# EFFECT OF HEAVY-TRUCK PLATOONING FUEL EFFICIENCY GAINS ON OVERALL FUEL EFFICIENCY

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## ABSTRACT

Many studies addressing the fuel-efficiency gains derived from heavy-truck platooning operations have shown that it is possible to achieve increases in fuel efficiency of 10% or more. These studies focus only on the gains realized while traveling under platooning conditions (i.e., highway speeds sustained for sizable intervals of time). However, heavy-truck long-haul operations involve many other travel conditions that fall outside platooning travel conditions. This paper studies the effect of platooning fuel efficiency gains on the fuel efficiency of the overall operation. The authors used real-world data collected by the Oak Ridge National Laboratory (ORNL) for a U.S. Department of Energy (US DOE) study to determine the percentage of distance traveled that is "platoonable." With this and the fuel consumption information collected in the study, the fuel-efficiency gain for the entire operation is computed, as well as annual fuel cost savings.

*Keywords*: Heavy-Truck Platooning, Fuel-Efficiency Gains, Annual Cost Savings, Real-World Data.

## INTRODUCTION

Many studies have shown that truck platooning can substantially improve the fuel efficiency achieved by these vehicles. With gaps of 30 ft, the gains in fuel efficiencies have been shown to be high, more than 10%, and in some studies up to 17%. These studies, in general, focus only on the gains realized while traveling within platooning conditions (i.e., highway speeds sustained for sizable intervals of time). However, heavy-truck long-haul operations involve many other travel conditions that fall outside platooning-travel conditions. Therefore, the overall fuel efficiency for the entire operation will be lower. This paper addresses the question of how much lower that overall fuel efficiency gain is compared to the platoon fuel efficiency gain.

This paper uses real-world data collected at a very fine resolution by the Oak Ridge National Laboratory (ORNL) during a year-long study for the US Department of Energy (DOE) to attempt to answer this question. In that study, data was collected by six long-haul heavy trucks during more than a year (55 weeks) at high resolution (5 Hz). Information such as vehicle speed, geolocation, instantaneous fuel consumption rate, vehicle weight and other data was gathered by on-board data acquisition systems while the vehicles performed their regular day-to-day operations. See *(1)* and *(2*) for more details about the US DOE study.

The collected information was used to quantify the proportion of travel that is done under potential-platooning conditions. We defined those potential-platooning conditions as intervals of time larger than 30 minutes where speeds of 55 mph or higher are maintained. With this information and some assumptions about platooning formation and fuel efficiency gains during platooning operations, we derived lower and upper limits of overall fuel efficiency gains. These were then used to compute annual fuel savings due to platooning operations.

The first section of this paper contains a literature review of research relevant to this paper. The next section defines the variables, as well as the equations, used in the computations. This is followed by a description of the methodology, including a discussion of the assumptions we made. The results of this study are discussed in the next section, followed by the conclusions.

## LITERATURE REVIEW

Previous research has provided some essential information regarding the potential for cost savings available in heavy vehicle platooning. Lammert et al. (2018) *(3)* conducted an analysis of over 210 million miles of class-8 heavy vehicle telematics data to determine the proportion of these miles suitable for platooning operations. Waypoints for over 57,000 vehicles were collected hourly, and a given segment of travel was considered to be platoonable if it involved travel at a minimum average speed of 50 mph and a potential platooning partner was nearby (no more than 15 minutes and 15 miles away). Using these criteria, it was found that 33% of all segments were found to be platoonable, representing 55.7% of all miles traveled for which a determination could be made, given the resolution of the data set. Furthermore, 54% of these platoonable miles are traveled by the 32% of trucks whose operations are least 70% platoonable. Given that direction of travel was not considered in this analysis, the results represent a somewhat optimistic scenario for platooning potential in the absence of advanced planning and coordination.

Estimates of fuel savings available through platooning are the other key measure of interest. Lammert et al. (2014) *(4)* conducted test track testing to examine the effect of weight, speed, and following distance on fuel savings for class-8 heavy vehicles. The lead vehicle experienced fuel savings of about 1-4%, and the following vehicle experienced fuel savings of approximately 4-10%. Taken together, this represented an overall "team" fuel savings of approximately 3-6% combined, depending on the platooning parameters.

The research of McAuliffe et al. *(5)* examined the fuel savings of two- and three-vehicle platoons using cooperative adaptive cruise control. This testing was performed at 65 mph with test vehicles loaded to 65,000 lb. with various following distances. The combined "team" fuel savings for the two-vehicle platoon was found to be approximately 3-7%, and that of the three-vehicle platoon was approximately 4-13%. These results are consistent with another study by Lu and Shladover *(6)*. They tested a range of target inter-truck following gaps for truck platoon beginning with 33 ft and going up to 13 ft gap. Their results show fuel savings in the 4–5% range for the lead truck and between 10 and 14% for the following trucks, when the gap between vehicles was 20ft.

