Quarterly Report 1

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

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1 Introduction

The objective of this research is to perform the necessary technical work, evaluation, and industry engagement to identify the key questions that must be answered prior to market introduction of heavy truck Cooperative Adaptive Cruise Control (CACC), and to answer those questions. These questions must address industry needs as well as the needs of other highway travelers relating to traffic flow and safety. To complete this research, Auburn University is working in conjunction with several organizations including the American Transportation Research Institute (ATRI), Peloton Technology, Peterbilt Trucks, and Meritor WABCO. The partnership is organized with Auburn as the prime and the other organizations as subcontractors.

1.1 Auburn University

The primary groups within Auburn on the project are the GPS and Vehicle Dynamics Laboratory (GAVLAB); the Wireless Engineering Research and Education, and the Occupational Safety, within the Computer Sciences and Software Engineering Department (CSSE); and the Ergonomics and Injury Prevention Center, within the Industrial and Systems Engineering Department (ISE-MW).

1.1.1 GPS and Vehicle Dynamics Laboratory (GAVLAB)

The GAVLAB is composed of mechanical and electrical engineers, and it focuses on the control and navigation of vehicles using GPS in conjunction with other sensors, such as Internal Navigation System (INS) sensors. The GAVLAB is undertaking several tasks, including developing simulations of the sensory technology using TruckSim, writing algorithms for sensor fusion for robust positioning, estimation of truck properties including mass and engine torque, and live implementation of the system.

1.1.2 Wireless Engineering Research and Education Center (CSSE)

The main objectives of the CSSE group are design, implementation, and evaluation of vehicle-vehicle (V2V) communication for CACC, in which critical requirements for wireless networks that support for automated truck platooning are satisfied by providing high reliability in the transmission of control information, security against various forms of attacks and high data rates for rapid delivery of large amount of control and driver feedback data.

1.1.3 Occupational Safety, Ergonomics and Injury Prevention Center (ISE-MW)

The ISE-MW group is responsible for analyzing current trucking traffic to identify critical freight corridors in which platooning operations are likely to be viable as a result of CACC. This analysis requires the determination of estimated expected platoon sizes, impacts to delivery schedules, and waiting times for trucks to join a platoon. The ISE-MW group is also charged with supporting Task 1.5 (Examine Business Case for Near-Term CACC Trucking Operations).

1.2 American Transportation Research Institute (ATRI)

ATRI maintains one of the world's largest databases of real-time and near-real time truck GPS data. The Freight Performance Measures (FPM) program is partially sponsored by the FHWA to provide average travel times, speeds and reliability measures on the Interstate system. Beyond these activities, ATRI has successfully developed processes and algorithms for monitoring and managing truck travel throughout North America. The FPM database includes more than 500,000 large trucks that operate throughout North America. The data has been used by MPOs, State DOTs and the U.S. DOT to support multiple freight transportation objectives. ATRI will apply this FPM data to the project.

1.3 Peloton Technology

Peloton technology was founded expressly for the purpose of commercializing truck CACC. Based in Menlo Park, California, the company has a primary prototype on a box truck. This system has been developed to explore the user experience of truck platooning, and for this purpose a simple CACC system has been implemented. This includes radar, V2V communication, and a linked video display between the vehicles. Peloton uses rapid prototyping and data analysis tools which will be applied to this project. Peloton will provide technology leadership based on their work in exploring technical approaches with fleets.

1.4 Peterbilt Trucks

Peterbilt Trucks is headquartered in Denton, Texas, where they produce trucks and also perform advanced engineering. This facility will be leveraged for preparatory work on the trucks before delivery to the project team.

1.5 Meritor WABCO

Meritor WABCO is a 50/50 Joint Venture between Meritor and WABCO, established in 1990. The company, a leader in the integration of safety and efficiency technology for the commercial vehicle industry in North America, is a major supplier of Anti-Lock Braking and Electronic Stability Control systems for Class 8 tractors and has offered its OnGuard™ Collision Mitigation System (CMS) since 2007.

2 Overall Progress

The project has been moving forward since the start of the contract. Peloton is completing the Concept of Operations (ConOp) and will submit the document separately from this report. The CSSE group is currently evaluating wireless communication hardware options, while the ISE-MW group is writing code for platooning as well as exploring software to enable the visualization of dynamic truck data on maps.

