MPC-599
April 16, 2019

Project Title

Connected-Autonomous Traffic Signal Control Algorithms for Trucks and Fleet Vehicles

University

University of Wyoming

Principal Investigators

Milan Zlatkovic
Assistant Professor
University of Wyoming
Phone: (307) 766-2390
Email: mzlatkov@uwyo.edu
ORCID: 0000-0002-6777-230X

Mohamed Ahmed
Associate Professor
University of Wyoming
Phone: (307) 766-5550
Email: mahmed@uwyo.edu
ORCID: 0000-0002-1921-0724

Research Needs

Connected vehicle (CV) technologies enable vehicles to exchange information with each other (vehicle-to-vehicle [V2V]) and with the roadside infrastructure (vehicle-to- infrastructure [V2I]) in real time. The CV systems combine different technologies, such as wireless communications, advanced vehicle sensors, advanced roadside infrastructure, onboard computers/processing and similar. Autonomous vehicles (AV) use various technologies (radar sensors, LiDar, GPS and similar) to sense their surroundings and take driving functions from the driver at different levels. The connected-autonomous vehicles (CAV) integrate the functions of CVs and AVs for a greater benefit. The US DOT recognizes several areas of CAV technology applications, such as V2I safety, V2V safety, road weather, environment and mobility, among others.

WYDOT is in the process of upgrading six traffic signals and installing CAV hardware and software. This creates opportunities for developing strategies that would benefit traffic operations and safety, sustainability and economic development. All roadway facilities in Wyoming experience high percentages of heavy truck traffic that has negative impacts on operations and safety. On the other hand, the efficiency of freight transportation is of a high economic importance. Another area that can significantly benefit from the implementation of CAV technologies is emergency response. Therefore, it is recommended that the research on CAV mobility applications important for Wyoming conditions begin with the following:

- Intelligent Traffic Signal System (ISIG)

- Freight Signal Priority (FSP)
- Emergency Vehicle Preemption (PREEMPT)
- Dynamic Speed Harmonization (SPD-HARM)

The ISIG system is using high-fidelity data collected from vehicles through V2V and V2I communications to control signals and maximize throughput in real time. The ISIG application also plays the role of an overarching system optimization application, accommodating signal priority, preemption, and non-motorized movements to maximize overall network performance.

Certain parts of urban networks, such as industrial, warehouse or port areas, experience high truck traffic. Large trucks have significantly different physical characteristics from passenger cars, requiring more space and time for maneuvers. Therefore, the operation of traffic signals along truck routes can be modified to give certain priority for trucks, called Freight Signal Priority (FSP). This priority will allow for extra time for trucks to clear the intersection without stopping, improving their travel time reliability and enhancing safety.

A fast response and arrival to the scene is critical for emergency vehicles (EV). In signalized networks, EVs receive the highest level of priority, called preemption. Once the approaching EV is detected, the downstream signal changes its operation to allow the EV to pass without stopping and conflicts. Traditionally, the preemption is triggered by different types of wireless communication between the vehicle and the signal. These vehicles communicate with the traffic signal controller by sending a message that will call a special preemption or priority control logic and timing feature on the traffic controller. Therefore, the CAV technologies are a logical successor for communication. It has many advantages, such as communication of the EV requests throughout the network, accounting for effects of multiple EV requests through the same traffic network, warning the other vehicles of the EV approach and similar.

Dynamic Speed Harmonization (SPD-HARM) uses the communication among vehicles to control the speeds of clustered CAVs. The objective of this application is to dynamically adjust and coordinate maximum appropriate vehicle speeds in response to downstream congestion, incidents, and weather or road conditions in order to maximize traffic throughput and reduce crashes (*ITS JPO, 2018c*). Speed harmonization increases the capacity of traffic facilities and reduces congestions due to the phantom traffic jam effects. It also allows creating and maintaining vehicle platoons, increasing mobility through signalized intersections. The signals communicate their status (through SPaT) and the clustered vehicles will respond by adjusting and harmonizing their speeds so that the platoon reaches the signal during the green phase time.