Using sophisticated modeling techniques, including driving simulations, as well as field testing, Liang et al. *(7)* studied fuel-efficient cooperation strategies for two or more scattered vehicles. They found that when considering the origin and destination of the trucks forming the platoon, as well as the topography of the roadway, that energy savings in the range of 1.7% to 3.8% (depending on the vehicle load) could be achieved. In their study the gap between platoon members was about 33 ft.

## DEFINITIONS

The following definitions of distance traveled, fuel consumed, and fuel efficiencies are used in this study. The study defines potential-platooning conditions as traveling conditions where speeds of 55mph or higher are maintained for at least 30 minutes. We used 55mph (lower bound) since the literature reports fuel efficiency gains while platooning for those speeds *(4)*. Also, since fuel efficiency gains in a platoon are derived from the elimination of drag, which is a proportional to the square of the vehicle speed, there will be no significant fuel efficiency gains due at low speeds. Regarding the minimum time interval, we adopted this threshold because shorter intervals of time at which a given speed is maintained may be an indication of congested conditions. Traveling under these conditions may result in the platoon separating with the consequence of the participating vehicles "paying a penalty" to rejoin (see below), thus potentially negating any gains in fuel efficiency.

If a vehicle traveling within these parameters can participate in a platoon, the distance traveled (and fuel consumed) while platooning is defined as distance traveled under realized-platooning operations. Travel that happens at speeds lower than 55mph or at sustained speeds equal or larger than 55mph, but that last less than 30 minutes, is defined as travel outside potential-platooning conditions.

$DT_{T}$: Total distance traveled during the analysis period.
$FC_{T}$: Total fuel consumed during the analysis period.
$DT_{PPC}$: Distance traveled under potential-platooning conditions during the analysis period.
$FC_{PPC}$: Fuel consumed under potential-platooning conditions during the analysis period.
$DT_{RPO}$: Distance traveled under realized-platooning operations during the analysis period.
$FC_{RPO}$: Fuel consumed under realized-platooning operations during the analysis period.
$DT_{OPC}$: Distance traveled outside potential-platooning conditions during the analysis period.
$FC_{OPC}$: Fuel consumed outside potential-platooning conditions during the analysis period.

These quantities are related as shown in Eq. (1) and Eq. (2).

$$DT_{\mathrm{T}} = DT_{\mathrm{OPC}} + DT_{\mathrm{PPC}} \tag{1}$$

$$FC_{\mathrm{T}} = FC_{\mathrm{OPC}} + FC_{\mathrm{PPC}} \tag{2}$$

Then the total fuel efficiency ($\mathrm{FE_T}$) is computed as show in Eq. (3). The other fuel efficiencies (i.e., fuel efficiency for potential-platooning conditions, fuel efficiency for realized platooning operations, and fuel efficiency for outside-platooning conditions) are computed in the same manner using the corresponding parameters.

$$FE_{\mathrm{T}} = \frac{DT_{\mathrm{T}}}{FC_{\mathrm{T}}} \tag{3}$$

$DT_{\mathrm{RPO}}$ is a fraction $p$ of $DT_{\mathrm{PPC}}$ Eq. (4). This fraction $p$ could be as high as 1 if a vehicle could travel all $DT_{\mathrm{PPC}}$ in a platoon formation. This may be possible if, for example, a company sends two or more vehicles from the same origin to the same destination. If the platoon is formed while traveling, it is almost certain that $p$ will never be 1. For this analysis we assume that there is sufficient market penetration of platoon-forming technology such that $p$ is at least 0.7 or 70%. That is, we assume that a vehicle willing to participate in a platoon can do so for 70% or more of $DT_{\mathrm{PPC}}$. Since this parameter is unknown at the present time, we conducted a sensitivity analysis varying $p$ from 0.7 (70%) to 1 (100%) by 0.05 (5%) increments.

$$DT_{\mathrm{RPO}} = p\ * DT_{\mathrm{PPC}} \tag{4}$$

where

$$p \leq 1 \tag{5}$$

Research *(2, 3)* has shown that there is a sizable increase in fuel efficiency for vehicles traveling in platoons. The relationship between the fuel efficiency under realized-platooning operations and potential-platooning conditions is shown in Eq. (6) where $\gamma$ is a coefficient that indicates the gain in fuel efficiency while traveling in a platoon. This parameter has considerable uncertainty and studies show it to be between 3% and 13% *(2, 3)*. Most of the studies assessing this parameter have been conducted at test tracks, and therefore, it is expected that in real-world conditions the gains in fuel efficiency while traveling in a platoon may be lower. Nevertheless, since there is so much variability in this parameter, we conducted this study using a coefficient $\alpha$ that went from 0.06 (6%) to 0.12 (12%).

$$FE_{\mathrm{RPO}} = (1+\gamma) * FE_{\mathrm{PPC}} \tag{6}$$

With Eq. (4) and (6), and the fuel efficiency equation, the fuel consumed under realized-platooning operations can be computed as shown below in Eq. (7).

$$FC_{\mathrm{RPO}} = \frac{p}{(1+\gamma)} * \frac{DT_{\mathrm{PPC}}}{FE_{\mathrm{PPC}}} \tag{7}$$

