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

GPS and Vehicle Dynamics Lab
Auburn University

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

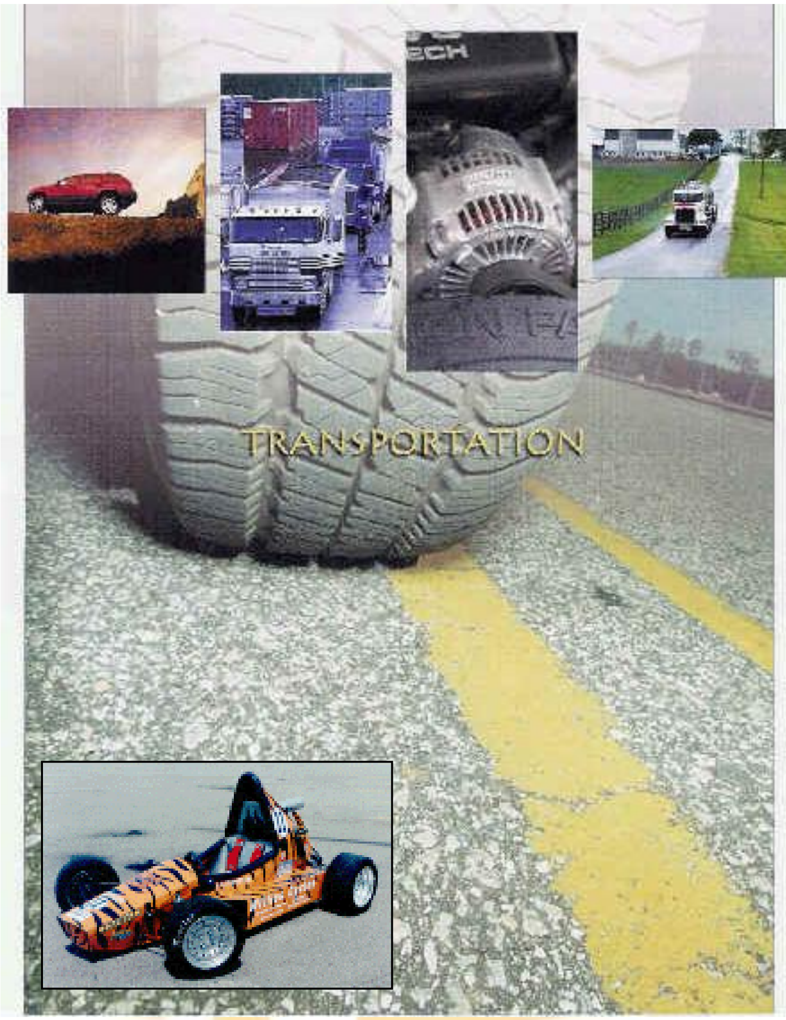
Industrial & Systems Engineering

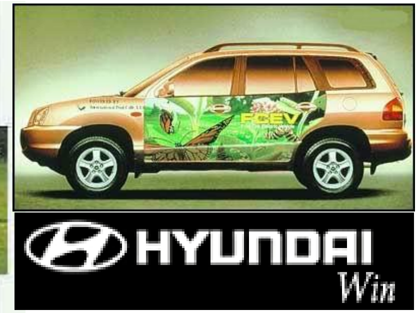
Aerospace Engineering

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

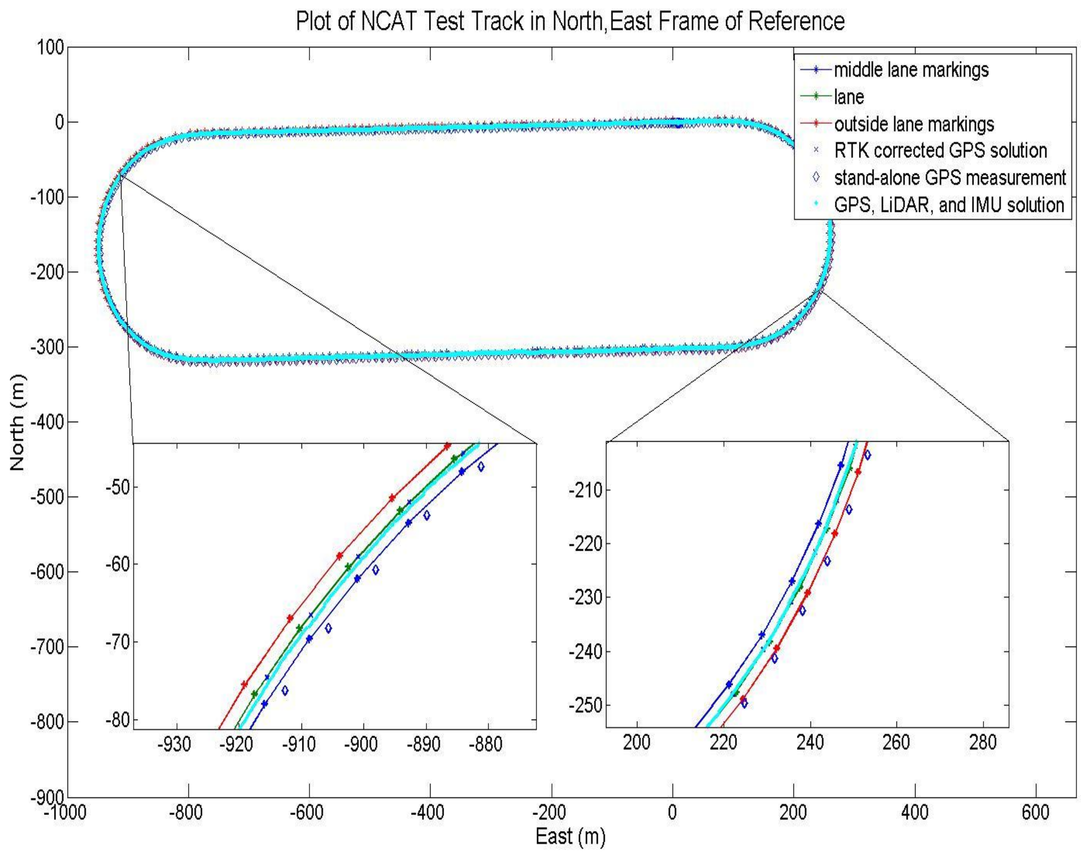
NCAT Test Track (& Trucks)

