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Exploring Telematics Big Data for Truck Platooning Opportunities

Michael P. Lammert, Bruce Bugbee, and Yi Hou National Renewable Energy Laboratory

Andrea Mack Montana State University

Matteo Muratori, Jacob Holden, and Adam Duran National Renewable Energy Laboratory

Eric Swaney Volvo Group

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Abstract

NREL completed a temporal and geospatial analysis of telematics data to estimate the fraction of platoonable miles traveled by class 8 tractor trailers currently in operation. This paper discusses the value and limitations of very large but low time-resolution data sets, and the fuel consumption reduction opportunities from large scale adoption of platooning technology for class 8 highway vehicles in the US based on telematics data. The telematics data set consist of about 57,000 unique vehicles traveling over 210 million miles combined during a two-week period. 75% of the total fuel consumption result from vehicles operating in top gear, suggesting heavy highway utilization. The data is at a one-hour resolution, resulting in a significant fraction of data be uncategorizable, yet significant value can still be extracted from the remaining data. Multiple analysis methods to estimate platoonable miles are discussed. Results indicate that 63% of total miles driven at known hourly-average speeds happens at speeds amenable to platooning. When also considering availability of nearby partner vehicles, results indicate 55.7% of all classifiable miles driven were platoonable. Analysis also address the availability of numerous partners enabling platoons greater than 2 trucks and the percentage of trucks that would be required to be equipped with platooning equipment to realize more than 50% of the possible savings.

Keywords

heavy-duty truck platooning, heavy-duty truck partial automation, heavy-duty truck fuel economy, big data, telematics

Introduction

Truck platooning is a near-term technology solution for reducing fuel consumption of Class 8 vehicles during highway operation. Platoon-capable vehicles are equipped with a variety of sensors and communications to inform the vehicle about surrounding traffic and status of partner vehicles. In acceptable conditions, two or more trucks with partial automation can be electronically linked to synchronize longitudinal control (optionally with lateral control) of the vehicles in a safe manner at much shorter following distances than can be safely accomplished by independent human drivers. This significantly reduces aerodynamic drag energy losses and achieves higher fuel economy [1,2].

Reported fuel savings results for trucks platooning from controlled track studies are very appealing to fleets operating primarily in the highway environment. Studies from Lammert *et al.* (2014) [3], Bevly et al (2017) [4], McAuliffe *et al.* (2017) [5] and McAuliffe *et al.* (2018) [6] demonstrate savings from a team of two or three platooned vehicles to be in the 5% to 7.6% range for expected early deployment following distances and up to 13% team savings for a 3 truck close formation platoon [6]. Class 8 combination trucks in the freight sector consumed 29.6 billion gallons of fuel in 2016 [7] and fleet operators and the federal government would likely welcome the opportunity to reduce that consumption by 5% or more. However, many unknowns can influence the realized savings: availability of a partner vehicle to platoon with, time spent at appropriate highway speeds versus on arterials, or traffic driving are two prominent factors impacting the availability of platooning as a fuel consumption reduction strategy. Muratori *et al.* attempted to provide a preliminary answer to the question of fraction of platoonable miles using a high-resolution dataset of almost 200 vehicles driving over 3 million miles in commercial operation [8]. Muratori *et al.* found approximately 65% of the miles traveled by class 8 combination trucks in the U.S. to be platoonable. This study seeks to build on that experience using a significantly larger data set and considering not only vehicle speed but also vehicle proximity to a possible partner vehicle to assess the share of miles driven in platoonable condition by class 8 tractor trailers currently in operation (we do not assume changes in driving behavior to accommodate platooning). To evaluate the availability of a platooning partner we assume that all vehicles are compatible with one another and do not make distinction for different fleet or manufacturers. A minimum speed threshold serves to weed out significant weather and traffic limitations to the use of platooning systems but some systems may employ safety thresholds not approximated by the minimum average speed over the hour. As such, the findings attempt to assess the upper bound of the savings potential of this technology well into the future when the technology is well adopted.

