Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment
Presentation Overview

- Team Overview
- Project Scope
  - Responsibilities by Team Members
- Proposed System
- Project Tasks/Milestones
- Project Schedule
Team Overview

- Auburn
  - ME (David Bevly, Project PI)
  - ISE (Richard Sesek and Chase Murray)
  - AE (Andy Shelton)
  - CS (Alvin Lim)
  - CE (Rod Turochy)
  - Richard Bishop
  - Robert Rosenthal

- Peloton
  - Josh Switkes

- ATRI
  - Dan Murray & Lisa Park

- Meritor-Wabco
  - Alan Korn

- Peterbilt
  - Bill Kahn
Samuel Ginn College of Engineering

- 150 Faculty
- First Wireless Engineering Program in Nation
- 2500 Undergraduates
- 30 million dollars in research

Mechanical Engineering
- 26 Faculty
  - 20 Mechanical Engineering
  - 6 Materials Engineering
- 500 Undergraduates
- 100 Graduate Students
- 6 million dollars in research expenditures

Industrial & Systems Engineering
Aerospace Engineering
Computer Science
Civil Engineering
TRANSPORTATION
Research Priority Area
GPS and Vehicle Dynamics Lab

Currently 21 Students (8 PhD, 8 MS, 5 BS)

- Vehicle modeling
- Vehicle parameter estimation
- Determination of rollover propensity
- Vehicle sensor fusion/integration
- GPS/INS navigation
  - Using various grade IMUs and receivers
  - Analysis of different aiding techniques
- IMU & laser scanner fusion
- Sensor characterization and modeling
- Development of a software GPS receiver
- High speed control of ground vehicles
NCAT Test Track (& Trucks)

- Two Lane Track
- 1.7 Mile Oval
- Asphalt Instrumentation
- Well Surveyed
  - Level
  - 2° Crowns
  - 8° Banked Turns
- 802.11 and wireless serial communication around entire facility
- RTK system setup with corrections available in all paved areas

Test facility is available for validating vehicle modeling and estimation algorithms using instrumented vehicle test-beds
Integrate vision measurements (camera and/or lidar) with GPS/INS to provide lane level positioning.
Fuse all available outputs on a vehicle for positioning to improve positioning accuracy and robustness (in GPS degraded environments) and mitigate subsystem faults.

Prior Work with FHWA EAR (#2)
Prior Work with FHWA EAR (#3)

- Assist blind or visually-impaired people in navigating in large unstructured environments that they encounter in daily life
  - Parks
  - Parking lots
  - Airports
  - Sports arenas
  - Intersections
  - Pedestrian zones

Underground Atlanta – an underground mall
Current EAR Scope (#4)

• Demonstration of Heavy Truck C-ACC
  • Utilize V2V (DSRC) to enable improved truck ACC
  • Develop and study various concepts of operations
  • Evaluate system robustness

• Determine Potential Benefits
  • Traffic congestion effects
  • Teaming logistics/feasibility
  • Fuel saving benefits
  • User (driver) interfaces and acceptability
David Bevly (ME)

- General Area of Expertise
  - Vehicle Dynamics, Control, and Navigation
- Project Focus Area
  - System Integrator
  - Interface to Peloton
- Phase 1 Tasks
  - Initial analysis of radar, GPS, and Truck CAN data
  - Development of mass estimation algorithms
- Phase 2 Tasks
  - Implement optimized sensor fusion algorithms
  - Implement mass estimation algorithms
  - Integrate control systems for vehicle testing
- Graduate Students
  - Dan Pierce
  - Sostenes Perez
  - William Apperson
Richard Sesek (ISE)

- General Area of Expertise
  - Human Factors Engineering, Usability, and Safety
- Project Focus Area
  - Human Machine Interface/Usability
- Phase 1 Tasks
  - Initial evaluation of HMI impacts, safety considerations
  - Development of human performance evaluation heuristics
- Phase 2 Tasks
  - Evaluation of system against HMI measures of effectiveness
  - Use Technology Acceptance Model (TAM) to assess user control and display needs and preferences
- Graduate Students
  - Nicholas Smith
Chase Murray (ISE)