- 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

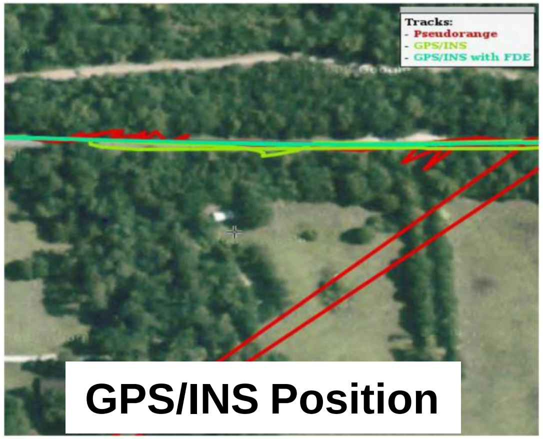
Test facility is available for validating vehicle modeling and estimation algorithms using instrumented vehicle test-beds

Prior Work with FHWA EAR (#1)

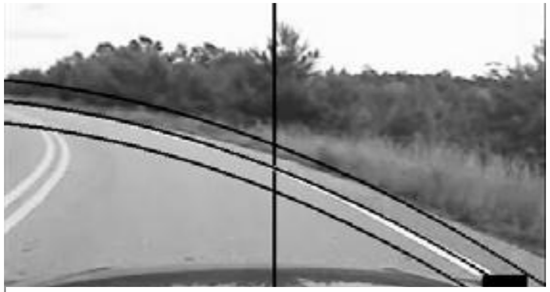
Integrate vision measurements (camera and/or lidar) with GPS/INS to provide lane level positioning