Methods

The National Renewable Energy Laboratory (NREL) and Volvo Trucks North America analyzed a two-week period of Volvo Trucks telematics data from over 57,000 unique vehicles traveling over 210 million miles during the summer of 2016 that includes a total of 11 million GPS way points. GPS Lat & Long and GPS speed telematics elements were used in the analysis. Direction of travel wasn't used at this time but may be incorporated into future geospatial partner analysis. GPS speed was used in both methods to determine platoonable threshold speed. GPS Lat & Long were used in the geospatial partner analysis to determine distance proximity to possible partner vehicles and in conjunction with speed to determine travel time threshold for partner availability. These data, while covering a large population, have very low time-resolution consisting primarily of hourly observations of the vehicles throughout the day. As such, specific duty cycle understanding is primarily limited to knowing what likely happened over the course of the hour if average vehicle speeds are based on the odometer change between observations. For example, high average hourly speed indicates that the vehicle must have been operating on the highway for most of the hour. Low average hourly speeds, however, could be the result of a number of scenarios, such as highway driving for a fraction of the hour followed by slow driving or stop time or other combinations of platoonable and not-platoonable driving cycles.

It is likely that most trucking fleet operators do not have access to high-resolution telematics data as the expense may not be justified by the business need. By exploring platooning availability with this data NREL is preparing for future industry partners with this more common type of telematics data.

NREL explored the potential of platooning opportunities following a two-tiered approach. The primary method replicates the method of Muratori *et al.* [8] with a larger, more comprehensive data set. Average hourly speeds for individual vehicles are inspected to determine platoonability. Following this work, a supplementary partner analysis was conducted to explore not only individual platoonability based on driver behavior but also the impact of partner availability.

Vehicle Speed Method Description

Truck platooning opportunities were explored by mining the data set. For around 91% of the data, the time interval of two adjacent way points is 1 hour. The situations where time interval larger than 1 hour are mainly caused by drivers turning the keys off, and have been removed from this analysis. The data were processed in the following steps to approximate the study by Muratori *et al.* [8]:

1. **Calculating hourly average speed.** Hourly average speed for each vehicle was easily calculated by dividing the mileage difference of two adjacent way points by the time interval.
2. **Trip segmentation.** Trips were identified by assuming that a new trip begins when a vehicle average hourly speed was lower than 40 mph, based on the assumption that highway driving achieves higher hourly average speeds unless a vehicle stops.

Geospatial Partner Method Description

An exploratory geospatial analysis was carried out to supplement the vehicle speed method described previously. The primary focus here was to inspect the dataset to identify vehicles that have sufficient opportunities for platooning with nearby partner vehicles in addition to operating in a manner that allows for platooning (appropriate average hourly speed). Better understanding the overall group behavior of commercial trucks will lead to a more nuanced understanding of the potential for vehicle platooning.

Consistent with platooning thresholds set by Muratori *et al.* [8], an observation was considered platoonable under the following assumptions:

1. The vehicle was traveling at least 50 mph
2. The vehicle observed at least one potential partner within a 15-mile radius and 15-minute travel time window.

Detailed analysis of the impact of the spatial and temporal windows is not included here. Further study on the "best" windows for this type of exploratory analysis would involve a more detailed discussion on the characteristics of platooning partners and the interaction with vehicle driving characteristics and will be a focus in future work.

Results

Findings from both methods largely agree on the total share of platoonable miles.

Vehicle Speed Method Results

The hourly average speed distribution with respect to the share of miles is shown in Figure 1. Since any one-hour interval with average speed less than 40 mph was assumed to be the beginning of a new trip, the true hourly average speed in the beginning hour of each trip was unknown. As shown in Figure 1, approximately 22% of total miles were driven at an unknown speed. More than half of total miles were driven at speed between 55 and 70 mph.

The platooning opportunities were identified by assuming that the miles driven when the hourly average speed was larger than a threshold value are considered platoonable. Figure 2 presents the share of platoonable miles with respect to the total traveled miles by setting different threshold speeds ranging from 50 to 70 mph with 5 mph increments. Results in Figure 2 indicate that the share of platoonable miles decreases from 63% to less than 16% with the increasing of the average speed threshold from 50 to 65 mph (namely, only 16% of miles would be platoonable if the minimum platoonable speed threshold was 65 miles driven in an hour).

