Potentials for Platooning in U.S. Highway Freight Transport

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Abstract

Smart technologies enabling connection among vehicles and between vehicles and infrastructure as well as vehicle automation to assist human operators are receiving significant attention as a means for improving road transportation systems by reducing fuel consumption – and related emissions – while also providing additional benefits through improving overall traffic safety and efficiency. For truck applications, which are currently responsible for nearly three-quarters of the total U.S. freight energy use and greenhouse gas (GHG) emissions, platooning has been identified as an early feature for connected and automated vehicles (CAVs) that could provide significant fuel savings and improved traffic safety and efficiency without radical design or technology changes compared to existing vehicles. A statistical analysis was performed based on a large collection of real-world U.S. truck usage data to estimate the fraction of total miles that are technically suitable for platooning. In particular, our analysis focuses on estimating "platoonable" mileage based on overall highway vehicle use and prolonged high-velocity traveling, and established that about 65% of the total miles driven by combination trucks from this data sample could be driven in platoon formation, leading to a 4% reduction in total truck fuel consumption. This technical potential for "platoonable" miles in the United States provides an upper bound for scenario analysis considering fleet willingness and convenience to platoon as an estimate of overall benefits of early adoption of connected and automated vehicle technologies. A benefit analysis is proposed to assess the overall potential for energy savings and emissions mitigation by widespread implementation of highway platooning for trucks.

Introduction

Connected and automated vehicles (CAVs) are receiving significant attention as a technology solution to realize safer, more cost-effective, and efficient operation of several transportation systems [1]. CAVs can also potentially help curb energy consumption and greenhouse gas (GHG) emissions from the transportation sector. In this paper we focus on the role of platooning for combination trucks[1] in the United States, one of the most promising CAV technologies that could experience widespread adoption in the next 5 to 10 years.

[1] Combination trucks include Class 7 and Class 8 trucks, as defined by the U.S. Federal Highway Administration. Class 8 trucks, which are the majority of combination trucks, are vehicles with a gross weight rating exceeding 33,001 lbs (14,969 kg). Class 8 includes tractor-trailer tractors as well as single-unit dump trucks. The typical 5-axle tractor-trailer combination, also called a "semi" or "18-wheeler," is a Class 8 vehicle.

Platooning is a demonstrated method of groups of vehicles travelling close together actively coordinated in formation at high speed that has the potential to reduce energy consumption resulting from aerodynamic drag [2] [3]. Trucks are ideal applications for platooning due to their technical characteristics and mode of operation (several vehicles driving for long distances along the same route, often concentrated in few corridors).

Combination trucks, currently powered by petroleum-derived fuels, account for the majority of the energy use in the U.S. freight sector (64.9% of freight, and 4.8% of total U.S. energy use in 2013 [4]) and an even larger share of GHG emissions (77.1% of freight, and 7.5% of total U.S. GHG emissions in 2013 [5]). Looking at the future, the importance of trucking on the U.S. energy use and GHG emissions is likely to increase, due mainly to three factors: *a)* freight transport has been growing more rapidly than passenger transport, and the trend is likely to continue in the future [6] [7]; *b)* a continued increase in the share of trucking in total freight activity [8] [9] [10]; *c)* transportation, and freight in particular, is more expensive to decarbonize compared to other sectors, and will experience lower energy and GHG emissions reduction in response to economy-wide climate change mitigation measures [11].

Several studies, reviewed in the Methods section, have been focusing on assessing the potential savings achievable by platooning operations for a group of two or more trucks, as well as extrapolating these savings on a national scale, based on overall miles traveled by trucks. However, a key element has been neglected in the existing literature: what is the "platoonable" fraction of traveled miles during real-world operations? Namely, in a fleet of trucks, what fraction of miles driven is amenable for platooning operation? Clearly not every mile driven can be driven in a platoon formation, and platooning operations at low speeds do not lead to significant fuel saving. However, for large trucks operating extensively on highways over long distances the fraction of platoonable miles at high speed can be significant (in estimating the potential savings related to trucks platooning, MacKenzie *et al.* [12] assume that every mile traveled by trucks is platoonable, leading to significantly different results compared to this study).