Then, the total fuel consumed $FC_{\mathrm{TP}}$ for the entire operation with a certain level $p$ of platooning and can fuel efficiency gain $\alpha$ be calculated as shown in Eq. (8).

$$FC_{\mathrm{TP}} = FC_{\mathrm{OPC}} + \frac{p}{(1+\gamma)} * \frac{DT_{\mathrm{PPC}}}{FE_{\mathrm{PPC}}} + (1-p) * \frac{DT_{\mathrm{PPC}}}{FE_{\mathrm{PPC}}} \tag{8}$$

And the overall fuel efficiency with platooning $FE_{\mathrm{TP}}$ can be computed as presented in Eq. (9).

$$FE_{\mathrm{TP}} = \frac{DT_{\mathrm{T}}}{FC_{\mathrm{TP}}} \tag{9}$$

Which then can be compared to the fuel efficiency shown in Eq. (3) to determine the actual fuel efficiency gain due to platooning for the entire operation. Cost savings (fuel saved) attributed to platooning can also be computed using this overall fuel efficiency.

## METHODOLOGY

For this study we used real-world data collected by ORNL for the US DOE. Several years ago, ORNL instrumented six Class-8 trucks with different sensors and collected information (including geolocation information, terrain altitude, vehicle speed, fuel consumption and other 50+ channels) at a 5 Hz (five times per second). The information was collected while these vehicles conducted day-to-day long-haul operations during approximately 13 months. These vehicles logged close to 700,000 miles in that period. Details of the study can be found at Capps et al. *(1)* and Franzese et al. *(2)*.

The data collected in the US DOE study was post-processed to determine the distance that was traveled under what we defined as potential-platooning conditions –i.e., speeds larger than 55 mph sustained during intervals of time longer than 30 minutes– as well as non-platooning conditions. The fuel consumed under these two traveling conditions was also computed. The results are presented in Table 1 as percentage of the total distance traveled and total fuel consumed for the six vehicles during the entire year during which the data was collected. Notice that there is a substantial percentage (56.4%) of the distance traveled by long-haul operations that falls in the potential-platooning conditions category. As expected, fuel efficiencies are significantly larger for this category.

To account for potential variabilities in the long-haul operations, the data was processed by week for all participant vehicles. Figure 1 shows the distance traveled under and outside potential-platooning conditions as percentage of the total distance traveled for each one of the 55 weeks of data collection. Except for two weeks (i.e., week 7 and 11), the distance traveled under potential-platooning conditions was above 50% of the total distance traveled that week. On the other hand, the total fuel consumed under these conditions is, on average, 50% of the total fuel consumed (see Figure 2 and Table 1). Fuel efficiencies achieved each week under potential-platooning conditions and outside platooning conditions are shown in Figure 3 as a percentage of the total fuel efficiency achieved that particular week. For both distance traveled, and fuel consumed, the coefficient variation (i.e., the ratio of the standard deviation of the distribution with respect to its mean) is presented in Table 2 for both distance traveled, and fuel consumed for each one of the two main categories (i.e., potential-platooning conditions, and outside potential-platooning conditions). Both of these present very similar coefficients of variation for distance traveled and fuel consumed.

For each week, we computed $DT_{\mathrm{T}}$, $FC_{\mathrm{T}}$, $FE_{\mathrm{T}}$, $DT_{\mathrm{PPC}}$, $FC_{\mathrm{PPC}}$, $FE_{\mathrm{PPC}}$, and $FC_{\mathrm{OPC}}$ using the data collected in the DOE study. Given a level of platooning $p$ and a gain in fuel efficiency while traveling in a platoon $\gamma$, $FC_{\mathrm{TP}}$ was computed using Eq. (8), and the total fuel efficiency with platooning $FE_{\mathrm{TP}}$ with Eq. (9). With that, we then computed the Overall Fuel Efficiency Gains with Platooning $\gamma_P$ as

$$\gamma_{\mathrm{P}} = \frac{FE_{\mathrm{TP}}}{FE_{\mathrm{T}}} - 1 < \gamma \qquad (10)$$

## RESULTS

The results of the analysis are presented in Table 3. The fraction of the distance traveled under potential-platooning conditions for which the vehicle was assumed to be part of a platoon, $p$, was varied from 0.70 to 1.00 in 0.05 increments, and the fuel efficiency gain due to platooning, $\gamma$, from 5% to 12% in 1% increments. The real-world data used in this study shows that, as expected, $\gamma_{\mathrm{P}}$ increases with $\gamma$, but the proportion is almost constant. This value is around 32% for $p = 0.7$ to 48% for $p = 1.0$, and it is about 44% for a more realistic upper bound of $p = 0.9$. This means that for long-haul operations, whatever fuel-efficiency gain $\gamma$ is obtained by platooning will translate into an overall fuel efficiency gain of between 0.32 $\gamma$ and 0.44 $\gamma$. Considering the variability presented in Table 3 (e.g., using three standard deviations around the mean), the overall fuel efficiency gain was between 1/4 $\gamma$ and slightly over ½ $\gamma$.