In order to better assess the return on investment of installing platooning technology on a specific truck, the share of platoonable miles for each individual truck was computed. Figures 3 and 4 present the distribution of individual trucks' platoonable miles when 50 and 60 mph are used as threshold values to enable platooning. Figure 3 shows that 32% of trucks would account for 54% of the total platoonable miles if only trucks with platooning percentage larger than 70% were

FIGURE 1 Distribution of hourly average speed.

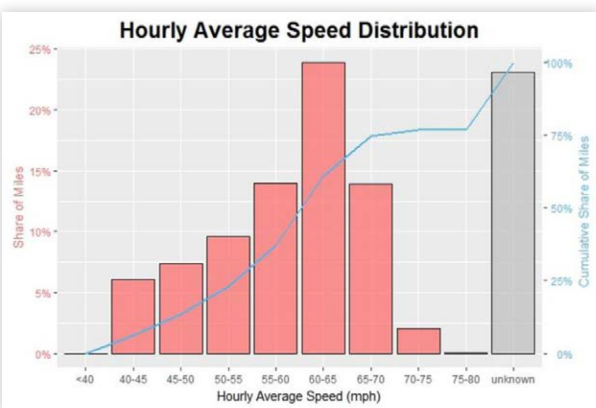


FIGURE 2 Platooning opportunities.

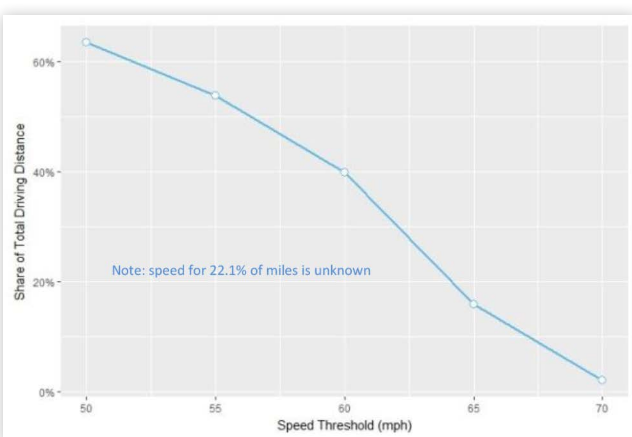
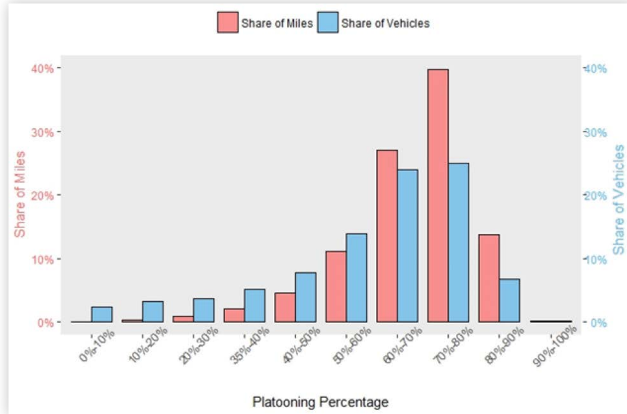


FIGURE 3 Distribution of platooning percentage of an individual truck with threshold greater than 50 mph.



equipped with platooning technology when 50 mph is the platooning threshold. Figure 4 shows that 25% of trucks would account for 52% of the total platoonable miles if only trucks with platooning percentage larger than 50% were equipped with platooning technology when 60 mph is the platooning threshold.

Both temporal and spatial variations of hourly average speed were investigated. Based on the assumption of the study that a truck stopped during a time interval if the corresponding truck hourly average speed is lower than 40 mph, trucks were considered to be inactive if hourly average speed was lower than 40 mph. Figure 5 shows the geospatial representation of hourly average speed of all active trucks in the dataset at different times of a weekday. Overall, there are more trucks traveling on the roadway networks during day-hours than night-hours and early morning. The traveling speed during night operations is generally higher compared to day-operations due to lower traffic volumes at night. Figure 5 also implies that the east coast, west coast, and urban areas have higher temporal dependency than the central part of the US.