We provide an estimate of the platoonable fraction of miles driven by combination trucks in the United States based on a large set of driving data collected by the National Renewable Energy Laboratory (NREL) and others. This data set includes over 3 million miles of driving data across a variety of fleet operators, truck manufacturers, times of operation, and regions. In particular, we assume that a truck could potentially operate in a platoon if it continuously travels at a speed larger than a certain threshold for a significant period of time. A sensitivity analysis shows that the velocity and the time threshold significantly impact the resulting fraction of platoonable miles. These thresholds have been chosen to be 50 mph (80.5 km/h) and 15 minutes for representative operations in the United States.

This estimate represents a technical potential, or upper bound, which does not account for truck and fleet operators' willingness to platoon. This willingness, which will be assessed in future works, reduces the technical potential identified in this paper due to three main factors. First, the economic savings related to platooning operations (value of fuel saved) must outweigh the increased costs, namely the additional drivers' time cost during platoon formation (as most likely some drivers will have to wait for other trucks traveling towards the same destination) and the value of delayed delivery.[2] Second, truck and fleet operators must be willing to cooperate. While this might be easier for large fleets including hundreds of vehicles, smaller operators might not have the required connectivity and willingness to collaborate with direct competitors. Third, uniform and standard technologies are required across vehicle manufacturers and operators to allow for widespread implementation of platooning across fleets.

The remainder of this paper is structured as follows: The Methods section describes the data set and the methodology used to estimate the real-world fraction of platoonable miles for combination trucks in the United States and a review of literature of existing studies on energy savings achievable by operating trucks in platoons. The Results section reports the quantitative results on this analysis, including a sensitivity analysis aimed at understanding the impact of time and velocity thresholds in estimating the fraction of platoonable miles and additional insights for targeted applications (i.e., platoonable miles for vehicles performing only long-distance missions on highways). These insights are used in the National Impact section to calculate an upper-bound estimate of the potential energy savings and GHG emissions reductions related to widespread adoption of platooning for combination trucks. Concluding remarks and proposed future work are reported in the last section.

Methods

In this paper we use a large data set of about 200 real-world Class 8 tractors' driving data, which includes over 3 million miles of data, to estimate the fraction of platoonable miles in a variety of real-world operations in the United States. The data considered have been collected directly by NREL and other partners who have contributed data to NREL's Fleet DNA database using on-board data logging devices or telematics systems [13]. Vocations represented in the data set include line haul truck load, less than truck load, regional parcel movement, port drayage, refrigerated operations, tanker operations, transfer truck operations, and regional food delivery. The data set includes information on vehicle speed (1-second resolution), global positioning system position, road segments (classified as highway, freeway, or collectors and local), and various levels of engine/vehicle parameters such as fuel rate and engine temperatures.

Table 1 summarizes the data set considered, while Figure 1 and Figure 2 show the distribution of all the trips included in the data set based on trip length and duration, respectively. Trips shorter than 0.5 mile and 6 minutes have been excluded to avoid including logging errors and short vehicle movements that do not constitute trips.

Table 1. Summary statistics of the driving data set considered in this study.

DATA SET	
Vehicles	194
Days	9,154
Trips	54,583
Hours	60,450
Miles	3,170,079

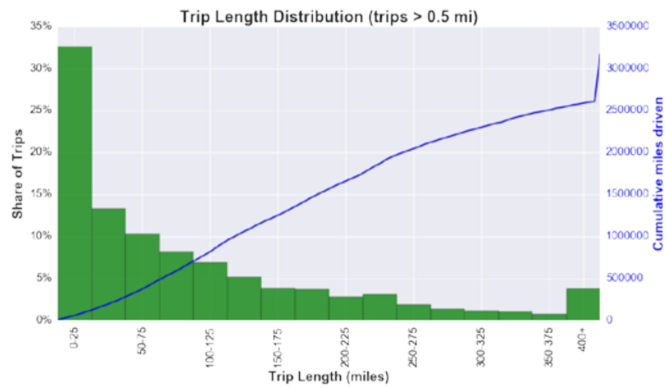

Figure 1. Distribution of trips included in the data set based on trip length.