The results presented in Table 3 corresponded to an average ratio of the distance traveled under potential-platooning conditions to the total distance traveled by all the vehicles that participated in the study of 0.56. When we analyzed each vehicle separately, this ratio was between 0.504 and 0.614. For the lowest ratio observed (i.e., 0.504 for Vehicle 5), the overall fuel efficiency gain was between 0.29 $\gamma$ and 0.39 $\gamma$ while for the highest ratio (i.e., 0.614 for Vehicle 3) it was between 0.35 $\gamma$ and 0.48 $\gamma$, for $p$ between 0.7 and 0.9 and $\gamma$ between 5% and 12%. For a middle range $p = 0.8$ and $\gamma = 7\%$, then the overall fuel efficiency gain could be expected to be between 0.34 $\gamma$ (= 2.38%) and 0.42 $\gamma$ (= 2.94%). For $p = 1.0$ (probably only achievable if a company sends two or more vehicles from the same origin to the same destination at the same time) and $\gamma$ = 7%, the overall fuel efficiency gain could be expected to be between 0.43 $\gamma$ (= 3.01%) and 0.53 $\gamma$ (= 3.71%).

These overall fuel efficiency gains assume that a vehicle joining a platoon already formed does it with a fuel efficiency and speed equal to that of potential-platooning conditions. This may not be the case. The vehicle may be traveling downstream of the already-formed platoon, in which case that vehicle will have to slow down until the platoon reaches it, with a cost associated to an increase in travel time. If, on the other hand, the vehicle upstream of the already formed platoon, it will need to accelerate and travel at a higher speed than that of potential-platooning conditions. This will affect the overall fuel efficiency of the vehicle since accelerations and higher speeds will decrease the fuel efficiency compared to that of potential-platooning conditions. To illustrate the second case and (in general terms) quantify this effect, we assumed a scenario where a vehicle is traveling at 65 mph and through on-board platooning technology determines that there is a platoon formation 2.5 mile downstream and traveling at the same speed (i.e., 65 mph). The candidate vehicle will then need to accelerate to 70 mph (maximum speed allowed) and travel for 30 minutes at that speed to reach the platoon. With data collected by one of the vehicles in the DOE study (Vehicle 4 traveling during a specific day of week 17 with a load of 71,500lbs) we selected four events where the vehicle accelerated from approximately 65 mph to 70+ mph. Those are presented in Figure 4. The figure shows the vehicle speed (dotted line) as a function of the distance traveled during the acceleration and the terrain profile (solid line), and the fuel efficiency achieved during the acceleration event (inset). The four graphs were drawn to the same scale (abscissas and ordinates) for easy comparison. Notice that there are three types of terrains: downslope (highest fuel efficiency), flat, and upslope (lowest fuel efficiency). On average, the fuel efficiency during an acceleration from 65 mph to 70 mph was 3.19 mpg and the distance traveled 0.13 miles. During that day, Vehicle 4 traveled 419.4 miles and consumed 68.5 gallons of fuel, for a total fuel efficiency of 6.12 mpg. Of those 419.4 miles, 283.0 miles were traveled under what are defined here as potential-platooning conditions, and 41.3 gallons of fuel were consumed for a potential-platooning condition fuel efficiency of 6.85 mpg. Also, when the vehicle was traveling at 65 mph and 70 mph (both ends of the acceleration events) the fuel efficiencies were 6.90 mpg and 6.68 mpg, respectively.

With these parameters it is possible to compute the revised total fuel efficiency under potential-platooning conditions if there were one acceleration event or platooning-joining operation. For the platooning-joining operation, of the total fuel consumed during the potential-platooning conditions, 35.13 miles were traveled outside potential-platooning conditions with a total fuel consumption of 5.3 gallons. Assuming $p$ = 0.8 and $\gamma$ = 7%, of the remaining 247.87 miles (i.e., 283.0 miles - 35.13 miles), 198.3 miles (i.e., 0.8 * 247.87 miles) were traveled with a realized-platooning operation fuel efficiency of 7.33 mpg (i.e., 1.07 * 6.85 mpg), and the remaining 49.6 miles under potential-platooning conditions with a fuel efficiency of 6.85 mpg. The total fuel consumed was 39.6 gallons. If the platooning-joining operation is not considered, then the total fuel consumed is 39.1 gallons. That is, the platooning-joining operation added an additional 0.5 gallons of fuel due to the acceleration from 65 mph to 70 mph and travel distance of 35 miles at 70 mph to join the platoon formation. Considering that the distance traveled outside potential-platooning conditions was 136.4 miles and the fuel consumed was 27.2 gallons, the overall fuel efficiency with platooning, both with and without one platooning-joining event, are 6.28 mpg and 6.32 mpg, respectively. That is, the effect of one platoon-joining operation reduced the overall fuel efficiency by 0.6%, a small percentage. If two platooning-joining operations are required, then the overall fuel efficiency goes, in this example, from 6.28 mpg to 6.24 mpg.