The standards and protocols of CAV technologies are currently in development, with limited number of implementations. The installation of CAV hardware/software in traffic signals in Wyoming creates opportunities for developing methods and algorithms that would help the State’s unique transportation challenges (primarily high heavy truck traffic and adverse weather). This study will review the current protocols and recommend options applicable to Wyoming conditions. The focus will be on optimizing operations of freight and emergency vehicles through signalized networks, primarily those that experience high truck traffic (signalized freeway ramps and arterials). Six test sites will be used to develop and test the appropriate algorithms. The study will use high-fidelity traffic microsimulation, with CAV and traffic control emulators, that would help develop field-ready control programs, as well as driving simulation that will test the drivers' responses to the control programs.

Research Objectives

The main research objectives of this study are as follows:

- Synthesize the current state of research and practice related to signal control programs under the CAV environment

- Recommend intersection communication protocols for CAV implementation suitable for Wyoming conditions, but transferable to other locations. The measure of success will be that the protocols can be incorporated in the current and standardized hardware and software for CAV implementation.

- Develop and test algorithms for ISIG, FSP, PREEMPT and SPD-HARM. The measure of success will be that the algorithms can be implemented in traffic control programs and that they are efficient: responding to dynamic inputs, changing operations and improving efficiency (delay reduction, speed increase, queue reduction) when compared to the base scenario.

Research Methods

The study will use the review of literature and practice, collection of the existing field data, and traffic microsimulation models to develop, test and select the most appropriate CAV control algorithms for ISIG, FSP, PREEMPT and SPD-HARM. Field data (geometries, traffic and control) will be collected from selected test-sites and used in the analysis and models development. The algorithms will be developed according to the actual standards and protocols for CAV technologies. Traffic microsimulation software VISSIM will be used extensively to develop and test actual control programs that will be field-ready. The focus of the algorithms will be to improve traffic operations, as well as create traffic conditions that will benefit safety. Driving simulation will be used to assess drivers' responses to the control systems.

Expected Outcomes

The first outcome of the study will be a synthesis of existing literature and practice on CAV technologies and algorithms, with a focus on traffic signal operation. The literature review will recognize the current state of research and practice, technologies, implementations and potential gaps and problems that need to be addressed in the future. The second outcome will be a set of microsimulation and driving simulation models for selected locations, that can also be used in future research. The models will use state-of-the-art software and traffic control programs through software-in-the-loop (SIL) implementation. The modeling process will be described in detail for future references and similar uses. The most important outcome of the study will be a set of field-ready traffic control algorithms and programs that use CAV technologies to improve operations of freight and emergency vehicles through signalized intersections and urban arterials. The focus will be on freight transportation and emergency services, with a potential to expand to other special control options in the future. This research would not be beneficial only for WYDOT and Wyoming agencies, but also for agencies across the US that are preparing for the era of CAV technologies. The research will also represent an excellent starting point for special signal operations using connectivity technologies.

Relevance to Strategic Goals

This study will ultimately be related to all five USDOT strategic goals. Safety and Livable Communities will be impacted the most by this study. Trucks have significantly different characteristics than other vehicles, which impacts their maneuverability. They require more time to start, stop and turn, and more space to perform different maneuvers. Emergency vehicles, especially fire trucks and ambulances, also require more time and space, but at the same time they have to move quickly. FSP, when designed properly, can significantly improve both safety and operations for trucks at signalized intersection. PREEMPT is a strategy that will facilitate the movements of emergency vehicles and shorten the response times, reducing conflicts between emergency and other vehicles. SPD-HARM can be used in both interrupted and uninterrupted traffic facilities to achieve platooning and harmonization of speeds, minimizing the effects of traffic shockwaves and improving operations and safety. All of these applications can benefit significantly from the CAV technologies that will be researched in this study. The main postulate of livable communities is integration of transportation with housing and economic development to increase transportation choices and access to transportation services. Increasing the efficiency of freight transportation and emergency services creates a better economic environment, faster response times, as well as more favorable conditions for other traffic modes, motorized or otherwise. Improving operations for freight and emergency vehicles can also have significant impacts on economic competitiveness, state of good repair by maintaining infrastructure, and environmental sustainability by reducing emissions and noise.

Furthermore, this study will have even greater significance for the new USDOT 2018 – 2022 strategic goals: safety, infrastructure, innovation and accountability. In addition to improving safety through better truck and emergency vehicle operations, the study will also help develop strategies to preserve infrastructure and yet increase its efficiency. Innovative technologies are the core of this study and it will help better understand and improve on some of the special operations of traffic signals within the CAV environment.

