CTIPS Center for Transformative Infrastructure Preservation and Sustainability
USDOT Region 8 University Transportation Center

Improving Compatibility of Truck Platooning with Existing Infrastructure via Development of Dynamic Operational Rules on Highway Networks

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University

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Research Needs

Truck platooning is electronically linking two or more trucks in convoy using automated driving support systems and connected technology (*1–3*). It has great potential in reducing fuel consumption and emissions while increasing highway freight transport capacity (*4–7*). Truck platooning is a promising technology for the US Great Plains and Mountain West regions, where the backbone of economic development relies heavily on ground freight transport. For example, in 2022, transportation and warehousing contributed $4,173.7 billion (i.e., 8.5%) to Wyoming's gross domestic product, and truck transportation produced $511.2 billion (*8*). Truck transportation also moved $35.4 billion (i.e., 39%) of all Wyoming-related freight shipment value ($90.7 billion) in 2018 (*9*).

Currently, truck platooning is at the stage where adaptivity of the technology to complex roadway infrastructure and environments are at the focal point. It is a crucial step to understand the possible interactions in truck platoon operations on different types of highways and determine the rules and regulations for safe deployment. In Wyoming, for example, the current 13 key freight corridors identified by Wyoming Department of Transportation (WYDOT) collectively span over 8,000 lane-miles (*9*, *10*). Those corridors consist of roadway segments of the US Interstate, US Highway, and Wyoming State Highway systems, with various geometric design features. When navigating through various roadway geometry, truck platoons face control challenges such as losing string stability (*11–13*). Environmental factors such as weather are also shown to affect truck platoon operations and safety (*14*, *15*). Adding to the complexity, truck platoons operating in mixed traffic need to avoid all types of collisions with the surrounding vehicles (*16*). Prior research has offered solutions including applying collision avoidance systems or using complex control strategies to react to surrounding vehicles' risky maneuvers such as cut-ins (*17–19*). However, rather than totally relying on reactive collision avoidance, offering safe conditions for both truck platoons and surrounding vehicles by establishing operational rules and regulations would be a necessary action to take to ensure safe and efficient deployment of the technology, as it builds a multi-layer safety guarantee.

Infrastructure owner operators (IOOs) play an important role in deployment of truck platooning by setting up roadway management rules and guiding traffic and truck platoon operations using conventional and innovative strategies and technologies (*4*). Currently in the US, state laws on truck platooning are at the stage of defining truck platooning, permitting criteria, and restricting certain operational features. For example, twenty states have passed laws regulating truck platoons' minimum internal following gaps, ranging from 250 to 500 ft (*20*). However, a following gap as large as those would likely diminish the fuel-saving benefit of platooning, and may also induce risky maneuvers such as cut-ins. To ensure safety while maintaining desired benefits of truck platooning, appropriate operating parameters should be determined based on specific operating conditions.

IOOs need a clearer understanding of how truck platooning technology can be adapted to the existing highway system to develop management strategies to regulate truck platooning operations, with a goal to ensure safety while gaining considerable environmental and economic benefits. The above review of current status in truck platooning research and practice shows that compatibility of the technology with existing highway infrastructure is still not sufficiently studied, and there is not yet an effective guidance for IOOs on how to strategically deploy and regulate truck platooning operations on existing highways. IOOs would benefit from addressing the following specific needs:

- A set of criteria for selecting roadways that are suitable for truck platooning deployment.
- A dynamic regulatory system on top of existing intelligent transportation systems (ITS) on highway networks to guide safe and efficient truck platooning operations.

This project will address those needs by studying the interactions between truck platoons, highway geometry, weather, traffic flow, and drivers. Using the insights in those relationships this project will carry out a truck platooning infrastructure compatibility analysis and propose a dynamic truck platooning regulatory system.