Using these parameters and an average cost of diesel fuel = \$3.253 for the month June 2018 *(8)*, it is possible to compute the annual cost saved due to platooning. To do this, we considered the average distance traveled and average fuel consumed per vehicle per year in our database. These values were $DT_T$ = 128,866 miles, $FC_T$ = 19,357 gallons, $FE_T$ = 6.66 mpg, $DT_{PPC}$ = 72,652 miles, $FC_{PPC}$ = 9,725 gallons, $FE_{PPC}$ = 7.47 mpg. As discussed previously, for a middle range $p = .8$ and $\gamma = 7\%$, the overall fuel efficiency gain could be expected to be between 0.34 $\gamma$ (= 2.38%) and 0.42 $\gamma$ (= 2.94%) with no platooning-joining operation, and between 0.338 $\gamma$ (= 2.36%) and 0.417 $\gamma$ (= 2.92%) with one platooning-joining operation. We also computed the annual costs savings for the case where $p = 1.0$ and $\gamma = 7\%$. As discussed before, this ratio $p$ = 1.0 is probably only achievable if a company sends two or more vehicles from the same origin to the same destination at the same time.

The results are presented in Table 4. The table shows the amount of fuel saved for both the lower- (LB) and upper-bound (UB) overall fuel efficiency due to platooning. Under the assumptions discussed in this paper and with the real-world data collected in the DOE study, the annual costs saving range from \$1,476 to \$1,823. Of course, these costs savings are a function of the ratio $p$ ($DT_{RPO} / DT_{PPO}$); the lower this ratio, the lower the costs savings. If a $p$ =1 could be achieved, the annual costs savings could range between \$1,864 and \$2,277 for a platooning fuel efficiency gain of 7%.

## CONCLUSIONS

This paper used very detailed data collected by six long-haul heavy trucks to quantify the proportion of travel that is done under potential-platooning conditions. We defined those potential-platooning conditions as intervals of time larger than 30 minutes where speeds of 55 mph or higher are maintained. Information such as vehicle speed, geolocation, instantaneous fuel consumption rate, vehicle weight and other data was collected at 5 Hz for a period of 55 weeks during which those vehicles performed their regular day-to-day operations. Analysis of this real-world shows that there are substantial opportunities for platooning under the conditions described. Between 50% and 60% of the distance traveled by these vehicles (56% on average) was under potential-platooning conditions.

Many studies have focused on assessing the fuel efficiency gains due to platooning and have shown that these gains can be significant. Our research question was related to how these fuel efficiency gains, which can be achieved only during a part of a long-haul trip translate on and overall fuel saving for the entire operation. Using the real-world data to assess the proportion of miles traveled under potential-platooning conditions and outside potential-platooning conditions and some assumptions about platooning formation and fuel efficiency gains during platooning operations, we derived lower and upper limits of overall fuel efficiency gains.

Until platooning-formation technology is widespread, it may not be possible to travel all the potential-platooning-condition miles in a platoon, unless a company sends two or more vehicles from the same origin to the same destination at the same time. We conducted a sensitivity analysis varying the proportion $p$ of distance traveled in a platoon from 0.7 to 1.0. For the sensitivity analysis we also varied the platooning fuel efficiency gains $\gamma$ from 5% to 12% since studies have shown great variation in this parameter. With these assumptions, we generated distributions of overall fuel efficiency gains. Those varied from 1.7% ($p$ = 0.7,

$\gamma$ = 5%) to 5.7% ($p$ = 1.0, $\gamma$ = 12%). We also analyzed each one of the vehicles participating in the DOE study to assess the variability in the proportion of distance traveled under potential-platooning conditions to total distance traveled. This allowed us to determine lower and upper bounds for the overall fuel efficiency gains.

A vehicle willing to participate in a platoon will have to reach the platoon formation or reach another vehicle that is willing to platoon as well. This may imply some disruption of the potential-platooning conditions (e.g., accelerations and traveling at higher speeds than normal may be needed to catch up with the platooning formation). We used real-world data from the DOE study to quantify this effect, which we called platooning-joining operations. The effect was not significant; that is, it only reduced the overall fuel efficiency gain by 0.6% per each platooning-joining operation per trip.

Using those derived and real-world parameters, we then selected a likely scenario, $p$ = 0.8, $\gamma$ = 7%, and computed annual cost savings due to platooning for cases with one or no platooning-joining operations per trip. Those cost savings varied between $1,476 to $1,823 using the June 2018 average price per gallon of diesel fuel posted by the US Energy Information Administration of the US DOE.

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## AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design: Oscar Franzese, Luke Loy, and Mary Beth Lascurain; literature review: Mary Beth Lascurain and Oscar Franzese; data collection: Oscar Franzese and Mary Beth Lascurain; analysis and interpretation of results: Oscar Franzese, Mary Beth Lascurain, and Luke Loy; draft manuscript preparation: Oscar Franzese and Mary Beth Lascurain. All authors reviewed the results and approved the final version of the manuscript.