Educational Benefits

Students will be involved in all aspects of this study, and it will provide a good material for transportation courses in traffic operations, control, simulation and design. The students will perform main tasks in literature review, data collection, models creation and algorithm development and implementation. The students will have the opportunity to learn and work with state-of-the-art traffic simulation software, which is more and more being used by companies and agencies. The material developed throughout the study will be used to update the course syllabi and class lectures/labs in related transportation courses.

Technology Transfer

The research team will reach out to the transportation community to discuss and present the methodologies and results of the study. Practitioners and researchers will be the target audience, since the study aims to develop control programs that can be implemented in the field. This will be done through personal communication, web sites, social media, conferences and journal publications. The research team will seek input from other interested parties to improve upon the study design and methodology. WYDOT has also approved this study, so their personnel will be involved through all phases of the research.

Work Plan

The work plan is divided in seven tasks and developed for a two-year performance period. The tasks are as follows:

Task 1: Review of literature and practice related to CAV technologies and operations (NTP – Month 3, and updated throughout the study)

The review will include existing standards and protocols, hardware and software, operational and safety methodologies, and CAV implementations and testing. The literature review will also provide some recommendations for the selection of test cases, methodologies, models development, testing and results interpretation.

Task 2: Data collection (Month 3 – Month 9)

The research team will identify the traffic data needed for the research, and the existing data sources. The data will include geometrical characteristics of the test locations, operational characteristics (traffic volumes, traffic composition) and traffic control data (traffic signal timings and roadway/intersection signage). The test locations are six signalized intersections in Evanston, Rock Springs, Rawlins, Laramie and Cheyenne.

Task 3: Development of traffic simulation models (Month 6 – Month 12)

The research team will create and calibrate traffic microsimulation models for the six locations. The models will be developed in PTV VISSIM software with traffic signal control emulators. Selected locations will be recreated in a driving simulator to test drivers' responses in combination with the signal control strategies.

Task 4: Development of CAV algorithms and control programs (Month 9 – Month 15)

The focus of the CAV algorithms will be on FSP, PREEMPT and SPD-HARM, but the research team will also assess other applicable cases that fall under the ISIG control set. The reason for this is two-fold: first, Wyoming experiences high heavy truck volumes, so FSP and SPD-HARM will be very beneficial for local conditions; and second, it is more likely that the fleet vehicles will be the first to be equipped with CAV technology. The algorithms will not be focused on priority/preemption only, but will also include other strategies such as dynamic yellow/red clearance intervals, adaptive left turn treatments and operations, adaptive ring/barrier structure and phasing, and similar.

Task 5: Testing of CAV algorithms and control programs (Month 12 – Month 20)

The initial tests of algorithms and programs will be performed in microsimulation. Different scenarios will be developed by upgrading the base models, and the algorithms will be implemented through VISSIM's CAV external driver modules and SIL traffic controllers using logic processors.

Task 6: Providing recommendations for field implementation (Month 20 – Month 22)

Through microsimulation and driving simulation testing, the most promising methods will be selected and recommended for field implementation. The recommendations will include detailed descriptions of algorithms' operations and implementation steps.

Task 7: Final report (Month 20 – Month 24)
The research team will summarize the study in a formal final report. Technical reports and memos will be developed throughout the study. The final report will be a complex document that include the review of literature and practice, algorithms, models, testing procedures, results and recommendations.

Project Cost

Total Project Costs:	$209,589
MPC Funds Requested:	$ 60,723
Matching Funds:	$148,866
Source of Matching Funds:	Wyoming Department of Transportation

References

1. Leonard, B. D. *Installing DSRC Systems for Vehicle to Infrastructure Applications*. Western States Rural Transportation Technology Implementers Forum, June 2017.

2. University of Arizona, University of California PATH, Savari Networks Inc., and Econolite. *Multi-Modal Intelligent Traffic Signal System Phase II: System Development, Deployment and Field Test*. Connected Vehicle Pooled Fund Study, September 2016.

3. Michigan DOT. *Moving Michigan Forward: 2040 State Long-Range Transportation Plan - Connected and Automated Vehicles and New Technology*. July 2016.

4. Yang, X. *Traffic Operations with Connected and Automated Vehicles*. AAAI-17 AI-CAV Workshop, February 2017.

5. Cronin, B. *Vehicle Based Data and Availability*. USDOT, 2012.

6. USDOT. *Transportation for a New Generation: Strategic Plan 2014 – 2018*. June 2015.

7. USDOT. *Strategic Plan for FY 2018 – 2022*. August 2018.