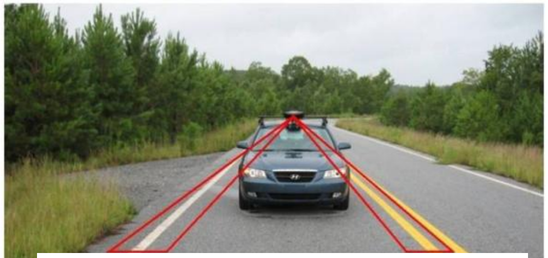
Combined GPS/INS/Vision Position



GPS/INS Position



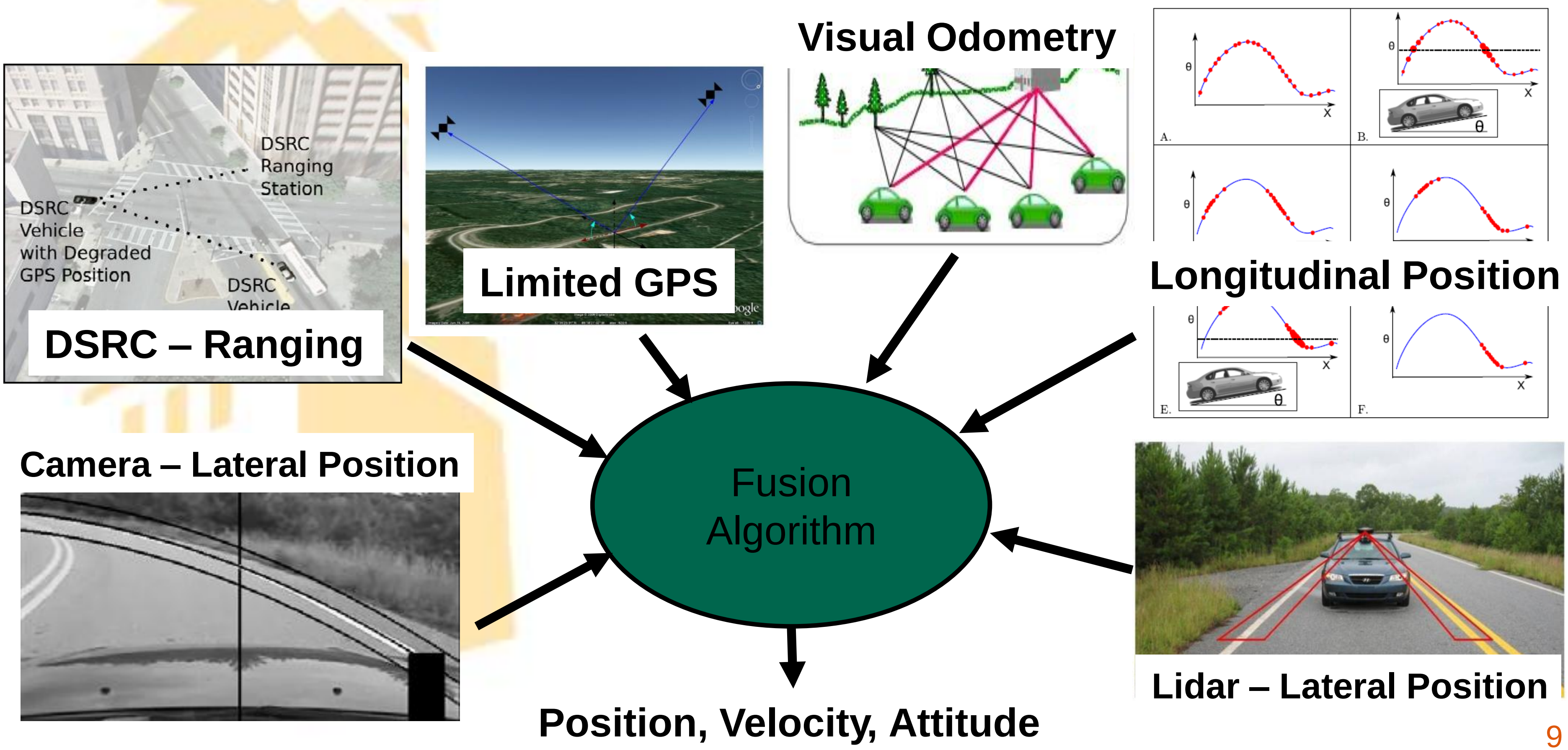
Camera Lateral Position



Lidar Lateral Position

Prior Work with FHWA EAR (#2)