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**TABLE 5 Distance Traveled, Fuel Consumed, and Fuel Efficiencies under Potential-Platooning Conditions and Outside Potential-Platooning Conditions**

| | | **1min to 30min** | **30min to 60min** | **60+ min** | **Total for Speed Interval** |
|---|---|---|---|---|---|
| **Distance Traveled** | **0mph (idling)** | 0.0% | 0.0% | 0.0% | 0.0% |
| | **>0mph to 35mph** | 2.6% | 0.3% | 0.1% | 3.0% |
| | **35mph to 55mph** | 6.7% | 1.8% | 0.9% | 9.4% |
| | **55mph to 75+mph** | 31.2% | **19.3%** | **37.1%** | 87.6% |
| | **Total for Sustained-speed Interval Duration** | 40.5% | 21.4% | 38.1% | 100.0% |
| **Fuel Consumed** | **0mph (idling)** | 0.1% | 0.0% | 5.6% | 5.7% |
| | **>0mph to 35mph** | 4.3% | 0.3% | 0.2% | 4.8% |
| | **35mph to 55mph** | 7.6% | 2.1% | 1.1% | 10.8% |
| | **55mph to 75+mph** | 28.5% | **17.8%** | **32.4%** | 78.8% |
| | **Total for Sustained-speed Interval Duration** | 40.5% | 20.2% | 39.2% | 100.0% |
| **Fuel Efficiency [mpg]** | **0mph (idling)** | 0.00 | 0.00 | 0.00 | 0.00 |
| | **>0mph to 35mph** | 4.11 | 5.48 | 4.33 | 4.21 |
| | **35mph to 55mph** | 5.83 | 5.97 | 5.35 | 5.81 |
| | **55mph to 75+mph** | 7.27 | **7.20** | **7.63** | 7.40 |
| | **Total for Sustained-speed Interval Duration** | 6.66 | 7.03 | 6.47 | 6.66 |

**TABLE 6 Coefficient of Variation for Distance Traveled and Fuel Consumed Distributions for Potential-Platooning Conditions and Outside Potential-Platooning Conditions**

| Traveling Condition | Distance Traveled | Fuel Consumed |
|---|---|---|
| **Potential-Platooning Conditions** | 0.26 | 0.26 |
| **Outside Potential-Platooning Conditions** | 0.25 | 0.24 |

**TABLE 7 Overall Fuel Efficiency Gains with Platooning as a Function of the Fraction of the Potential-Platooning Distance Traveled Where Platooning Operations Is Realized and the Percentage of FE Gains Due to Platooning (55 Weeks)**

| Platooning FE Gain | Statistics | Fraction of Distance Traveled within a Platoon to Distance Traveled under Potential-Platooning Conditions | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **0.70** | **0.75** | **0.80** | **0.85** | **0.90** | **0.95** | **1.00** |
| **5%** | **Min.** | 1.3% | 1.4% | 1.5% | 1.6% | 1.7% | 1.8% | 1.9% |
| | **Max.** | 2.0% | 2.1% | 2.2% | 2.4% | 2.5% | 2.7% | 2.8% |
| | **Mean** | 1.7% | 1.8% | 1.9% | 2.1% | 2.2% | 2.3% | 2.4% |
| | **Std. Dev.** | 0.1% | 0.1% | 0.1% | 0.2% | 0.2% | 0.2% | 0.2% |
| **6%** | **Min.** | 1.6% | 1.7% | 1.8% | 1.9% | 2.0% | 2.1% | 2.2% |
| | **Max.** | 2.3% | 2.5% | 2.7% | 2.8% | 3.0% | 3.2% | 3.4% |
| | **Mean** | 2.0% | 2.2% | 2.3% | 2.5% | 2.6% | 2.8% | 2.9% |
| | **Std. Dev.** | 0.2% | 0.2% | 0.2% | 0.2% | 0.2% | 0.2% | 0.2% |
| **7%** | **Min.** | 1.8% | 1.9% | 2.1% | 2.2% | 2.3% | 2.5% | 2.6% |
| | **Max.** | 2.7% | 2.9% | 3.1% | 3.3% | 3.5% | 3.7% | 3.9% |
| | **Mean** | 2.3% | 2.5% | 2.7% | 2.9% | 3.0% | 3.2% | 3.4% |
| | **Std. Dev.** | 0.2% | 0.2% | 0.2% | 0.2% | 0.2% | 0.2% | 0.3% |
| **8%** | **Min.** | 2.1% | 2.2% | 2.4% | 2.5% | 2.7% | 2.8% | 3.0% |
| | **Max.** | 3.1% | 3.3% | 3.5% | 3.8% | 4.0% | 4.2% | 4.4% |
| | **Mean** | 2.7% | 2.9% | 3.1% | 3.2% | 3.4% | 3.6% | 3.8% |
| | **Std. Dev.** | 0.2% | 0.2% | 0.2% | 0.2% | 0.3% | 0.3% | 0.3% |
| **9%** | **Min.** | 2.3% | 2.5% | 2.6% | 2.8% | 3.0% | 3.1% | 3.3% |
| | **Max.** | 3.4% | 3.7% | 3.9% | 4.2% | 4.5% | 4.7% | 5.0% |
| | **Mean** | 3.0% | 3.2% | 3.4% | 3.6% | 3.9% | 4.1% | 4.3% |
| | **Std. Dev.** | 0.2% | 0.2% | 0.3% | 0.3% | 0.3% | 0.3% | 0.3% |
| **10%** | **Min.** | 2.5% | 2.7% | 2.9% | 3.1% | 3.3% | 3.5% | 3.7% |
| | **Max.** | 3.8% | 4.1% | 4.4% | 4.6% | 4.9% | 5.2% | 5.5% |
| | **Mean** | 3.3% | 3.5% | 3.8% | 4.0% | 4.3% | 4.5% | 4.8% |
| | **Std. Dev.** | 0.3% | 0.3% | 0.3% | 0.3% | 0.3% | 0.4% | 0.4% |
| **11%** | **Min.** | 2.8% | 3.0% | 3.2% | 3.4% | 3.6% | 3.8% | 4.0% |
| | **Max.** | 4.2% | 4.5% | 4.8% | 5.1% | 5.4% | 5.7% | 6.0% |
| | **Mean** | 3.6% | 3.9% | 4.1% | 4.4% | 4.7% | 4.9% | 5.2% |
| | **Std. Dev.** | 0.3% | 0.3% | 0.3% | 0.3% | 0.4% | 0.4% | 0.4% |
| **12%** | **Min.** | 3.0% | 3.2% | 3.4% | 3.7% | 3.9% | 4.1% | 4.3% |
| | **Max.** | 4.5% | 4.8% | 5.2% | 5.5% | 5.9% | 6.2% | 6.6% |
| | **Mean** | 3.9% | 4.2% | 4.5% | 4.8% | 5.1% | 5.4% | 5.7% |
| | **Std. Dev.** | 0.3% | 0.3% | 0.3% | 0.4% | 0.4% | 0.4% | 0.4% |