Research Objectives

The objective of this project is to design and prototype a dynamic truck platooning regulatory system. We will develop algorithms for selecting a compatible roadway network for truck platooning and determining operational rules for truck platooning that can achieve the goal of safe traffic movement, while achieving traffic operational and environmental goals. The system will be simulated and assessed based on Wyoming roadway, traffic, and weather condition data. The goal is to firstly develop a fundamental understanding of the potential effects of truck platooning operations on existing highway networks, and secondly, use the insights to prototype and showcase a truck platooning regulatory system that serves as a preliminary resource for IOOs to develop guidelines for safe truck platooning deployment and operations.

The project will first analytically model the relationship between truck platoon operational parameters and restricting factors including traffic, highway geometry, weather, and driver behavior. The model will primarily focus on safety outcomes but will also consider operational and environmental outcomes. Those outcomes can be quantified by measures such as road-segment-level overall collision risk, travel time or delay, and overall or truck platoon energy consumption or emissions.

Based on the analytical model, two algorithms will be developed:

- An algorithm to select highway segments compatible with truck platooning. Selection criteria will be developed based on highway functional classification, roadway geometry, traffic, and typical weather conditions, with consideration of restriction to truck platooning operations.
- An algorithm to dynamically determine operational rules for truck platoons to follow on highway segments. The algorithm will enable fast calculation of permitted truck platooning operational parameters including operating speed, following gap, and number of trucks in platoon, based on both static features such as roadway geometry, and real-time data such as traffic, weather and road surface conditions, and surrounding driver behavior.

The two algorithms will serve as the core components for a dynamic truck platooning regulatory system. Data of Wyoming highway network, traffic, and weather will be collected and used to evaluate roadway network compatibility with truck platooning and develop operational rule determining algorithm. Simulation will be used to prototype and assess the dynamic truck platooning regulatory system.

Research Methods

Literature review. The review will synthesize research findings from most recent studies on truck platooning, especially studies modeling truck platoon interactions with roadway infrastructure, weather, traffic flow, and other drivers.

Data source identification and data collection. Data sources related to truck platooning operations and safety will be identified. Preliminary types of datasets include roadway network, functional classification, geometry (e.g., horizontal, vertical, and cross-sectional profiles; intersections; entrance/exit ramps), traffic volumes, and weather. Data will then be requested from agencies maintaining the identified data sources. Presumably, all needed data will be available from WYDOT and publicly accessible databases.

Modeling and algorithm design. A modeling framework of the relationship between truck platooning parameters and all considered restricting factors will be constructed. Mathematical modeling of the specific relationships will be based on existing research findings. The models will serve as core components of the two algorithms to be developed. The first algorithm will be designed for selection of compatible highway segments for truck platooning, based on a set of criteria to be defined. The goal for this algorithm is to filter out the most unsuitable segments (e.g., local collector roads, unpaved segments) and provide a preliminary network for truck platooning. Selection criteria will be defined and methods such as clustering and ranking will be used for network compatibility analysis. The second algorithm will be designed for determining operational rules for truck platooning on a road segment, with a goal of ensuring traffic safety, while maintaining traffic efficiency and environmental benefits to a desired extent. The problem of determining truck platooning operational parameter values for desired safety, efficiency, and environmental goals will be modeled as an optimization problem and solved by the algorithm. The algorithm will rely on a pre-defined safety guarantee level and randomly sampled driver behavior parameters, applying statistical methods to ensure the guarantees are held on the sampled drivers. The driver behavior parameter distributions can be calibrated with local observations.

Prototyping in simulation. A simulation of the truck platooning dynamic regulatory system based on a subset of the Wyoming road network will be built using software such as PTV-VISSIM or SUMO. Traffic and truck platoon behavior in car following and lane changing will be simulated using models such as Wiedemann, Intelligent Driver Model (IDM), SUMO's Lane Changing Model, and MOBIL ("Minimizing Overall Braking Induced by Lane Changes"). Upon the simulation model, dynamic truck platooning regulations will be implemented based on the operational rule determining algorithm. The system will be similar to a traffic management system with variable message and speed limit signs, but only for truck platoons. Performance of the dynamic regulatory system will be assessed from perspectives of safety, traffic efficiency, and environmental benefits.