The potential truck platooning opportunities for different hours of the day is also examined. By adopting the 50-mph threshold speed to enable platooning opportunities, the percentage of active trucks that can be classified as platoonable was calculated for every hour of a day and is displayed in

FIGURE 4 Distribution of platooning percentage of an individual truck with threshold greater than 60 mph.

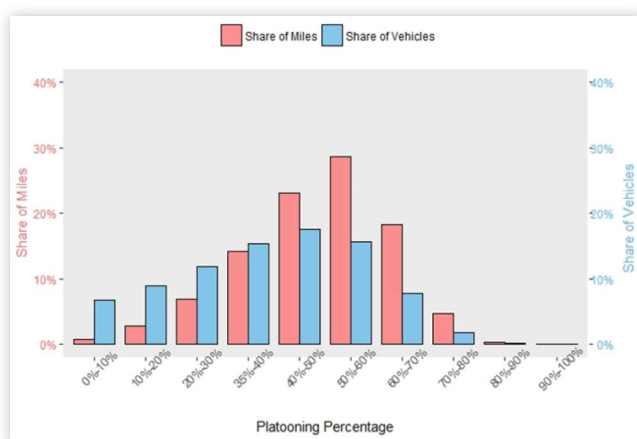


FIGURE 5 Geographic representation of hourly average speed in different time of day. Map created with *ggmap* R package [10].

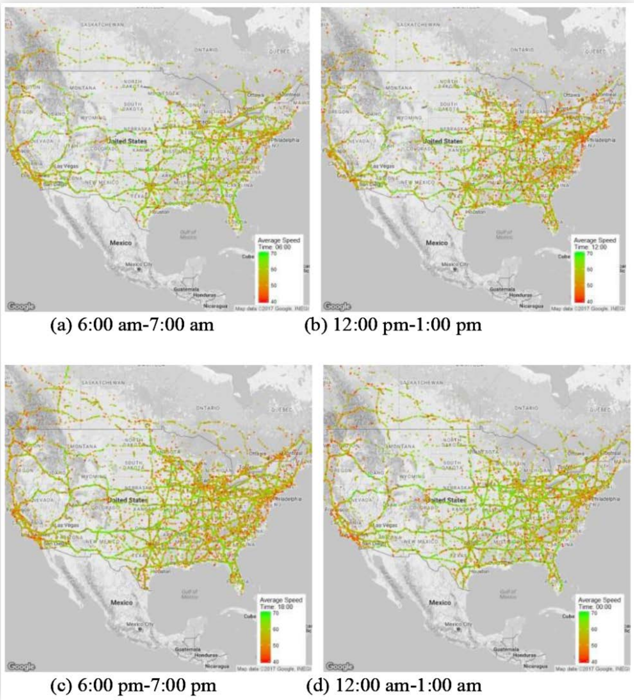


FIGURE 6 Percentage of platoonable vehicles at different time of the day.

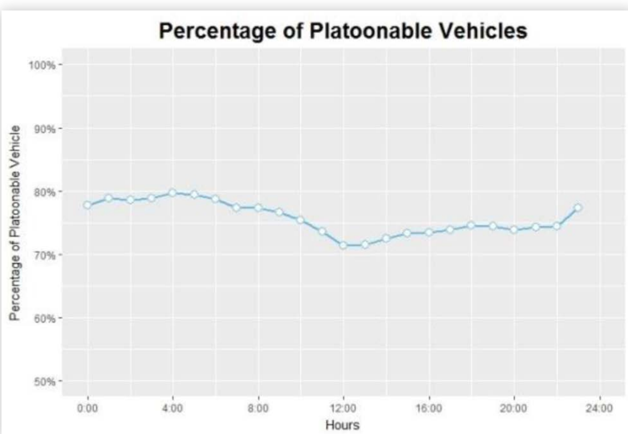
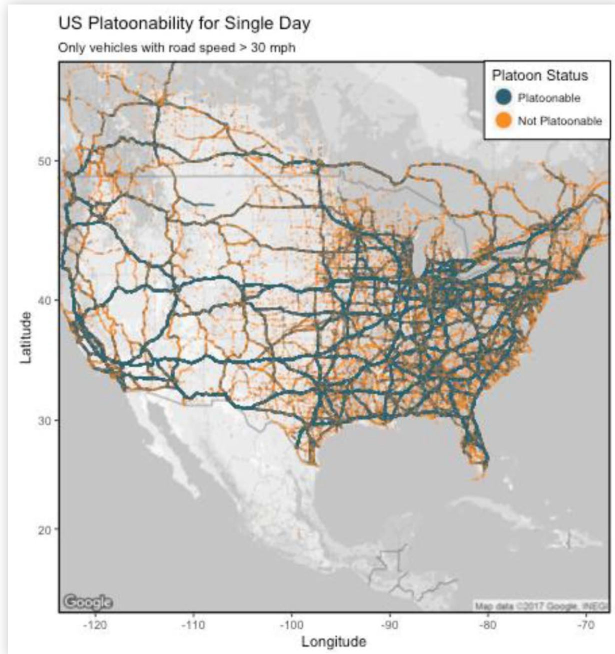