- General Area of Expertise
  - Vehicle Routing & Logistics, Scheduling

- Project Focus Area
  - Identify impacts to trucking industry operations
  - Interface with ATRI

- Phase 1 Tasks
  - Analyze current trucking traffic to identify critical freight corridors in which platooning operations are likely to be viable
  - Estimate expected platoon sizes, impacts to delivery schedules, and waiting times for trucks to join a platoon

- Phase 2 Tasks
  - Identify road segments in which platoons should be avoided (e.g., due to speed limitations or road curves)
  - Characterize the types of trucking operations that are likely to benefit from platooning (e.g., line-haul operations, or LTL carriers)

- Graduate Student
  - Jonathan Woodruff
Andrew Shelton (AE)

• General Area of Expertise
  • Aerodynamics, Computational Fluid Dynamics (CFD)

• Project Focus Area
  • Aerodynamic modeling of platoon configuration

• Phase 1 Tasks
  • Lower fidelity CFD simulations for Ahmed body, Ground Transportation System (GTS), and Generic Conventional Model (GCM)
  • Initial aero model for pair of GCM tractor trailer models

• Phase 2 Tasks
  • High fidelity CFD simulations
  • Improved aero model with parameter effects such as leader or follower and crosswind

• Graduate Students
  • Andrew Watts
Alvin Lim (CS)

- General Area of Expertise
  - Wireless, Mobile and Reconfigurable Networks
- Project Focus Area
  - Reliable, Secure and High-Throughput Wireless Networks for Supporting Truck Platooning
- Phase 1 Tasks
  - Initial analysis of requirements for wireless platooning
  - Develop tools for measuring reliability and throughput
- Phase 2 Tasks
  - Implement reliable wireless vehicular communication protocols
  - Implement optimization of throughput for platooning messages
  - Implement security protocols for vehicle networking
  - Integrate and test high throughput and reliable vehicle networks
- Graduate Students
  - Song Gao
Rod Turochy (CE)

- General Area of Expertise
  - Traffic Flow and Simulation
- Project Focus Area
  - Evaluation of impacts of C-ACC platooning of heavy vehicles on traffic operations
- Phase 1 Tasks
  - Task 1.6: Preliminary evaluation of traffic impacts using VISSIM (a traffic simulation software)
- Phase 2 Tasks
  - Task 2.7: Detailed evaluation of traffic impacts using VISSIM based on test track experiment
- Graduate Students
  - One graduate student to be determined
Richard Bishop (Auburn consultant)

- General Area of Expertise
  - Intelligent / Connected / Automated Vehicles
  - Intelligent Vehicle-Highway Systems
- Project Focus Area
  - Operational Concepts
  - Business Case
  - User / Industry Acceptance
- Phase 1 Tasks
  - ConOps and requirements development
  - Business case evaluation
  - Impacts evaluation
- Phase 2 Tasks
  - System evaluation against MOEs
  - Evaluate operating strategies
  - Assist in Final Report and Demonstration
- Phase 3 Tasks
  - Presentation of project findings at key industry conferences
Peloton Technology

• Lead: Dr. Josh Switkes
  • Chris Gerdes, Stanford
  • Dave Lyons (Former Dir Eng. Tesla)
  • Steve Boyd

• General Area of Expertise
  • Vehicle Dynamics and Control
  • Production safety/assistance/control systems

• Project Focus Area
  • System implementation
  • Market analysis and feedback

• Phase 1 Tasks
  • ConOps
  • Requirements

• Phase 2 Tasks
  • System Prep
  • Test and Revision
Peterbilt

- Lead: Bill Kahn - Mgr Advanced Concepts
  - Bryan Knight - Project Engineer
- General Area of Expertise
  - OEM Vehicle Research and Development
- Project Focus Area / Contributions
  - System Integration
  - Vehicle Test
- Phase 1 Tasks:
  - System Design Input
- Phase 2 Tasks
  - Integration and Test
Meritor WABCO