Relevance to Strategic Goals

This project will focus on adapting new transportation technologies to existing roadway infrastructure. It is closely related to the USDOT strategic goal of *Transformation*. On one hand, by screening existing infrastructure and assess the compatibility of new technologies to the system, we will be able to understand how much of our existing infrastructure will be able to keep bringing benefits of safe and efficient freight movement. On the other hand, throughout the research process, we will be able to identify parts of the existing infrastructure system that can be improved to better accommodate new technologies to achieve our potential goals for accessibility and mobility improvements.

The project will also address the USDOT strategic goal of *Safety*. The algorithms for dynamic truck platooning regulatory system will prioritize traffic safety while maintaining viable operational and environmental benefits brought by the new technology. The system will be designed from the perspective of IOOs to help plan for future incorporation of truck platooning technology into the transportation system. Throughout the project process, the team will facilitate information exchange with WYDOT and obtain advice on safety and operational goals regarding freight transportation and truck platooning. The final products from this project will serve as a preliminary framework for WYDOT and other IOOs to develop standardized guidance and regulations for truck platooning operations.

Educational Benefits

Graduate students will be directly involved in all aspects of this study, and it will provide material for transportation courses in traffic engineering, safety, and control. The students will perform main tasks in literature review, data collection, mathematical modeling, algorithm design, and simulation modeling and analysis. They will also author publications and present research results. The materials developed throughout the project will be used to update the course syllabi, lecture slides/notes, and assignments of relevant transportation courses. Students in these courses will have the opportunity to work with real-world data, mathematical models, algorithms, and simulation models related to truck platooning, and more generally, traffic operations and safety.

Outputs through Technology Transfer

The research team will reach out to the transportation community to discuss and present the methodologies and results of the study. Transportation practitioners and researchers are the target audience. The information dissemination will be carried out through personal communication, webpages, in-person workshops, webinars, as well as conference and journal publications and presentations. The research team will seek input from other interested parties to expand research scope and improve the study design and methodology for future projects. WYDOT has a great interest in research related to freight transportation operations and safety, therefore, personnel from WYDOT and other relevant agencies will be invited to participate in certain aspects of the project. The dynamic regulatory system with its algorithms and simulation models created in this project can be improved and expanded for development into a practice-ready system for pilot testing and deployment. The research findings will contribute to developing truck platooning related operational and design guidelines and manuals. The research team will work with WYDOT and other interested DOTs on sharing relevant findings and data, and further improving the code into a practical software application for testing and evaluating truck platooning regulatory strategies.

Expected Outcomes and Impacts

A synthesis of literature on truck platooning, including up-to-date development and deployment status, regulations, and research on truck platooning's relationship with roadway geometry, weather, traffic, and driver behavior. Research gaps will be identified, and existing mathematical models will be used as the basis for the modeling in this project. The literature synthesis will also serve as a resource for further research in the general area of truck platooning.

A list of data sources and variables for the modeling of truck platooning interactions and regulatory algorithm design will be made available. The data will be used to power up simulations in this project. The list of data sources and items will be useful for future relevant research or similar system development by other agencies.

The dynamic regulatory system prototype, together with its mathematical models and algorithms for evaluating network compatibility and determining truck platooning operational rules will be the third outcome. The prototype will offer a preliminary proof of concept for a potential implementation on Wyoming roadways. The prototype's code and simulation assessment results will be documented in detail and serve as a resource for WYDOT to assess design and management alternatives, develop truck platooning related guidelines and manuals, and conduct system expansion or incorporation into an intelligent traffic management system.

A set of journal publications, reports, and presentations describing the research, its results, and recommendations.

