Truck CACC Fuel Economy Testing: Initial Test Track Results

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Outline

• Background
• CACC Control System Design
• Test Scenarios
• Test Procedures
• Test Results (Weighing Fuel Tanks)
• Alternate Analysis (without Weighing Tanks)
• Conclusions
Project Background

• Cooperative Truck Platooning
  – The prototype system tested is based on Cooperative Adaptive Cruise Control (CACC) technology
  – Multiple vehicles using 5.9 GHz DSRC based V2V communications and forward sensors to help maintain a constant distance between vehicles

• Potential Benefits
  – Improved fuel economy
  – Reduced emissions
  – Improved road-use efficiency
  – Reduce driver workload
CACC Control System Design – System Structure

- Dual DSRC Antennas
- Video camera (production)
- 5 Hz GPS
- ACC radar (Production)
- Supplementary display
- PC-104 computer
- Emergency disengage button by driver
CACC Control System Design – System Structure

PATH
Linux Laptop

PATH
PC-104
QNX RTOS

Volvo XPC:
sensor data processing

Dual Antenna

DSRC radio

Ethernet

Fused sensor data

J-Bus interface

J-Bus

Video recording computer

Engine/brake control commands

Tablet
DVI

Ethernet

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Multi-antenna system

DSRC radio

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CACC Control System Design – Control System

Diagram showing the flow of information from sensors and communications to control actuators through linear vehicle kinematics and inverted vehicle longitudinal dynamics.

- Front sensor
  - Sensor fusion
  - Linear vehicle kinematics
  - Desired acceleration
  - Inverted vehicle longitudinal dynamics
  - Desired engine driving/braking torque
  - Control actuators

Upper level control:
- DSRC Comm.

Lower level control:
CACC Control System Design – CACC

Control Logic for veh ID > 1

Default

Cut-in

Yes

CACC String split into two; each maintain CACC mode;

No

Cut-out

Yes

Joining the leader vehicle to resume the string

No

Cut-in time less < 30s

No

Two strings joining to form one string; veh ID reshuffling

Yes

CACC Mode: Following both leader and front vehicle with speed and distance control and driver set T-Gap and String Max Speed

Yes

Keep CACC mode: following front veh; dist split to D-Gap

No

cut-in time less < 30s
Truck CACC Test Scenarios

- Fuel consumption measurements based on SAE J1321
  - Time Gap (T-Gap):
    - 1.5s, 1.2s, 0.9s, 0.6s
  - Standard trailer vs. aerodynamic trailer
    - Boat tails & Side skirts
  - With/without ballast (rolling resistance)
    - 65,000lbs & 29,000 lbs
  - Maximum speed:
    - 65mph vs. 55mph
Test Procedures

- Synchronized operation of 3 trucks using CACC
- A manually driven control truck followed 2 miles behind (as baseline for variations in ambient conditions)
- Single truck constant speed reference runs, 4 trucks drove 1 mile apart
- Weighed auxiliary fuel tanks of all trucks after each run (64 miles)
- Each condition repeated 4 times to produce average fuel consumption estimates
Aerodynamics of Cooperative Truck Platooning

- As vehicles approach, they influence the flow-field around each other

Aerodynamics of Cooperative Truck Platooning

- As vehicles approach, they influence the flow-field around each other
  
  Low-speed air-wake of lead vehicle influences trailing vehicle
  
  *(lower airspeed = lower drag)*

Aerodynamics of Cooperative Truck Platooning

• As vehicles approach, they influence the flow-field around each other

High-pressure zone in front of trailing vehicle influences lead vehicle *(pushes on the front vehicle)*

Aerodynamics of Cooperative Truck Platooning

- As vehicles approach, they influence the flow-field around each other

*Magnitude of each effect is dependent on separation distance!*

Transport Canada’s Motor Vehicle Test Centre, Blainville, Québec

- Northern suburb of Montreal
Boat Tail and Side Skirts
Fuel Tank Removal/Mounting
Load cell on fork lift for tank weighing
CACC 0.6s Gap @ 65 mph
CACC 0.6s Gap @ 65 mph
Test Results - NRC Canada Fuel Saving Estimates
(65 mph + 65,000 lbs)

Fuel Savings for Individual Trucks
Test Results - NRC Canada Fuel Saving Estimates (65 mph + 65,000 lbs)

Fuel Savings for Individual Trucks

Negligible savings for lead vehicle observed
Test Results - NRC Canada Fuel Saving Estimates
(65 mph + 65,000 lbs)

Fuel Savings for Individual Trucks

trailing vehicle shows highest savings
Test Results - NRC Canada Fuel Saving Estimates
(65 mph + 65,000 lbs)

Total Fuel Savings for 3-Truck Platoon
(ref. standard truck)
Test Results - NRC Canada Fuel Saving Estimates (65 mph + 65,000 lbs)

Total Fuel Savings for 3-Truck Platoon (ref. standard truck)

no change beyond 22 m for standard trailers
Test Results - NRC Canada Fuel Saving Estimates (65 mph + 65,000 lbs)

Total Fuel Savings for 3-Truck Platoon (ref. standard truck)

Up to 14% fuel savings when combining aero devices with platooning

no change beyond 22 m for standard trailers
Alternate Analysis – without Weighing Tanks

• Data used:
  – Trailers with side skirts and rear end flaps
  – Only in reasonably good weather conditions
• Based on vehicle measurement
  – Cumulative distance from J-1939 Bus speed
  – Cumulative fuel consumption of fuel rate from J-1939 Bus
  – Average Fuel Rate:

$$\text{Ave Fuel Rate} = \frac{\text{Cumulative fuel Consumption}}{\text{Cumulative Distance}}$$
Alternate Analysis (65 mph + 65,000 lbs)

- What’s happening at 1.2s might be due to weather (e.g. windy), which we will work on further.
Conclusions

• Collaboration among multiple project partners conserved resources, close cooperation promoted mutual learning

• Truck CACC showed significant energy savings for followers, but not for leader, for selected range of gaps

• Consistent with findings from other research projects

• Test drivers were professionals and enthusiastic about use of the system

• Additional experiments needed for other conditions to show wider range of trends