**TABLE 8 Annual Costs Savings Due to Platooning as a Function of Platooning Fuel Efficiency Gain $\gamma$, Ratios of Distance Traveled in a Platoon to Distance Traveled under Potential-Platooning Conditions $p$, and Number of Platooning-Joining Operations *PJO***

| $\gamma$ | $p$ | PJO | Measure | FE$_{T}$ | FE$_{TP}$ LB | FE$_{TP}$ UB |
|---|---|---|---|---|---|---|
| **7.0%** | **0.8** | **0** | **Fuel Efficiency** | 6.66 | 6.82 | 6.86 |
| | | | **Total Distance Traveled** | 128,866 | 128,866 | 128,866 |
| | | | **Total Fuel Used** | 19,357 | 18,899 | 18,797 |
| | | | **Total Fuel Saved** | 0 | 458 | 560 |
| | | | **Annual Cost Savings**[*] | 0 | $1,488 | $1,823 |
| | | **1** | **Fuel Efficiency** | 6.66 | 6.82 | 6.85 |
| | | | **Total Distance Traveled** | 128,866 | 128,866 | 128,866 |
| | | | **Total Fuel Used** | 19,357 | 18,903 | 18,800 |
| | | | **Total Fuel Saved** | 0 | 454 | 557 |
| | | | **Annual Cost Savings**[*] | 0 | $1,476 | $1,811 |
| | **1.0** | **0** | **Fuel Efficiency** | 6.66 | 6.86 | 6.91 |
| | | | **Total Distance Traveled** | 128,866 | 128,866 | 128,866 |
| | | | **Total Fuel Used** | 19,357 | 18,784 | 18,657 |
| | | | **Total Fuel Saved** | 0 | 573 | 700 |
| | | | **Annual Cost Savings**[*] | 0 | $1,864 | $2,277 |

[*] Assumes $3.253 per gallon of diesel fuel as posted in https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_m.htm for June 2018.