- **Lead:** Alan Korn
  - Bryan Murphy – principle engineer
- **General Area of Expertise**
  - Active Safety Systems
  - Vehicle dynamics and control
- **Project Focus Area / Contributions**
  - System implementation
  - Integration with braking system
- **Phase 1 Tasks**
  - Develop concept of operations
  - Define requirements
- **Phase 2 Tasks**
  - System preparation
  - Evaluate operating strategies
• Lead: Lisa Park
  • Dan Murray
  • David Pierce
• General Area of Expertise
  • Industry Analytics
  • Trucking Industry SMEs
  • GIS Data Analysis
• Project Focus Area / Contributions
  • Identify industry technical requirements
  • Solicit and evaluate industry input and feedback
• Phase 1 Tasks
  • Establish Industry Operations Panel (IOP) with carrier and driver subcommittees
  • Identify industry issues, technology requirements, operational requirements and system/project expectations
• Phase 2 Tasks
  • Evaluate operating strategies and assess driver acceptance
C-ACC Limitations & Current Needs

• Operation in mixed traffic
• Operation with non-identical vehicles
  • Mass
  • Drivetrain
• Human factors
• Fleet operations applicability
• Robustness
  • Communication disruptions
  • Sensor errors
Proposed System

- Two Peterbilt Trucks
  - GPS/IMU/Radar for positioning
  - DSRC Radios for V2V Communications
- Various Experiments
  - Analytical/Simulation Analysis
  - Test Track Validation
  - Interstate Validation
Phase One: Defining the Right System for Industry

- **Task 1.1:** Project Management
- **Task 1.2:** Develop Concept of Operations
  - user issues
  - operational requirements
  - technical approach
  - input from Industry Operations Panel (IOP)
  - using standard IEEE or ANSI template
  - Auburn lead (Bishop)
- **Task 1.3:** Instrument NCAT Trucks to Perform Sensor/RF Level Assessments
  - instrument trucks with DSRC, radar
  - run trucks manually on Auburn track with typical inter-vehicle gaps
  - collect data to support requirements development
  - Auburn lead
Phase One: Defining the Right System for Industry

- **Task 1.4: Define Requirements**
  - based on ConOps
  - define detailed requirements to guide prototype development
  - validate requirements in simulation
  - requirements reviewed by IOP Carrier Subcommittee
  - Deliverable 1.1: Concept of Operations and Requirements Definition Summary
  - Auburn lead

- **Task 1.5: Examine Business Case for Near-Term CACC Trucking Operations**
  - internal experts plus fleet data used to define initial business case
  - factors addressed include
    - potential market size
    - cost factors and tradeoffs
    - payback time
    - potential enablers and/or barriers
    - coordination of trucks for coupling
    - assessing which types of fleet operations are most suited for early deployment of CACC
  - review by IOC
  - ATRI lead
Phase One:
Defining the Right System for Industry

• Task 1.6: Perform Preliminary Evaluation of Impacts
  – mobility, safety, and other factors
  – traffic simulations included
  – working with industry groups to identify potential safety issues for examination in Phase Two
    • IOC
    • TMC
    – Auburn lead (Bishop)

• Task 1.7: Prepare Phase One Report
  – Deliverable 1.2: Phase One Results Summary
  – presented to FHWA in summary meeting
  – Auburn lead
## Phase One Milestones