Figure 6. It demonstrates that the platooning ratio reaches to the peak of 80% at 4:00 am and drops down to the lowest of 71% at 12:00 pm.

Geospatial / Partner Method Results

Our exploratory geospatial analysis focused on all observations observed on a single day (Wednesday, July 13, 2016) across the United States. This results in a data set of 919258 unique observations over 54247 unique vehicles. Since this partner analysis

FIGURE 7 Snapshot of US platoonability based on partner analysis for a single day. Observations with speed less than 30 mph are omitted for clarity. Map created with *ggmap* R package [10].



requires pairwise comparison with algorithmic complexity bounded above by $O(N^2)$ computations, a single day was chosen for our analysis to limit computational burden.

Following the assumptions laid out in the “Geospatial partner method description” section; based on road speed and partner availability approximately 33% of all observations were deemed platoonable. Approximately 83% of all vehicles observed had at least one platoonable observation. Within this 83% of vehicles the average proportion of platoonable observations was 37%.

Figure 7 highlights the spatial distribution of platoonable observations with partner considerations for our single day snapshot. The patterns evident in Figure 5 are also present here. The highest regions of platoonability occur across major shipping corridors and interstate highways. Urban areas, particularly those in dense regions on the East Coast, West Coast, and Great Lakes, appear to have fewer opportunities than West and Midwest regions. There is also significant opportunity on Canadian shipping corridors.

Investigating Platoonable Mileage As with the results from the vehicle speed method discussed above, a more apt metric of investigation for the impact of platooning focuses on the miles driven by a vehicle while in a platoonable state. This is a relatively simple classification for the individual vehicle speed method. However when we add the constraint of partner availability, calculating platoonable miles becomes more cumbersome. Our method for classifying distance traveled is as follows:

- The cumulative distance traveled by a vehicle between two consecutive platoonable observations is classified as **platoonable**.

- The cumulative distance traveled by a vehicle between two consecutive non-platoonable observations is classified as **non-platoonable.**
- Any distance traveled between observations that switch states (platoonable to non-platoonable or vice versa) is classified as **unknown**.

The rationale behind the addition of the unknown classification is that we lack the ability to accurately describe the when the partner vehicle behavior changes to cause a state change in our vehicle of interest (e.g. when do we "lose" our platooning partner?). More advanced investigations that incorporate interpolation models, auxiliary data, etc. could potentially reduce or adequately remove the need for unknown classifications.

Table 1 details the classification breakdown for all observed distance traveled. Omitting all unknown classifications results in 55.7% of all classifiable miles driven being platoonable. This is in line with the results from Figure 2 where 60% of all miles driven occurred above the 50 mph threshold. Such good agreement suggests that speed based analysis is sufficient for outer envelope calculations.

Figure 8 shows the distribution elapsed distance between consecutive observations of individual vehicles based on platoonability classification. The main result here is that the platoonable observations tend to encompass longer distances travelled versus non-platoonable segments. This is obviously expected given the higher rate of speed required to be classified as platoonable. It should be noted here that observation times, while tending to occur hourly, are not always equally spaced. This is either due to missing data or other data cleaning requirements.