The schedule for the project is listed below in Table 1. Task 1.2 is nearing completion, and Task 1.3 is in progress. Over the next few months, the team will instrument NCAT trucks with DSRC and radar and collect performance data, the software concept will be tested in a simulation environment (TruckSim). Requirements will be identified and documented in Deliverable D1.1. Table 2 shows the deliverables and the due dates.

Table 1: Schedule

Near Term Deployment of Heavy Truck Cooperative Adaptive Cruise Control -- PHASE ONE												
	FY2014											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Task 1.1: Project Mgmt												
Task 1.2: Develop ConOp			M1.1									
Task 1.3: Sensor/RF Assess												
Task 1.4: Define Rqmts							M1.2 D1.1					
Task 1.5: Ex. Business Case												
Task 1.6: Evaluate Impacts											M1.3	
Task 1.7: Phase One Report												D1.2

Table 2: Deliverables

	Due Dates
Phase One	
D1.1: Concept of Operations and Requirements Definition Summary	7 months from effective date of contract
D1.2: Phase One Results Summary	12 months from effective date of contract

3 Auburn University

3.1 GPS and Vehicle Dynamics Laboratory (GAVLAB)

3.1.1 Current Progress

For the past three months, the GAVLAB has focused on acquiring and testing hardware. So far, the GAVLAB has interfaced, tested, and recorded radar data in order to study noise and interference characteristics in certain environments. These measurement results were compared with results from an RTK GPS. While the radar data was noisier than the GPS data, the results showed that the radar could be used in environments where GPS would be unavailable. The GAVLAB also acquired and interfaced with a CAN Bus to communicate truck state properties (engine condition, torque, truck speed, braking, etc.).

In addition to testing hardware, TruckSim has been used to test an algorithm to detect the distance between two trucks. Two vehicle models independently pass their information to Simulink where a simple radar model is used to determine the relative distance between the trucks.

Figure 1, shown below, shows a simulation of two trucks, travelling on a public highway, with the following truck scanning the distance between the two trucks. The following truck uses radar, depicted here as a green light wave emanating from the following truck to the lead truck, to verify the distance.

Figure 1: A platoon of two trucks, simulated using TruckSim, traveling on a public highway. This simulation will be adapted to include an EKF for sensor fusion, as well as a controller for the following truck to maintain a constant distance from the lead truck.

3.1.2 Future Work

Moving forward, the GAVLAB intends to mount two Advantech computers as well as sensors (GPS, IMU, RADAR, and CAN) onto the NCAT trucks. Once mounted, data will be collected with the trucks driven manually. The GAVLAB also plans to develop an Extended Kalman Filter (EKF) for fusing measurements of all sensors for confident relative position estimation. The EKF algorithm will be added to the TruckSim algorithm, and a controller algorithm will be written for the following truck to maintain a desired distance from the lead truck.

3.2 Wireless Engineering Research and Education Center (CSSE)

3.2.1 Current Progress

3.2.1.1 Evaluating Different DSRC Solutions

The CSSE group examined different DSRC solutions to compare their capabilities for implementing enhancements to the wireless networking protocols that will support CACC:

1. **Denso**, an automotive supplier company, provides DSRC devices. They have extensive experience in working with car companies and that cooperation will be useful for us to pursue further research in our academic communities. The CSSE group hopes to obtain considerable technical support on drivers and other software related to their DSRC devices. The CSSE group plans on experimenting with a couple of their DSRC devices and provide some benchmark test results.
2. **802.11p Communication Unit** from Unex Technology is an all-in-one solution for WAVE/DSRC. It is a mini-PC box that has DSRC, a simple GPS and various functionalities. It has software support for WAVE/DSRC stack. However, the fact that it is a complete solution means if we need to improve on their protocols for supporting CACC better, then it can be difficult to change. Also, it is extremely expensive (~$3,000) compared to other configurations.
3. **DSRC Mini-PCI Adapter (DCMA-86P2)** from Unex Technology is the 802.11p adapter used in their all-in-one solution above. It is based on the AR5414A chipset, which has been verified by other researchers to be working with a modified 802.11a driver (ath5k). It also has a high rejection Rx filter that gets best frequency response at 5.9GHz and weaker radio signals on other frequencies, which suggests it may suffer less from interference from other channels. The downsides are 1) mini-PCI interface is deprecated by most of hardware makers except some motherboards with old chipset and router systems; 2) Unex does not provide software support for this, which means that we will need to obtain software from other research groups or develop them ourselves.
4. **OBU from Componentality** is a mini-PC box that is equipped with DSRC devices. Their support is very responsive and their device allows some customization. Despite that, it is much cheaper (less than $1,000) than the all-in-one solution from Unex, it still suffers from "hard-to-change" problem. In addition, it chooses an adapter over the DCMA-86P2 in favor of transmission range. In the context of this CACC project, transmissions over 1 kilometer may not be necessary. So the DCMA-86P2 is a more reasonable adapter.