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Completion (Month)</th>
<th>Planned Evaluation Metrics</th>
<th>Criteria for Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1.1: Concept of Operations</td>
<td>3</td>
<td>Checklist as to standard ConOp elements as used in Sys. Eng.; system requirements acceptable to Fleet Operations Panel</td>
<td>D1.1 Concept of Operations and Requirements Definition accepted by FHWA</td>
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<tr>
<td>complete</td>
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<td>3-month checklist as to standard ConOp elements as used in Sys. Eng.; system requirements acceptable to Fleet Operations Panel</td>
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<tr>
<td>M1.2: Requirements Definition</td>
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<td>Requirements for functional operation, user interface, and aspects specific to fleet operations defined.</td>
<td>Requirements reviewed and accepted by IOP.</td>
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<td>complete</td>
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<td>7-month requirements for functional operation, user interface, and aspects specific to fleet operations defined.</td>
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<td>M1.3: Business Case and Impacts</td>
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<td>Quantified business case data and traffic simulations data. Approach accepted by IOP.</td>
<td>Business Case results reviewed by Industry Operations Panel. Traffic simulation results reviewed by FHWA.</td>
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<tr>
<td>Evaluation complete</td>
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<td>11-month quantified business case data and traffic simulations data. Approach accepted by IOP.</td>
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# Phase One Schedule

**2014**

<table>
<thead>
<tr>
<th>Oct</th>
<th>Nov</th>
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<th>Jan</th>
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<tbody>
<tr>
<td>Task 1.1: Project Mgmt</td>
<td>Early</td>
<td>Original</td>
<td>Removed</td>
<td>Bevly</td>
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<td>Task 1.2: Develop ConOp</td>
<td>Bishop/Peloton M1.1</td>
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<td>Task 1.3: Sensor/RF Assess</td>
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<td>Task 1.4: Define Rqmts</td>
<td>Peloton/Bevly M1.2 D1.1</td>
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<td>Task 1.6: Evaluate Impacts</td>
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<td>Task 1.7: Phase One Report</td>
<td>Bishop D1.2</td>
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- Accelerated compared to proposal
- ConOps has started already
Concept of Operations Draft Outline

- **Purpose of Document**
- **Background**
  - current situation on the roads for freight
- **Operational Needs**
  - trucking industry aspects relevant to CACC
  - where need is greatest
- **User-Oriented Operational Description**
  - what the system does
    - viewpoint of driver
    - viewpoint of fleet personnel
- **System Overview**
  - functionally focused engineering description
- **Operational Environment**
  - types of roads on which CACC operates
  - weather and other conditions under which CACC operates
- **Support Environment**
  - Maintenance
  - Standards
- **Operational Scenarios for Within-Fleet Operations**
  - trucks leave together hub-hub
  - trucks leave separately and find each other on the road
- **Appendices**
- **References**
Phase Two: Real-World Assessment

- **Task 2.1: Project Management**
- **Task 2.2: System Preparation on Vehicle**
  - implement based on Ph 1 functional requirements
  - Commercial ACC algorithms tuned for CACC
  - HMI implemented
  - Achieve Initial Operational Capability
  - Auburn lead
- **Task 2.3: Data Collection On-track to Assess Operational Envelope**
  - develop evaluation plan
    - scenarios and maneuvers
  - gain Human Subject Testing approval from Auburn IRB
  - data collection under strict safety protocol
  - Auburn lead
Phase Two: Real-World Assessment

- Task 2.4: Evaluate Initial System Against Measures of Effectiveness (MOEs)
  - use Task 2.3 data to evaluate
    - a) component/subsystem robustness and reliability (including V2V performance)
    - b) vehicle control performance (gap maintenance, hard braking, cut-ins, system faults, linking events)
    - c) HMI / driver control performance (resumption of longitudinal control, lane change coordination)
    - d) safety
    - e) fuel economy (SAE Type 2 test)
    - f) maintenance aspects
  - DFMEA completed
  - Deliverable D2.1: Initial Track-Testing Evaluation Results Summary
  - Auburn lead
Phase Two: Real-World Assessment

• Task 2.5: Implement Design Revision
  – system revisions as needed to improve performance
  – Auburn lead

• Task 2.6: Perform Extended Track Test
  – utilize ongoing truck operation on Auburn pavement testing track
  – perform test of two CACC trucks operating for an extended period (~60 hours)
    • including challenging maneuvers (cut-ins, etc.)
  – Auburn lead
Phase Two: Real-World Assessment