TABLE 1 Breakdown of mileage platoonability based on geospatial partner method.

	Platoonable	Non Platoonable	Unknown
All Data	34.0%	27.4%	38.6%
Known Data Only	55.7%	44.3%	NA

FIGURE 8 Distribution of segment length by platoonability classification. Each observation represents the cumulative mileage traveled by a vehicle between two consecutive observations.

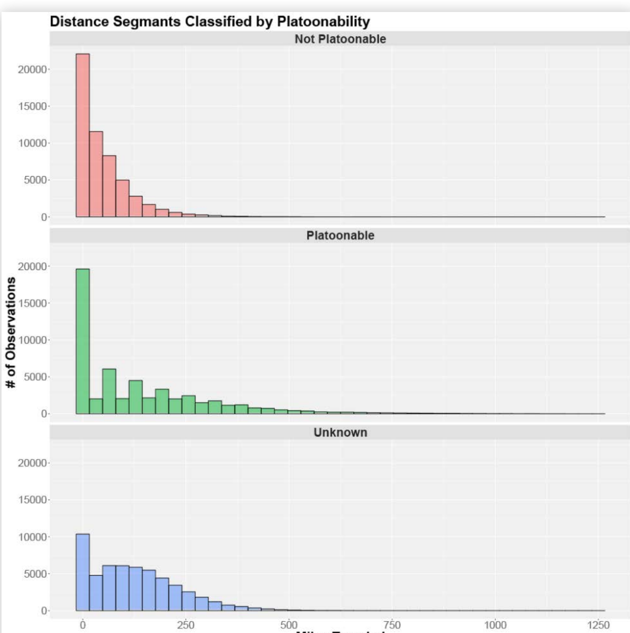


FIGURE 9 Number of available platooning partners distribution.

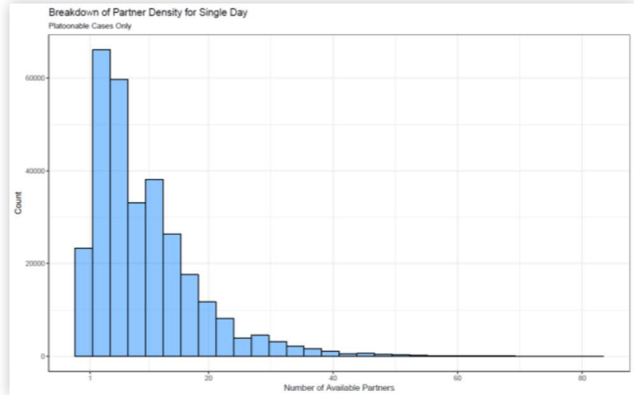


Figure 9 shows distribution of the number of available platooning partners for the platoonable cases. Of significant note is that when one partner is available there are usually many more available partners with a peak occurrence around 2-3 partners and a mean of 10. This means the opportunity for 3 and 4 truck platoons needs to be investigated, not just 2 truck platoons. This also likely means that even some level of fleet non cooperation and technology incompatibility could have minimal impact on partner availability.

Method Comparison

As mentioned in the previous section, both the proportion of platoonable miles traveled for known data (Table 1) and the overall spatial patterns of platoonable observations (Figure 7) track with the general conclusions of the vehicle speed method. This suggests that the computationally simpler vehicle speed method may be sufficient for "outer envelope" platooning analysis. The increased behavioral information gathered from the proximity analysis provides additional context for the analysis and will be critical for more advanced analysis of adoption scenarios where different platooning systems are incompatible, or fleets do not have platooning cooperation agreements in place. The proximity analysis also provides decision makers with information on the value of platooning technologies capable of connecting more than 2 trucks by identifying how often larger platoons could be formed. Additional partner characteristics such as vehicle type, load, heading, etc. could be included in future analyses but were omitted here.