Work Plan

Task 1: Review of Literature (Months 1 and 2, and updated throughout the project process)
The research team will review existing research literature on truck platooning operations and safety, as well as existing government policies and regulations regarding truck platooning testing and deployment. The literature review will serve as a guideline and resource for development of research methodology. It will also help the research team to better understand current operational and safety goals and strategies of IOOs regarding truck and truck platooning operations.

Task 2: Data Source Identification and Data Collection (Months 2 – 5)
Based on the literature review and a preliminary modeling framework, the research team will identify sources of data that will be used to support the modeling and designing of algorithms. Both publicly accessible data sources and WYDOT or other agency-maintained data sources will be identified. The team will collect data by accessing the public databases and requesting data from WYDOT and other relevant agencies. Preliminarily, data needed for this project are related to roadway network and geometric characteristics, traffic stream characteristics, and weather conditions.

Task 3: Modeling and Designing of Algorithms for Network Compatibility Evaluation and Dynamic Truck Platooning Operational Rules (Months 4 – 8)
The research team will develop a model framework describing the relationship between truck platooning operational parameters and factors including roadway geometry, traffic flow characteristics, driver behavior, and weather conditions. Relevant mathematical models from existing literature will be used to support and amplify the framework, with the addition of models to be developed by the research team. The framework and models will serve as the basis for the algorithms and simulations.

The team will develop an algorithm for selecting compatible roadway segments for truck platooning operations. The algorithm will take in inputs of roadway characteristics and generate output of a set of road segments that satisfy a set of pre-defined minimum truck platooning criteria. The team will develop another algorithm for dynamic determination of truck platooning operational rules. The algorithm will take in inputs of roadway characteristics, traffic flow characteristics, driver behavior characteristics, and weather conditions. The output will be a set of truck platooning operational parameters (e.g., speed, following gap, number of trucks), which are determined based on the mathematical models, along with a set of quantitative goals related to traffic safety, operational efficiency, and environmental effects. Essentially, the algorithm will solve the problem of how to achieve those goals through restricting truck platooning operations, which will be formulated mathematically as a multi-objective optimization problem.

Task 4: Simulation and Assessment of Dynamic Truck Platooning Regulatory System (Months 8 – 11)

The collected Wyoming roadway network data will be used to select suitable roadway segments for truck platooning. The identified segments will then be used as a base network for the simulation of dynamic truck platooning regulatory system. First, the subset of road network will be modeled using simulation software (e.g., PTV-VISSIM, SUMO). The geometry and traffic flow characteristics will be modeled using the collected Wyoming roadway geometry and traffic data. Traffic flow and driver behavior parameters will be calibrated as close to real-world conditions as possible, with the help of available traffic and driver behavior data from WYDOT or existing research literature. Truck platoons will be modeled based on parameters and corresponding ranges and distributions available from existing research literature. The dynamic regulatory system will be modeled based on the truck platooning operational rule determining algorithm and will be setup on the simulated network. For assessment of performance, specific network-level measures of traffic safety, traffic flow efficiency, and environmental effects will be proposed and used. Additionally, trucks and truck platoons will be separately assessed on throughput and environmental effects. Comparisons will be made between scenarios of with or without the dynamic regulatory system, and between scenarios of different ways of implementing the regulatory system (e.g., density of regulatory zones, frequency of rule changes).

Task 5: Final Report (Months 10 – 12)

The research team will compile all parts of the project into a final report. Progress reports will be developed throughout the study as applicable. The final report will include sections of literature review, model framework, mathematical models, algorithms, data, simulation setup details, simulation results, and relevant discussions and recommendations.

Timeline

Task	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1 Literature Review	■	■										
2 Data Collection		■	■	■	■							
3 Modeling and Algorithm Design				■	■	■	■	■				
4 Simulation								■	■	■	■	
5 Final Report										■	■	■

Project Cost

Total Project Costs: $153,370
CTIPS Funds Requested: $ 76,685
Matching Funds: $ 76,685
Source of Matching Funds: University of Wyoming

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