodynamic

(Chart showing fuel consumption reduction vs. vehicle spacing and time gap)
Main Findings

• With standard trailers, trucks can save 5% energy on average in a three-truck CACC string

• With aerodynamic trailers, these savings grow to 12-14% compared to standard-trailer solo driving

• Drag savings not very sensitive to time gap values from 0.6 s to 1.5 s (57 to 143 ft. at 65 mph)

• Lead truck saves limited energy in this range of gaps.

• Third truck saves the most energy

• Effects of short gaps and aerodynamic trailers reinforce each other

• Further studies are needed for shorter and longer gaps