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 (#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

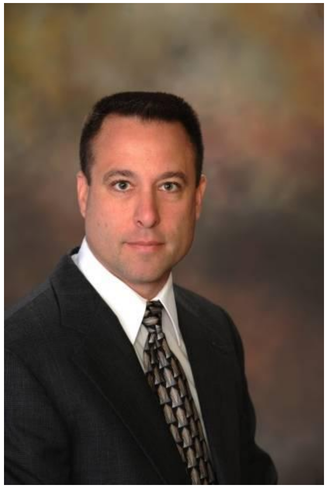
- Determine Potential Benefits
  - Traffic congestion effects
  - Teaming logistics/feasibility
  - Fuel saving benefits
  - User (driver) interfaces and acceptability

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)

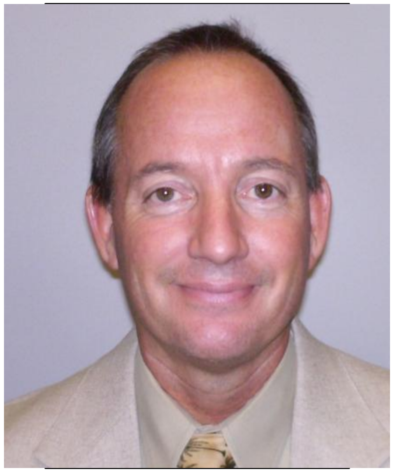
- General Area of Expertise
  - Intelligent / Connected / Automated Vehicles
  - Intelligent Vehicle-Highway Systems
- Project Focus Area
  - Operational Concepts
  - Business Case
  - User / Industry Acceptance
- Phase 1 Tasks
  - ConOps and requirements development
  - Business case evaluation
  - 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

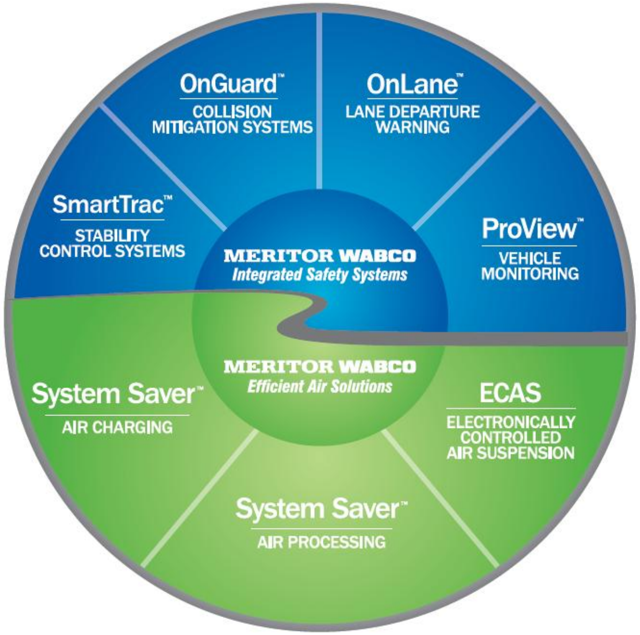
- Lead: Bill Kahn- Mgr Advanced Concepts
  - Bryan Knight- Project Engineer
- General Area of Expertise
  - OEM Vehicle Research and Development



