Breakout Session # 6: Trucking automation – key deployment scenarios

Summary of Key Findings and Lessons Learned

• Technology is ready – deployment the real challenge
• Key drivers
  • Fuel economy
  • Productivity
  • Safety
  • Driver shortage – AV is an opportunity to improve drivers’ jobs and retain the good drivers
• Challenge: Benefits (RoI) of automated trucking specific for the type of operation, diversity of operations, multidimensional problem
• **Key to deployment is to understand customers’ operations**
• L1 Platooning very close to market – will pave the way for other applications
• Public sector players interested in exploring managed / dedicated lanes for automated trucks
Breakout Session # 6: Trucking automation – key deployment scenarios

**Recommended Action Items**

- Stepwise deployment and validation in real operations
- Safety assurance: Collect field data, combine with track testing and simulation
- “Everybody want to know what the others are doing”, new strategic partnerships – interaction between stakeholders essential
- Educational campaigns for the public important to establish trust
- Harmonized regulations between states
Robots on Our Roads: 
*The Coming Revolution in Moving Freight*

Automated Vehicles Symposium, Truck AV Breakout Session 
July 11, 2017

Richard Bishop
Automated Driving: A Powerful New Wave
Myths!

The roads need to be changed to make automated driving possible. **WRONG!**
Myths!

All vehicles need to be connected (V2X) to enable automation.

WRONG!
Myths!

New laws / regulations are needed to enable automated vehicles.

...not necessarily
Automated vehicle development started a few years ago. 

...more like decades ago.
Electronic Tow Bar
A potential solution

DaimlerChrysler
Comparison CHAUFFEUR 1 and 2 (contd.)

New in CHAUFFEUR 2 (cont.): Platooning

On particular request of the EU in CHAUFFEUR 2 the electronic coupling of three trucks will also be realised.
The Promise of Highly Automated Trucks
What Factors Affect Trucking Today?

- Driver shortage
- Hours of Service
- Fuel cost
- Crashes
- Congestion
- Sustainability
- Trailer Length / Longer Combination Vehicles
- Increasing home-delivery parcel volumes
AV Use Cases for Heavy Trucks

On-Road

- Fuel Economy
  - Truck Platooning
- Driver Productivity
  - Traffic Jam Assist
  - Highway Pilot
  - Automated Movement in Queue
  - Automated Trailer Backing
  - Parcel Delivery Automation

Constrained Environments

- Trailer Switching
- Mine Hauling
- Drayage
- Dispersed Local Sites
  - manufacturing
  - distribution
from crash avoidance to automated driving
Doing Things Right!

- Automated driving is different from crash avoidance.
- Crash avoidance technology intervenes when things go wrong
- Automated driving technology automates the things we do RIGHT.
## The Levels of Vehicle Automation: SAE Standard J3016

<table>
<thead>
<tr>
<th>SAE level</th>
<th>Name</th>
<th>Narrative Definition</th>
<th>Execution of Steering and Acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Failback Performance of Dynamic Driving Task</th>
<th>System Capability (Driving Modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td></td>
<td>Automated driving system (“system”) monitors the driving environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
</tr>
</tbody>
</table>
Levels of Automation: Simplified

• Level 0: hands and feet ON
• Level 1: hands or feet OFF
• Level 2: hands and feet OFF, eyes ON
• Level 3: hands, feet, eyes OFF, brain on
• Level 4: hands, feet, eyes, brain OFF
  – constrained environments
• Level 5: hands, feet, eyes, brain OFF
  – unconstrained
Tech Developers
Freightliner “Inspiration:”
Highway Pilot (Level 3)
Uber Advanced Technology Group: Exit-to-Exit Driverless Operation
Starsky Robotics: Remote Driving
AV Use Cases for Heavy Trucks

On-Road

• Fuel Economy
  – Truck Platooning

• Driver Productivity
  – Traffic Jam Assist
  – Highway Pilot
  – Automated Movement in Queue
  – Automated Trailer Backing
  – Parcel Delivery Automation

Constrained Environments

• Trailer Switching
• Mine Hauling
• Drayage
• Dispersed Local Sites
  – manufacturing
  – distribution
Evolution of Truck Platooning