- **Task 2.7: Re-evaluate System based on Extended Testing**
  - evaluate system against MOEs and make revisions as needed
  - Auburn lead
- **Task 2.8: Conduct On-Highway Evaluation**
  - working with Alabama DOT
  - Evaluation
    - user issues
    - fleet issues
    - SAE Type III Fuel Economy Test
    - technical performance / robustness
  - Auburn lead
Phase Two: Real-World Assessment

• Task 2.9: Evaluate Operating Strategies
  – runs in parallel with other tasks
  – ATRI fleet-specific data used to apply the measured system performance parameters to actual fleet operations
  – Specific case studies based on anonymized fleet data
  – Results extrapolated to truck freight operations generally.
  – conduct traffic simulations based on the case studies and performance data to assess mobility impacts.
  – IOP review and comment
  – results feed into Deliverable D2.2: Operating Strategies & Driver Acceptance Results Summary
  – ATRI lead
Phase Two: Real-World Assessment

- **Task 2.10: Assess Driver Acceptance**
  - runs in parallel with other tasks
  - Data based on on-track testing and highway testing – both quantitative and qualitative – examined
    - provide guidance for system validation and refinement
    - inform business analysis.
  - Work with Driver Subcommittee of the IOP to explore driver issues relative to MOEs.
  - Areas of interest: specific controls, usability, training, and user acceptance
  - Identify issues for in-depth human factors experiments.
  - Technology Acceptance Model (TAM) will be used
  - feeds into Deliverable D2.2: Operating Strategies & Driver Acceptance Results Summary
  - Auburn lead
Phase Two: Real-World Assessment

• Task 2.11: Demonstrate Results and Prepare Final Report
  – demonstration for FHWA and invited stakeholders
  – Final Report to capture key aspects of task results and provide recommendations for next steps
  – Deliverable D2.3: Phase Two Results Summary
  – Deliverable D2.4: Final Demonstration
  – Auburn lead
## Phase Two Milestones

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Completion</th>
<th>Planned Evaluation Metrics</th>
<th>Criteria for Completion</th>
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</thead>
<tbody>
<tr>
<td>M2.1: Heavy Truck CACC Operational</td>
<td>2</td>
<td>System performing per requirements set in Phase One.</td>
<td>Initial technical capability achieved for 2-truck CACC system.</td>
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<tr>
<td>M2.2: Design Revision based on initial track testing complete</td>
<td>5</td>
<td>System upgrade performance goals achieved.</td>
<td>D2.1: Initial Track-Testing Evaluation Results Summary</td>
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<tr>
<td>M2.3: Extended duration track and on-highway testing complete</td>
<td>8</td>
<td>Meet test plan goals including length / duration of test, roadways, traffic scenarios.</td>
<td>Extended duration track and on-highway testing complete</td>
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<tr>
<td>M2.4: All assessments complete and prototype demonstrated</td>
<td>12</td>
<td>Full review by IOP and FHWA.</td>
<td>D2.2: Operating Strategies &amp; Driver Acceptance Results Summary</td>
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<td>D2.3: Phase Two Results Summary</td>
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<td>D2.4: Final Demonstration</td>
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<th>Task</th>
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<tr>
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<td>Jan</td>
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<tr>
<td>Task 2.1: Project Management</td>
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<td>Task 2.2: System Prep</td>
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<td>Task 2.3: Data Collection</td>
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<tr>
<td>Task 2.11: Demonstration / Final Report</td>
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- Accelerated from original proposal
- Overlaps with Phase 1 where logical
Phase Three: Disseminate Results

• Task 3.1: Project Management
• Task 3.2: Transition Research Results
  – Technical papers and presentations provided to:
    • ATA Technology and Maintenance Council
    • Mid-America Truck Show
    • SAE Heavy Vehicle Engineering Conference
  – Team will provide FHWA with an Interface Control Document (ICD), simulation parameters, and other documentation necessary to take the work forward.
  – ATRI will disseminate educational materials through their media outlets.
  – Auburn lead