- 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



ATRI

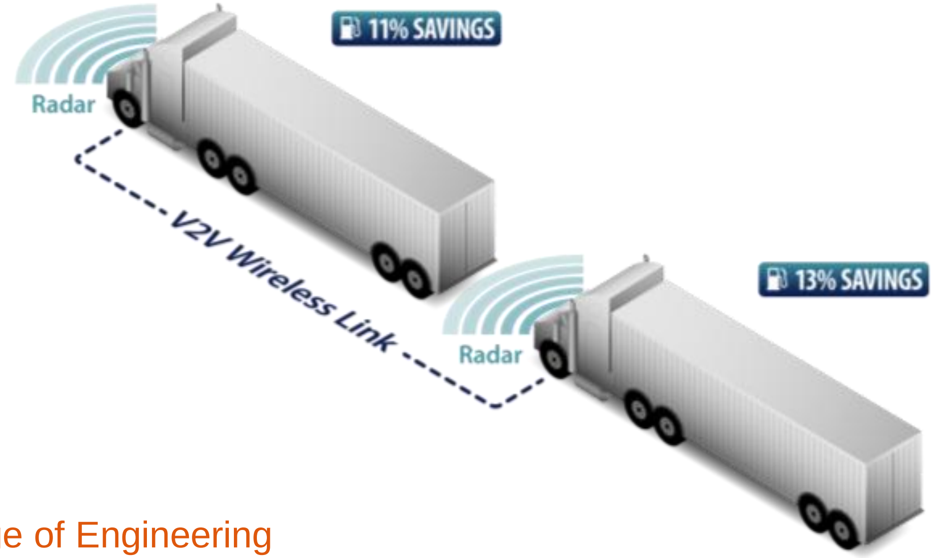
- Lead: Lisa Park
  - Dan Murray
  - David Pierce
- General Area of Expertise
  - Industry Analytics
  - Trucking Industry SMEs
  - GIS Data Analysis
- Project Focus Area / Contributions
  - Identify industry technical requirements
  - Solicit and evaluate industry input and feedback
- Phase 1 Tasks
  - 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

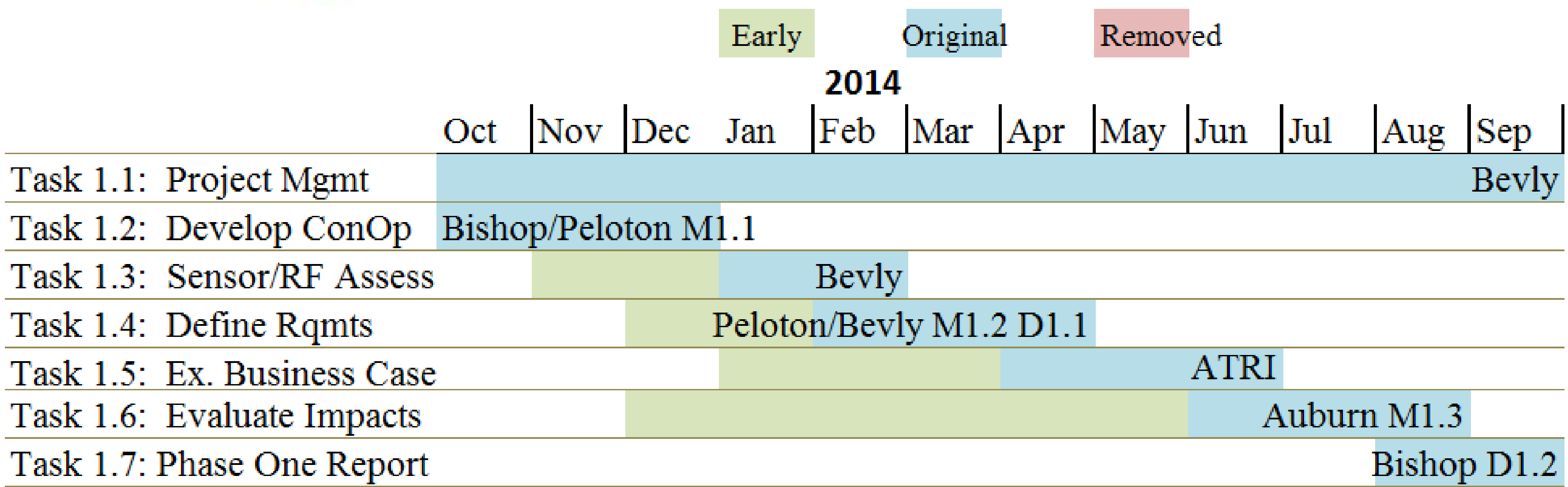
Phase One:
Defining the Right System for Industry