- Product introduction 2017 (USA)
- Within Fleet >> Inter-fleet
- Driver Role in Follower Truck Evolves to HAV
  - L1: driver steering and monitors road
  - L2: fully automated, driver supervises
  - ....
  - ....
  - no driver
AV Use Cases for Heavy Trucks

On-Road
- Fuel Economy
  - Driver Assistive Truck Platooning
- Driver Productivity
  - Traffic Jam Assist
  - Highway Pilot
  - Automated Movement in Queue
  - Automated Trailer Backing
  - Parcel Delivery Automation

Constrained Environments
- Trailer Switching
- Mine Hauling
- Drayage
- Dispersed Local Sites
  - manufacturing
  - distribution
JaxPort: Use Cases of Interest

Full Automation Within Immediate Port Area

- Assess shipper and drayage fleet interest in automating trucks operating the really short drays (less than ¼ mile) as a real world testbed.
Port of Palm Beach Gate Congestion
(adds up to 90 minutes to trip)
Resources
Resources

- ATA Technology and Maintenance Council, Future Truck

- Lessons Learnt: European Truck Platooning Challenge 2016
  - Dutch Rijkswaterstaat, Netherlands Ministry of Infrastructure and Environment
  - www.eutruckplatooning.com/

- Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment
  - Auburn U., Peloton, Peterbilt Trucks, Meritor-Wabco, ATRI, Bishop Consulting
  - Phase Two Final Report
  - [http://eng.auburn.edu/~dmbevly/FHWA_AU_TRUCK_EAR/](http://eng.auburn.edu/~dmbevly/FHWA_AU_TRUCK_EAR/)

- Managing the Transition to Driverless Road Freight Transport (labor issues)
  - OECD International Transport Forum

- Florida DOT
  - Driver Assistive Truck Platooning: Considerations for Florida State Agencies
  - Study underway by University of Florida
  - Report to be published later this year
Wrap-up
Robots on our Roads

- Market demand is strong: significant potential return-on-investment for trucking industry
- Industry aggressively developing products
- Powerful synergies between car- and truck-side stimulate momentum for freight
- Government is challenged to keep up
- Universal will amongst all players to make automated driving a reality
No other technology ever offered in vehicles allows drivers to do something else with their brain.
THIS IS NEW TERRITORY!
Thank You

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@ThinkingCarsH3B
CATERPILLAR’S JOURNEY TO AUTOMATION AND LESSONS LEARNED

Michael Murphy
VERY HIGH LEVEL OVERVIEW OF OUR JOURNEY TO AN OUR AUTONOMOUS HAULAGE SYSTEM

- FIRST GENERATION PROGRAM 1980’S TO 1990’S
- SECOND GENERATION PROGRAM 2000’S TO NOW
- LESSONS LEARNED @ 100,000 FEET FROM X MILLION MANHOURS OF EXPERIENCE
- OPERATIONAL RESULTS – CUSTOMERS & OUR SUCCESS
- QUESTIONS
FIRST GENERATION AUTONOMOUS TRUCK PROGRAM

- COMMENCED LATE 1980’S
- EARLY 1990’S RESEARCH PROGRAM: 2 x 50 TON CAPACITY TRUCKS - AT TEXAS QUARRY
ORIGINAL AUTONOMOUS MINING TRUCK – CIRCA EARLY 1990’S
FIRST GENERATION AUTONOMOUS TRUCK PROGRAM

- COMMENCED LATE 1980’S
- EARLY 1990’S 2 x 50 TON CAPACITY TRUCKS - RAN AT TEXAS QUARRY
- DEMONSTRATED IN 1996 AT LARGEST MINING SHOW
- PLACED PROGRAM ON HOLD IN 1998
SECOND GENERATION AUTONOMOUS TRUCK PROGRAM