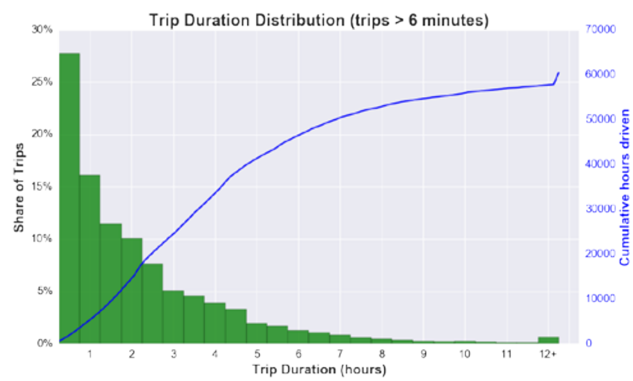

Figure 2. Distribution of trips included in the data set based on trip duration.

From Figure 1 and Figure 2, it appears that very short trips (*i.e.*, less than 25 miles and less than one hour) constitute a significant share of trips included in the data set considered. Nevertheless, these trips account for a small fraction of total miles driven, as shown in Figure 3 and Figure 4, which report the share of driven miles for several classes of trip length and duration. The majority of miles driven by the trucks included in the data set were driven in trips between 50 and 250 miles long that lasted between 2 and 6 hours. Some very long trips (*i.e.*, over 500 miles and 8 hours) are also present in the data set (about 10% of total miles driven), resulting from vehicles being driven by multiple drivers who took turns driving without turning off the engine for prolonged periods of time.

[2] Given the U.S. network and the large volume of freight moved on the road, we assumed that trucks will not modify their original route to travel in a platoon. Namely we assume that within a reasonable time a truck will be able to join others and form a platoon heading towards its final destination. This assumption might not be realistic for very early adoption in the United States or other countries.

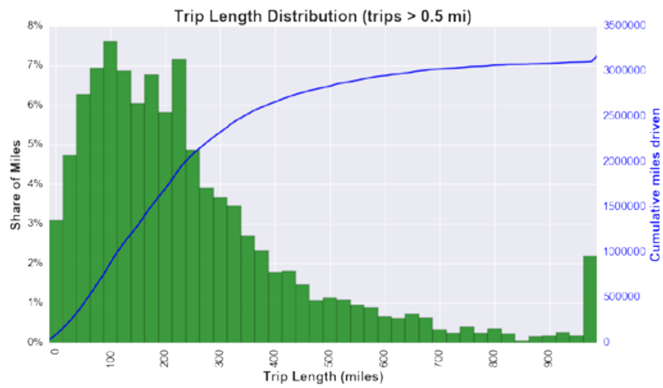

Figure 3. Share of miles driven as a function of trip length.

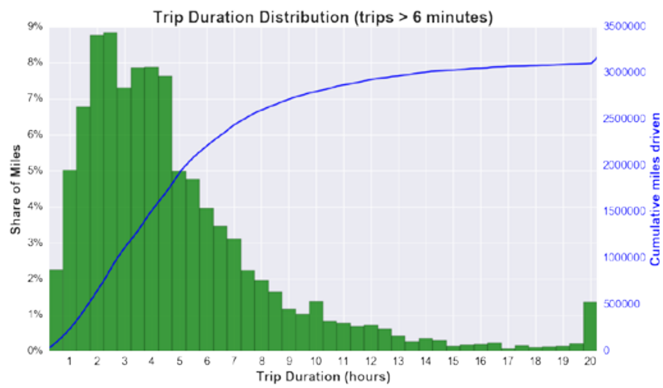

Figure 4. Share of miles driven as a function of trip duration.

The extensive and comprehensive data analyzed allow calculating a reasonable estimate of the total fraction of platoonable miles across different U.S. regions and truck applications.

State-of-the-art for Trucks Energy Savings in Platooning Operations

Several analyses, based both on simulation studies and experiments, have estimated the energy savings during platoon operations of two or more trucks. While platooning opportunities for a variety of applications have been explored for over a decade (*e.g.*, [14], [15]), no consensus has been reached in the open literature on the fuel savings related to platooning operations of more than two vehicles.