The CSSE group chose the DCMA-86P2 because it has reasonable amount of community support and it matches well with this project requirements. Componentality might be another good choice in the future as the project proceeds, as their team work extensively in this vehicular networking area and are very responsive and technical.

3.2.1.2 Setting Up Wireless Hardware With DSRC Adapter and OpenWRT

The CSSE group choose Routerstation Pro from Ubiquiti as target platform, because 1) it is extensible. It has 3 mini-PCI interfaces for 802.11 adapters and several serial ports for CAN devices and GPS devices; and 2) it runs OpenWRT, a lightweight Linux distribution for networking.

The CSSE group has set up the DCMA-86P2 with a Routerstation Pro box, and flashed OpenWRT system to it. They studied the OpenWRT system and become more familiar with its package manager, system structure, etc.

For now, the DCMA-86P2 is recognized as an 802.11a adapter, because the default Linux kernel does not have 802.11p driver yet.

3.2.1.3 Initial Design of a Diff Protocol for Beacon-like Messages

To support reliable transmission, the CSSE group is designing a bandwidth-efficient message passing protocol for beacon-like messages, such as GPS data and vehicle status data. Since beacon-like messages tend to remain relatively unchanged or only slightly change over time, transmitting complete message every time is inefficient. Instead, the CSSE group wants to only transmit only the "diff" of messages. This includes 1) Only transmit fields in a message that is different from the last message; 2) for each changed field, only transmit the difference from last value (which is also known as integration compression).

3.2.2 Issues

3.2.2.1 DSRC Driver is Not Formally Available

The Linux Kernel (or any other OS) does not have a proper formal driver for 802.11p. Some researchers modified Atheros 802.11a driver (ath5k) to make it compliant with 802.11p standard and made the modified driver public. However, these drivers have not made it to the kernel source repository and it is not actively maintained. As a result, when the kernel internal API is updated, the driver may not work correctly. In other words, the modified driver can only work with a specific version of the kernel.

There are two sources of such drivers. One is from a European vehicular networking community (GCDC). It is available as a source tarball. The other one is from Componentality, the company that also makes DSRC OBU boxes. The latter one is integrated with the OpenWRT source tree. Both of them are not in Linux kernel source tree so we cannot use either one directly.

The CSSE group will need to port the driver to the latest OpenWRT system that they are running on Routerstation Pro. The main issue is to determine the differences between the Componentality DSR driver and the original ath5k driver and implement the changes in the latest OpenWRT kernel. This will enable them to implement the DSRC driver.

3.2.2.2 IP Layer is Absent From WAVE/DSRC Standard

Due to the context of vehicular networking, the WAVE/DSRC standard purposely removes routing from the networking stack, so there is no IP layer in the standard. This means the networking stack in Linux cannot be used directly because TCP/UDP -> IP -> Link Layer is tightly incorporated into the networking APIs. A reasonable communication paradigm that is compliant with WAVE/DSRC stack will need to be designed. The routing and message forwarding methods will be similar to IP so that multi-hop adhoc routing methods for V2V communication can be implemented despite mobility and network topological changes.

Comment [BC1]: What is impact? Plus I wonder if Alvin and Peloton are communicating re this technical approach

3.2.3 Future Work

3.2.3.1 Port DSRC Driver to OpenWRT Kernel

To port the modified driver (for DSRC) to the platform we are using, the CSSE group will run a *diff* from a modified driver against the original ath5k module for the kernel that the driver is designed for, to determine the changes. Then they will take the source code of the ath5k driver module from the kernel in OpenWRT system that we are using on Routerstation Pro box, and apply the same changes to it.

3.2.3.2 Detailed Design of Diff Protocol and Develop Library for Transmitting Messages Using It

The CSSE group also plans to wrap up some details on the proposed Diff Protocol, and start developing the library that implements it so that it can be used later along with CAN messages.