- 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

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

Phase One Schedule



- 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

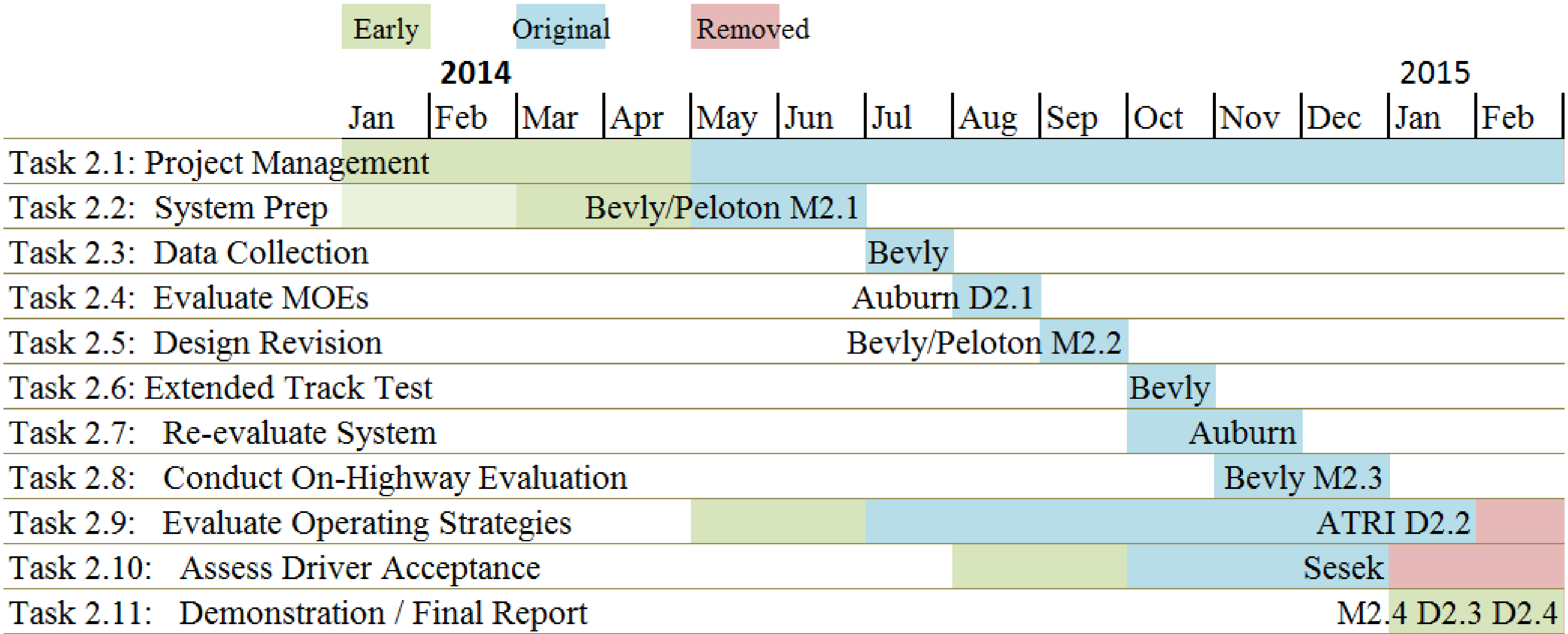
Phase Two: Real-World Assessment

- 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

Milestone	Completion	Planned Evaluation Metrics	Criteria for Completion
M2.1: Heavy Truck CACC Operational	2	System performing per requirements set in Phase One.	Initial technical capability achieved for 2-truck CACC system.
M2.2: Design Revision based on initial track testing complete	5	System upgrade performance goals achieved.	D2.1: Initial Track-Testing Evaluation Results Summary
M2.3: Extended duration track and on-highway testing complete	8	Meet test plan goals including length / duration of test, roadways, traffic scenarios.	Extended duration track and on-highway testing complete
M2.4: All assessments complete and prototype demonstrated	12	Full review by IOP and FHWA.	D2.2: Operating Strategies & Driver Acceptance Results Summary D2.3: Phase Two Results Summary D2.4: Final Demonstration

Phase Two Schedule



- 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

Questions?

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