Lu and Shladover [16] tested a platoon of three Class 8 tractor-trailers under different driving conditions and following distances, reporting a fuel saving of 4%–5% for the leading truck and 10%–14% for the following trucks. Lammert *et al.* [17] performed ten modified SAE Type II J1321 fuel consumption track tests to evaluate fuel consumption results of two Class 8 tractor-trailer combinations platooned together compared to their standalone fuel consumption, reporting combined “Team” fuel savings ranging from 3.7% to 6.4% (between 2.7% and 5.3% fuel savings for the lead tractor and between 2.8% and 9.7% for the trailing vehicle).

A recent study by the North American Council for Freight Efficiency (NACFE) reviewed the results of ten analyses performed over the last decade directly comparing driving speeds from 43 to 70 mph, conventional and cab-over-engine configurations, and a range of vehicle curb weights, which showed a significant spread among the different test results. While lead vehicle savings had significant correlation across the variables with following distance being most important factor in the 0-9% range of observed fuel savings; for the trailing truck(s) fuel consumption reductions was reported to vary between 3% and 23% and showed much higher dependence on speed, mass and cab configuration variables [18]. Combining results with all the above variables, NACFE estimates the savings to be approximately 4% for the lead truck and 10% for the following truck when trucks are operated on a closed track in a consistent two-truck platooning arrangement. This equates to a 7% fuel efficiency improvement on average between the two trucks versus a truck operating in isolation. Moreover, NACFE identified road congestion and actual platoonable miles as the two most relevant factors influencing real-world fuel economy of trucks operating in platoon formation and offered an estimate of impact from these factors [18]. Significant correlation was observed between multiple track studies, wind tunnel testing, and computational fluid dynamics analyses when compared at the same speed, mass, and aerodynamic class/type over a range of following distances [19].

In this paper we consider a 6.4% potential fuel saving for platooning operations, based on the study by Lammert *et al.* [17], with the best combined result being for 55 mph and a 30-ft following distance. In future applications, platooning fuel savings can be enhanced by addressing barriers to closer platoon formation – such as reduced engine cooling – and by including more vehicles in each platoon [19]. Alam *et al.* suggested that a large-scale cooperative method to enhance safety and efficiency of truck platoons by increasing the level of cooperation between vehicles be used to maximize platooning benefits [20]. Additional benefits of truck platooning, such as road capacity optimization and accidents reduction, as well as additional truck safety and operational considerations have also been explored in previous studies ([21], [22], [23]).

Results

Based on the data set described in the Methods section, we compute the fraction of miles that are continuously driven above a speed threshold V for at least T minutes, where T is a time threshold. This is intended to capture the fraction of driven miles that are suitable for platooning operations. In principle, V should equal the prescribed speed limit, and T should be a time long enough to offset the tradeoffs due to platoon formation.

Figure 5 shows the share of miles driven in each road segment based on the entire data set summarized in Table 1**,** as well as the fraction of miles continuously driven above a speed limit for time T for a set of different thresholds. The results show that for a time threshold of T = 15 minutes and a speed threshold V = 50 mph, 65.6% of vehicle miles are platoonable. The figure also shows how this number changes as different time and speed thresholds are selected.

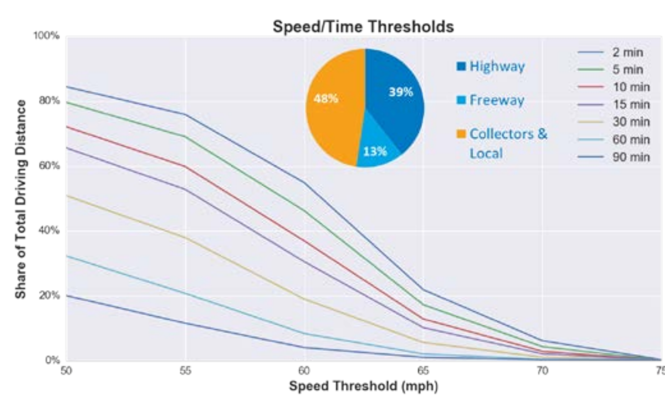

Figure 5. Share of total miles (y-axis) continuously driven above a certain speed threshold (x-axis) for T minutes (different lines) and share of load segments considering the entire data set.