3.3 Occupational Safety, Ergonomics and Injury Prevention Center (ISE-MW)

3.3.1 Current Progress

The ISE-MW group has obtained a sample set of truck location data from ATRI (10 records for 1 truck). Using this sample set as a template, a database structure has been developed in anticipation of obtaining significantly more data records in the next quarter. The group will use this data to determine metrics describing the feasibility of forming platoons along major Interstate corridors (details are provided in the Future Work below).

Woodruff has completed coding of the basic heuristics of Larson et al. (2013)[1] in C++, which will be used to determine optimal strategies for platoon formations (by adjusting individual truck speeds). The heuristics have thus far been tested with randomly generated data. Solutions from the heuristics indicate the required travel speed for each truck, the number of trucks that would form a platoon, and the total distance over which the platoon operates.

The ISE-MW group continues to explore Geographic Information System (GIS) software options to enable the team to visualize dynamic truck data on maps. The group is also identifying publicly available data sources containing the precise geographic locations of the Interstate corridors that are likely candidates for platoon operations. Finally, the group has begun writing a procedure

[1] J. Larson, C. Kammer, K-Y. Liang, and K.H. Johansson. Coordinated Route Optimization for Heavy Duty Vehicle Platoons. In *16th International IEEE Annual Conference on Intelligent Transportation Systems*, 2013.

(computer code) to determine the heading and the time/location at which each truck in the ATRI-supplied sample data set exit a road segment.

3.3.2 Future Work

In the next quarter, the ISE-MW group plans to select 3-4 candidate corridors along the Interstate system and request truck data along (at least) 1 of these corridors from ATRI. Using ATRI truck data for a single corridor and a fixed time horizon, the group will determine the following metrics:

- Average number of trucks that could feasibly form a platoon,
- Average length of travel for the platoon,
- Average platoon size, and
- Average required speed changes to allow platoon formation.

These metrics will provide insights into the near-term practicality of CACC, assuming minimal changes to current operating practices.

The group then plans to implement Larson's basic heuristics for optimal platoon formation using actual truck data from ATRI. Differences in truck locations over time, comparing current (based on historical data) and "optimal" (based on heuristic solutions) truck locations, may be used to quantify the changes required to current operational practices to more fully realize the benefits of CACC.

As Larson's heuristics are relatively simplistic (e.g., they assume that platoons may be formed only if trailing trucks accelerate beyond the speed limit, and the fuel efficiency estimates employed by the model account only for changes in vehicle speeds), the group will be begin development of an extended model to more appropriately address the real-world limitations of truck coordination. In particular, the new model will restrict truck speeds to posted speed limits on the road network. The group will also work to obtain terrain information, from publicly available sources, along the initial Interstate corridor under consideration (nominally, elevation changes). This information should be incorporated in a more realistic model of fuel efficiency calculations and platoon formation options.

4 American Transportation Research Institute (ATRI)

4.1 Work Completed by ATRI

Over the past quarter, the ATRI participated in project management, and attended a project kickoff meeting at the DOT Headquarters in Washington, D.C. They developed and submitted a summary document that defines and describes major components of the trucking industry, including stratifications for sector, fleet size and vehicle configurations for inclusion in the ConOps. Also, using industry databases, the ATRI developed and distributed a user requirements survey to motor carriers and professional truck drivers, and they collected and analyzed the survey response data. They then developed and submitted a summary document, outlining findings from the user requirements survey as they relate to potential DATP operations for inclusion in the ConOps.

4.2 Planned Work for Next Quarter

Over the next quarter, the ATRI intends to identify and recruit members of the Industry Operations Panel (IOP) with both Driver and Carrier Subcommittees. They will also review ConOps findings with the IOP, summarize the IOP review, and submit the IOP feedback to the team. Finally, the ATRI will assist, as needed, with the development of the Business Case for Near Term DATP Trucking Operations.

5 Conclusions

Milestone 1.1 is nearing completion – Peloton will complete and submit the Concept of Operations shortly. Positioning hardware is being acquired and tested, and range-finding algorithms have been written, using TruckSim for verification. Wireless communication hardware is also being acquired and tested, and compatibility issues are being addressed. Over the next three months, these components will be installed and tested on trucks at NCAT, and a Requirements Definition Summary will be submitted. Finally, feasibility studies regarding platoon formations on highways are underway, with the intent of selecting 3-4 candidate corridors where platooning would likely be practical.