- COMMENCED 2008

- MULTI LOCATION TEAM - AUSTRALIA, CANADA, INDIA, NEW ZEALAND AND UNITED STATES

- COMMERCIAL AT TWO MINE SITES IN AUSTRALIA MID 2013 NOW

- BHP: 50 TRUCKS END 2017

- FORTESCUE METALS GROUP: 56 TRUCKS MOVING TO 68- END 2017 - PLUS ANNOUNCED PLANS FOR ANOTHER TWO MINES

- OPERATING AT A MINE IN SOUTH AMERICA - NOT PUBLIC
Video – Fortescue Metals Group Solomon Mine
LESSTONS LEARNED

AT START OF PROGRAM – “WE DON’T KNOW WHAT WE DON’T KNOW”

- TECHNOLOGY
  - PERCEPTION
  - POSITIONING
  - COMMUNICATIONS
  - COMPONENT HARDENING
  - SYSTEM VALIDATION
  - APPLICATION/PRODUCTIVITY – “CORNER CASES”
LESSONS LEARNT

- PEOPLE
  - SKILL SETS
    - TECHNICAL
    - OPERATION OF THE SYSTEM
    - HOW DO PEOPLE REACT WITH AUTONOMOUS MACHINES?
    - CHANGE MANAGEMENT

- PROCESS
  - AUTONOMOUS MINING VS. MANNED MINING
  - SAFETY PROCESSES
  - PRODUCTIVITY
TIME TO GET A COMMERCIAL PRODUCT VIDEO SHOT IN DECEMBER 2010
SUCCESS WITH CAT COMMAND FOR HAULING

TONNES SAFELY HAULED BY AUTONOMOUS TRUCKS

82
CAT 793F CMD TRUCKS ON CUSTOMER SITES

4.0
YEARS IN OPERATION

500
MILLION TONNES SAFELY HAULED

0
LOST-TIME INJURIES

110
AUTONOMOUS TRUCKS OPERATING BY END OF 2017
QUESTIONS
Key Deployment Issues in On-Road Truck Automation

Public Policy, Regulation and Market Structure

Larry O’Rourke, ICF
Acknowledgement

Project NCHRP 20 102(3)

Challenges to CV and AV Applications in Truck Freight Operations

http://www.trb.org/Main/Blurbs/175965.aspx

Study funded by the National Cooperative Highway Research Program

Authors: David Fitzpatrick (BAH); Gustave Cordahi (BAH); Larry O'Rourke (ICF); Catherine Ross (GIT); Amit Kumar (GIT); David Bevly (UA)
Overview

- State laws
- Regulation
- Planning & infrastructure
- Market structure
18 State Autonomous Vehicle Laws Enacted

Source: National Conference of State Legislatures
Patchwork of State Autonomous Vehicle Laws

- Define autonomous vehicles differently

- Some states authorize:
  - Testing of autonomous vehicles
  - Use of autonomous vehicles by the public
  - Testing of “driverless vehicles” under certain conditions
  - Operation without drivers

- Some states require:
  - A special license for the driver of a test vehicle
  - Black boxes
State Laws Treat Platooning Differently

- Seven states have enacted legislation authorizing the deployment of Level 1 truck platooning
  - Including Arkansas, Georgia, Michigan, Nevada, South Carolina, Tennessee and Texas

- Following distance of trucks treated differently
  - Reasonable and prudent standard
  - Require that trucks follow at specific distances
  - Or at a certain duration of time behind another vehicle
Incorporating Automated Trucks into State Laws

- Reviewing existing state law for relevance to automated trucks
- Develop common legal and regulatory definitions
- Harmonizing laws between states
  - Following distance for platoons
  - Treatment of platooning video systems
  - Treatment of closely spaced vehicles and pavement damage
Federal Regulations

- Federal Motor Vehicle Safety Standards
  - Current regulations assume a driver
  - Volpe National Transportation Systems Center concluded that few of the existing FMVSS standards serve as a barrier to standard designs
  - Federal legislation to regulate automated vehicles in the US was introduced on June 20th
  - Increases FMVSS exemption caps from 2,500 to 100,000
  - Heavy-duty vehicles not included in the NPRM - Mandating V2V communications

- FMCSA
  - Hours of Service Regulations

- Security, Privacy & Others
Planning and Infrastructure

- Lane striping
- Quality of data on truck restrictions
  - Bridge heights
  - Load restrictions
  - Truck routes
  - Operational constraints – turning radius
- Understanding future demand
- V2I infrastructure
  - DSRC stoplights, work zone units, signage