Discussion

The high opportunities for class 8 trucks to platoon identified by these results, combined with track test analysis on platooning fuel savings in test scenarios, suggest that truck platooning could be an effective fuel saving strategy nationally. Combination trucks drove 174 billion miles in 2016 consuming 29.6 billion gallons of fuel [7]. If the nation's truck fleet were to save 6.4% [3] of fuel with a conservatively spaced 2 truck platoon teams on 56% of miles traveled the overall reduction in fuel consumption would be on the order of 1.1 billion gallons of fuel per year and approximately 10.7 million metric tons of CO_2 emissions [9]. Platoons of 3 close following trucks saving a combined 13% [6] on fuel consumption would save closer to 2.1 billion gallons of fuel per year.

The authors note some unique limitations of low time-resolution data sets such as this one. Depending on the method used, 22-39% of miles driven end up being unclassified as they relate to assigning platoonability. If all those observations resulted from a vehicle being parked for 30 minutes and then driving at highway speeds with partner available for the other 30 minutes of the hour, half of the unknown miles would in fact be platoonable. As such, any higher time resolution would have significant impact on the share of unknown miles and would improve the accuracy of this kind of analysis.

Summary/Conclusions

NREL previously conducted research estimating the share of platoonable miles driven by class 8 combination trucks using over 3 million miles of high resolution data from 194 tractors in the FleetDNA database [8]. The purpose of this previous work was to assess if trucks are significantly driven at platoonable speeds, without any trip coordination, and the impact of large-scale platooning in terms of fuel savings and reduction of carbon emissions, concluding that about 65% of the total miles driven by combination trucks could be driven in platoon formation, leading to a 4% reduction in total truck fuel consumption [8].

This study used a much larger database of unique vehicles, but at a lower time resolution, confirming previous findings and providing a framework for a more rigorous analysis that accounts for trucks proximity as well as speed. In particular, previous estimates of platoonability were based on the proportion of miles that trucks traveled at least at 50 mph for at least 15 consecutive minutes. The results presented here are inherently different as platooning is defined by incorporating spatial proximity, speed, and time variables differently.

Overall, the results presented here compliment those found in previous studies. Using a minimum 50 mph speed threshold 55% to 63% of classifiable segments were deemed platoonable depending on whether partner proximity is considered. Key findings include:

- 32% of trucks would account for 54% of the total platoonable miles if only trucks with platooning percentage larger than 70% were equipped with platooning technology, indicating targeted early adoption may see high impact.
- 71-80% of active trucks are travelling at platoonable speeds
- The share of platoonable vehicles for different hours of the day are relative flat, reaching a peak of 80% at 4:00 am and a minimum of 71% at 12:00 pm.
- 55.7% of all classifiable miles driven were platoonable when taking partner availability into account.
- When one platooning partner is available there are usually many more available partners with a mean of 10 partners and as such systems capable of more than 2 trucks in a platoon should be considered.

Future studies should focus on studying datasets with higher time resolutions to better estimate the true potential impact of platooning by decreasing the need for unknown classifications. Given the differences in computational feasibility, the vehicle speed method is acceptable for large datasets where spatial proximity comparisons prove cumbersome and the added value regarding number of available partners and technology penetration rate for savings rate are not required. These methods could potentially be augmented to included drive cycle information, regional data, vehicle type, and other additional characteristics that could potentially impact platoonability. Finally, studying fleets that incorporate behavioral changes to improve platoonability effectiveness will be an interesting area of study. Self-selecting fleets with duty cycles and route scheduling more ideal than the general population studied here likely will increase platooning opportunities. Additionally, fleets choosing to optimize operations to prioritize truck platooning opportunities could realize additional savings beyond the scope of this analysis.

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Contact Information

Corresponding Author:
michael.lammert@nrel.gov
National Renewable Energy Laboratory
15013 Denver West Parkway Golden
CO 80401-3305
(303) 275-4067

ORCID
Michael Lammert: 0000-0002-5888-7594
Bruce Bugbee: 0000-0002-5396-1791
Yi Hou: 0000-0002-8173-0923
Andrea Mack: 0000-0002-3896-5540
Matteo Muratori: 0000-0003-1688-6742
Jacob Holden: 0000-0002-4384-1171
Adam Duran: 0000-0002-7776-3896

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