Targeted Applications

The same methodology used to estimate the share of platoonable miles for the entire data set is applied to a subset of the data, including about 4,500 miles of mostly-highway long-distance driving to evaluate the fraction of platoonable miles for specific applications that might represent early adopters of this technology.

The results shown in Figure 6 indicate that for a time threshold of T = 15 minutes and a speed threshold V = 50 mph, 76.6% of vehicle miles are platoonable. The vocation represented in Figure 6 is a split-duty combination truck that runs local pickup and delivery trips during the day and regional line-haul operation at night (representing the majority of the miles driven, and making this application ideal for platoon operations).

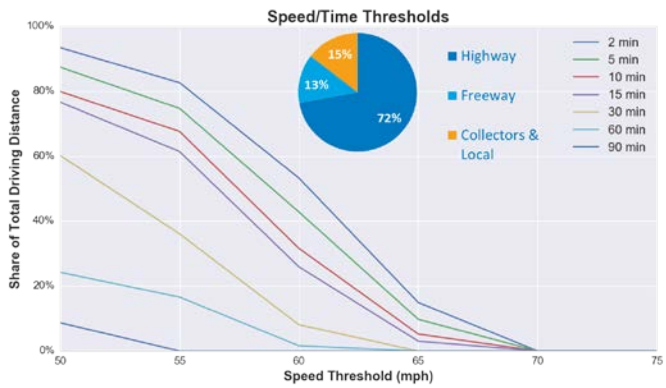

Figure 6. Share of total miles (y-axis) continuously driven above a certain speed threshold (x-axis) for T minutes (different lines) and share of load segments for targeted platoonable applications.

National Impact

In 2014 169.8 billion miles were driven by combination trucks in the United States [24], consuming a total of 29.1 billion gallons of fuel and emitting approximately 6.9 billion metric tons of carbon dioxide equivalent [25]. Based on the analysis provided in this paper, approximately 65.6% of those miles could potentially be driven in platoon formation. Assuming an energy (and emissions) savings of approximately 6.4% for each team of platooned vehicles (based on efficiency improvements previously published in a platooning benefits study [17]), widespread adoption of platooning operations can potentially reduce trucks energy use by approximately 4.2%.

With these bounding assumptions, the widespread adoption of platooning operations for combination trucks in the United States could lead to a total savings of 1.5 billion gallons of petroleum-derived fuels (equal to 1.1% of the current US import of oil: 2.7 billion barrels in 2015 [26]) and 15.3 million metric tons of CO_2 (a 0.22% emissions reduction).

Conclusions and Future Work

In this paper we estimate a technical potential, or upper bound, for the fraction of platoonable miles for combination trucks in the United States based on an extensive data set of real-world driving data. This study complements existing literature on this subject that neglected to consider that not all miles driven by trucks are suitable for platooning applications.

Our results show that approximately 65.6% of the total miles driven by combination trucks (Class 7 and 8) could be driven in platoon formation, leading to significant energy and emissions savings. For targeted applications, which are likely to be early adopters of connected and automated technologies, this fraction increases to approximately 76.6%. A more comprehensive "Big Data" analysis considering a larger data set that covers multiple years and a wider array of applications is planned to further refine this estimate.

Based on an assumed energy saving of 6.4%, resulting from a review of recent literature, this translates into 2.7% potential energy savings in the U.S. freight sector and a reduction in U.S. GHG emissions on the order of 15.3 million metric tons of carbon dioxide per year.

As discussed, this technical potential study presents an upper bound because in the real world, truck and fleet operators may not be willing to participate to platoon operations under all the conditions considered here (*e.g.*, an operator might not be willing to wait to form a platoon). Therefore, an expert elicitation study involving truck owners and fleet operators will be performed to assess the overall willingness to participate in platooning and the main barriers for the widespread adoption of this technology.

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