Quality of Lane Striping Affects Lane Keeping System Performance

Source: Ken Lund, https://www.flickr.com/photos/kenlund/16235995526
Market Structure – Area of Operation

- Most trucks are single unit vehicles operating close to their home base
- Long-haul combination vehicles operate more than half the vehicle miles travelled
- Greatest early opportunity for automation

<table>
<thead>
<tr>
<th>Truck Type</th>
<th>Area of Operation</th>
<th>Trucks</th>
<th>VMT (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Under 150 miles</td>
<td>7,150,695</td>
<td>71,901</td>
</tr>
<tr>
<td>Single-Unit</td>
<td>Long Haul</td>
<td>975,312</td>
<td>34,681</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>8,126,007</td>
<td>106,582</td>
</tr>
<tr>
<td>Combination</td>
<td>Under 150 miles</td>
<td>346,056</td>
<td>7,414</td>
</tr>
<tr>
<td></td>
<td>Long Haul</td>
<td>2,125,293</td>
<td>161,022</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2,471,349</td>
<td>168,436</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>10,597,356</td>
<td>275,018</td>
</tr>
</tbody>
</table>

Source: Truck and VMT sub-totals from FHWA, Highway Statistics; range distribution based on U.S. Census, Vehicle Inventory and Use Survey.
Market Structure Impact on Platooning Opportunity

- Most truck tractors are in private fleets
- Companies operating large private fleets, with homogeneity in their tractor OEM, and predictable routes may gain the best savings along their high density routes from platooning
- LTL carriers operating long-haul trucks on fixed routes between terminals.
- TL carries operating on high density lanes.

<table>
<thead>
<tr>
<th>Operation Type</th>
<th>Firms</th>
<th>Tractors</th>
<th>VMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private</td>
<td>82.3%</td>
<td>58.0%</td>
<td>32.0%</td>
</tr>
<tr>
<td>TL</td>
<td>17.1%</td>
<td>35.0%</td>
<td>60.0%</td>
</tr>
<tr>
<td>LTL</td>
<td>0.3%</td>
<td>5.0%</td>
<td>6.0%</td>
</tr>
<tr>
<td>Parcel</td>
<td>0.3%</td>
<td>2.0%</td>
<td>2.0%</td>
</tr>
</tbody>
</table>
Deployment of Automated Trucks

- Improved working environment for the driver in large long haul fleets is an opportunity. Large truckload carriers had a 74% turnover rate for drivers in first quarter 2017.

- Firms operating long haul trucks with team drivers provides an opportunity for large labor productivity benefits from highly automated trucks. Some labor productivity benefits depend on Hours of Service Rule changes.

- Larger carriers internalize safety risk, tend to invest first in safety.

- Almost all carriers expect a payback on investment in truck automation technology in three years or less.
Contact Information

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- 617-250-4226
- Larry.orourke@ICF.com
Truck Platooning:
State of the Art Review

Steven E. Shladover, Sc.D.
California PATH Program
University of California, Berkeley
AVS17 Truck Automation Breakout Session
July 11, 2017
Why care about truck platooning?

- Significant energy savings from aerodynamic drafting
- More stable vehicle following dynamics, reducing traffic flow disturbances and saving additional energy and emissions
- Increased highway capacity and reduced congestion from improved traffic dynamics and shorter gaps
- *(Potential)* safety improvement
- *(When Level 3 automation becomes feasible)* Improvement in truck driving working conditions, with more diverse assignments for drivers
- *(When Level 4 automation of followers becomes feasible)* Reduced need for truck drivers
Enablers of Truck Platooning

• Adaptive cruise control (forward ranging sensor, plus engine, braking and transmission control)
• Fast, highly reliable V2V communication
• Informative driver-vehicle interface
• Reliable early detection of cut-in vehicles
• (For L2+) Lane position detection and automatic steering control
• (For L3+) Central supervision, I2V comm.
• (For L4) Extensive safety assurance + dedicated, segregated truck lanes (?)
# Research Projects Building the Foundation Over 20+ Years

