**V2X Platooning Optimal Control: Minimizing Travel Time and Energy Consumption in Urban Setting**

Tianhao Wu, Joe Koszut, Aoyu Zou, Shih-Hung Chiu, Jarvis Yuan, & Margaret D’Auria

1. **Abstract**

Platooning is an emerging area of research in both systems and transportation engineering fields. The benefits of platooning are high; linking cars together as they travel saves these vehicles energy and time on their journey by eliminating margin needed for a human reaction and reducing aerodynamic drag forces. Platooning has to be designed correctly to achieve this goal, though. This study focuses on the energy modeling and optimization of connected and automated vehicles (CAV) platooning with time conscious control. It focuses on cars as they drive through an urban setting with a multitude of stop signs and traffic lights. One key focus of this study is the minimization of associated greenhouse gas emissions with platooning. Another is the travel time savings for cars as they travel in a CAV train. This study hopes to look at a range of vehicle powertrains - with an emphasis on battery electric vehicles (BEV) and internal combustion engines (ICE) - and model, optimize, and compare the options to find the optimal platooning method. This project applies data science strategies such as mathematical modeling, optimization, and optimal control to answer the question at hand.

1. **Introduction**
   1. The motivation for this study stems from the group’s heavy interest in systems engineering, in particular, the emerging systems technology associated with vehicle platooning associated with increasing roadway safety, energy efficiency, and the trend of transportation electrification worldwide. The small margin for error makes the problem more challenging and exciting to handle. Another major motivation behind the study is to compare the energy efficiencies of different vehicle powertrains in vehicle platooning context. Among BEV, ICE (gasoline and diesel), fuel cell electric vehicles (FCEV), and plug-in hybrid electric vehicles (PHEV), each of these vehicle types has unique emissions outputs and energy consumption characteristics. Comparing these technologies to assess which of these is the most effective at optimizing vehicle platooning is a question that will need to be answered if this technology is going to be successfully implemented on a large scale. Additionally, members of the group have heavy backgrounds in life-cycle assessments related to greenhouse gas emissions. In 2018, the U.S. transportation sector alone consumed over 143 billion gallons of motor fuel, and it is predicted that the fuel consumption in transportation in the U.S. will remain at a high level in the foreseeable future. Furthermore, the world consumption of transportation fuel is forecast to increase significantly with a steady increase in vehicle ownership as incomes in developing countries rise. Emissions will have to be cut from the vehicles themselves in order to reduce global greenhouse gas emissions. In the urban settings, there has been so-called eco-driving practices among the environmentally conscious drivers, which consists of avoiding hard and sudden acceleration and deceleration based on real-time surrounding conditions and traffic stops. This practice was shown to reduce energy consumption on an individual level, but without the advanced knowledge of traffic signal status and susceptible to a wide margin of error and uncertainty from the driver and others. Fortunately, the rapidly evolving CAV technology can overcome these limitations of eco-driving through better communication and greater vehicle control, and hence provides a powerful tool to reduce both fuel consumption and greenhouse gas emissions more effectively.
   2. The focus of this study is to find the optimal way to implement platooning for passenger vehicles with different powertrains in an urban environment that optimizes both greenhouse gas emissions and travel times. Currently, the transportation industry is one of the leaders in greenhouse gas emissions; minimizing these emissions as well as people’s time on the road will benefit the transportation industry as a whole.
2. **Relevant Literature**

Relevant literature is listed at the end of this document in the References section. Studies on urban platooning in the research literature have discovered that technologies such as adaptive cruise control or cooperative adaptive cruise control could bring benefits in energy saving. Optimization in speed trajectory between stops specifies acceleration and deceleration in maximum efficiency under the objective of low energy usage and travel time constraints. In addition, platooning enables a closer headway which reduces the aerodynamic drag and saves energy. On the other hand, traffic signals, which introduce stops and delays in urban transportation, are found to be responsible for a large amount of emissions. Thus it could ideally be a proper case study for practicing the proposed control and optimization strategies. The referenced literature would provide the foundation and a solid starting point for our study in formulating the problem and mathematical modeling.

1. **Statement of Work**

Since the submission of our declaration, we have made significant progress in narrowing down the scope of the problem we desire to study. Having a high-level description in mind, we have created a structured plan of action for the remainder of the semester which we will strive to follow closely. To begin, we will choose a relevant open source urban traffic drive cycle to use in our studies. If needed, we will make minor alterations to the drive cycle to make our problem more tractable. We will then form the skeleton of our optimization problem, choosing our objective function and constraints, keeping in mind that the details of our formulation may change between different powertrains. Once we have a skeleton for our optimization problem, we will create mathematical models for individual powertrains. We will initially focus on creating one powertrain model that we can simulate and optimize to ensure that the skeleton for our optimization problem does not need any major changes. An open-source optimization solver will be used to find (globally) optimal trajectories for a single leading vehicle, then it will be extended to our vehicle platoons. Once we have working powertrain models which can reliably be used as inputs to the solver, we will expand our optimization problem to study new parameters such as platoon length, following distance, and information delay. Throughout this work, we will manage our time such as to leave enough room for working on the progress report, presentation, and final report. These plans and the individual members responsible for them are outlined in Table 1.

**Table 1. Proposed project schedule**

| Date | Task | Members |
| --- | --- | --- |
| 10/08/21 | Choose a Preliminary Drive Cycle | Margaret & Tianhao |
| 10/14/21 | Form Skeleton of Optimization Problem with Constraints | Joe & Shih-Hung |
| 10/20/21 | Create and Calibrate Mathematical Powertrain Models | Joe & Tianhao |
| 10/27/21 | Solve an Instance of the Optimization Problem | Shih-Hung & Aoyu |
| 11/03/21 | Progress Report Complete | All |
| 11/10/21 | Expand the Optimization Problem to Incorporate More Parameters | Margaret & Jarvis |
| 11/17/21 | Test Solution in Simulation Environment for Optimal Control  *Run control problem on 2 powertrains, incorporating drag* | Aoyu & Jarvis |
| 11/29/21 | Final Presentation Complete | All |
| 12/10/21 | Final Report Complete | All |

1. **Summary**

The aim of the project is to optimize a platoon of vehicles traversing through an urban setting with a fixed variety of traffic lights and stop signs. The optimization problem defines a final destination that the vehicles need to reach and includes spatial, temporal, and safety constraints to represent red lights and stop signs. Vehicles will get to the final destination while minimizing energy and satisfying speed constraints, not going too slow nor too fast. To build the model, a real urban drive cycle will be used to provide positions and timings of traffic lights and stop signs. After a drive cycle is defined, the energy consumption of ICE and BEV vehicle powertrains will be modeled, giving us an implicit measure of emissions for comparison. Using this model and relevant constraints, we will generate an optimal position, time, and acceleration trajectory along with the energy consumption characteristic counterpart for the powertrains. After an optimal trajectory is generated for one vehicle, the model will be solved for a new vehicle powertrain and results will be compared.

The final results are to come in the final report, and progress updates will be provided in the progress report. The hypothesis is that an optimized platoon of vehicles will attempt to more closely follow the minimum energy scenario rather than the minimum time scenario, with BEV being the more efficient setting. Optimizing both energy and time simultaneously, the most efficient scenario might be the average of the two, but with traffic lights in the model the optimal solution will likely fall closer to the minimum energy scenario.

**References**

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