<table>
<thead>
<tr>
<th>Years</th>
<th>Where</th>
<th>Project</th>
<th># Trucks</th>
<th>Operating Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996-2004</td>
<td>EU</td>
<td>CHAUFFEUR</td>
<td>2, 3</td>
<td>CACC (mixed), L2 Towbar Platoon (dedicated), 6- 12 m gap</td>
</tr>
<tr>
<td>2000-2003</td>
<td>US</td>
<td>Caltrans/PATH truck platooning</td>
<td>2</td>
<td>L1 platoon, 3-10 m gaps, closed track tests</td>
</tr>
<tr>
<td>2005-2009</td>
<td>EU</td>
<td>Konvoi</td>
<td>4</td>
<td>L2 platoon, 10- 15 m gaps, mixed traffic tests</td>
</tr>
<tr>
<td>2008-2013</td>
<td>JP</td>
<td>Energy ITS</td>
<td>4</td>
<td>L2 platoon, closed track tests, 4-10 m gaps</td>
</tr>
<tr>
<td>2009-2012</td>
<td>EU</td>
<td>SARTRE (mixed truck and car platoon)</td>
<td>2</td>
<td>L2 Towbar platoon, mixed traffic tests, 6 m gaps for cars</td>
</tr>
<tr>
<td>2008-2011</td>
<td>US</td>
<td>FHWA EARP/PATH truck platooning</td>
<td>3</td>
<td>L1 platoon, 4 – 10 m gaps, closed track tests</td>
</tr>
<tr>
<td>2013-2017</td>
<td>US</td>
<td>FHWA EARP – PATH and Auburn Univ.</td>
<td>3, 2</td>
<td>L1 CACC for mixed traffic tests, 0.6 – 1.5 s gap (15 – 37 m)</td>
</tr>
<tr>
<td>2015-2016</td>
<td>US</td>
<td>TXDOT/ TTI truck platooning</td>
<td>2</td>
<td>L2 platoon, 15+ m gap, closed track tests</td>
</tr>
<tr>
<td>2015-2016</td>
<td>EU</td>
<td>European Truck Platooning Challenge</td>
<td>2 (3 mfg)</td>
<td>L1 platoons from 6 manufacturers, on public roads</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 (3 mfg)</td>
<td></td>
</tr>
</tbody>
</table>
L1 Truck Platooning State of the Art

Automated longitudinal control only
- Cooperative ACC as first step (pre-platoon)
  - V2V communication/coordination
  - Ad-hoc joining and leaving
  - Constant time-gap following
- L1 Platooning
  - Add coordination/supervision by leader
  - Extend to constant clearance distance gap and shorter distances
- Many research and development projects
- Peloton Technology planning 2-truck product release
- Major truck manufacturers considering it seriously, but no announcements yet
PATH/Volvo Truck CACC at 0.6 s Gap on Transport Canada’s Test Track
L2 Truck Platooning State of the Art

L1 platooning + automatic steering control

– Automatic steering likely necessary for shorter longitudinal gaps (visibility limitations)

• Multiple research projects have tested it, from CHAUFFEUR (1996-2004) to Konvoi, SARTRE, Energy ITS, etc.
• Some companies doing R&D on it (Daimler, Scania, Otto, ...)
• Product releases??
L3 Truck Platooning State of the Art

L2 + driver can divert attention temporarily to other tasks, while remaining available to intervene when needed

- Follower truck driver could work as sales person or logistics manager en route

• Research needed on driver-vehicle interface to try to ensure driver availability when needed

• Remote supervision (by lead driver over V2V or central supervisor over I2V communication link) could be needed

• Passenger car applications likely to precede heavy trucks
L4 Truck Platooning State of the Art

L3 + ability to ensure minimal risk condition without any human intervention (while operating within its specified Operational Design Domain – ODD)

• L4 platoon followers likely to be coupled behind a leader driven at L0, L1 or L2.
• Singapore requesting this for a 10 km route connecting two container terminals
• Safety assurance state of the art not sufficient to support this level of automation for mixed traffic and highway-speed operations
• Likely to need segregated truck-only lanes to simplify the ODD.