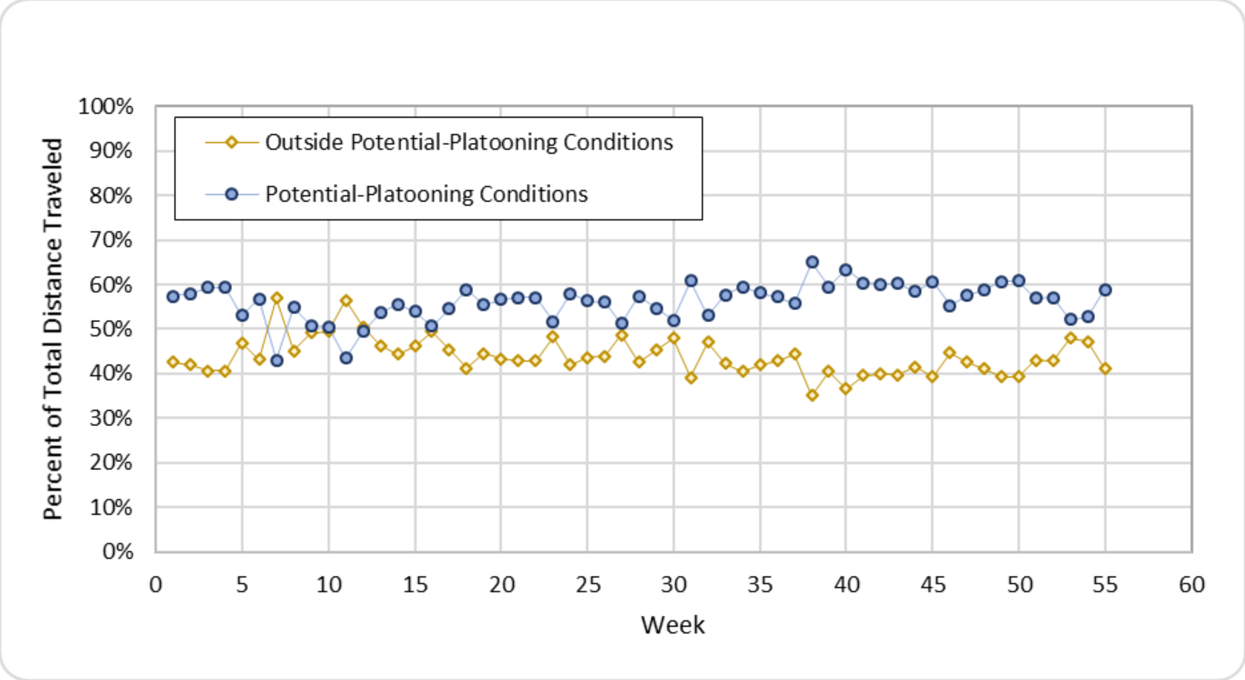

**FIGURE 5 Percentage of Total Distance Traveled under Potential-Platooning and Outside Potential-Platooning Conditions by Week.**

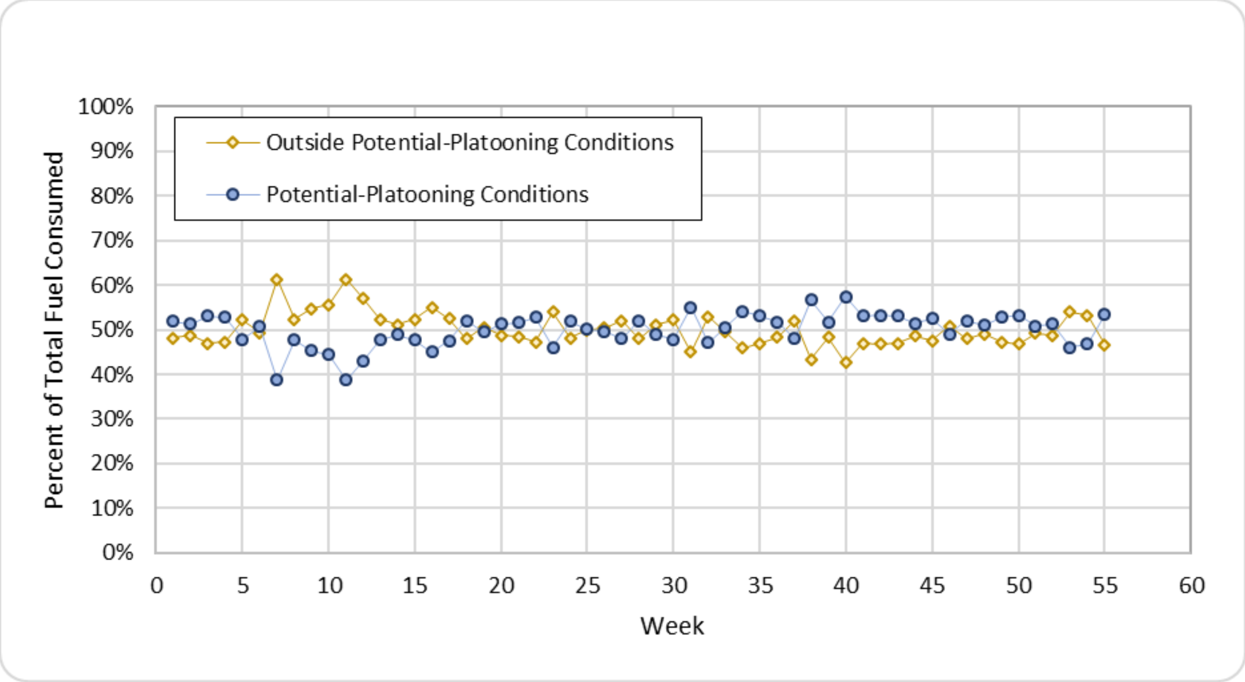

**FIGURE 6 Percentage of Total Fuel Consumed under Potential-Platooning and Outside Potential-Platooning Conditions by Week.**

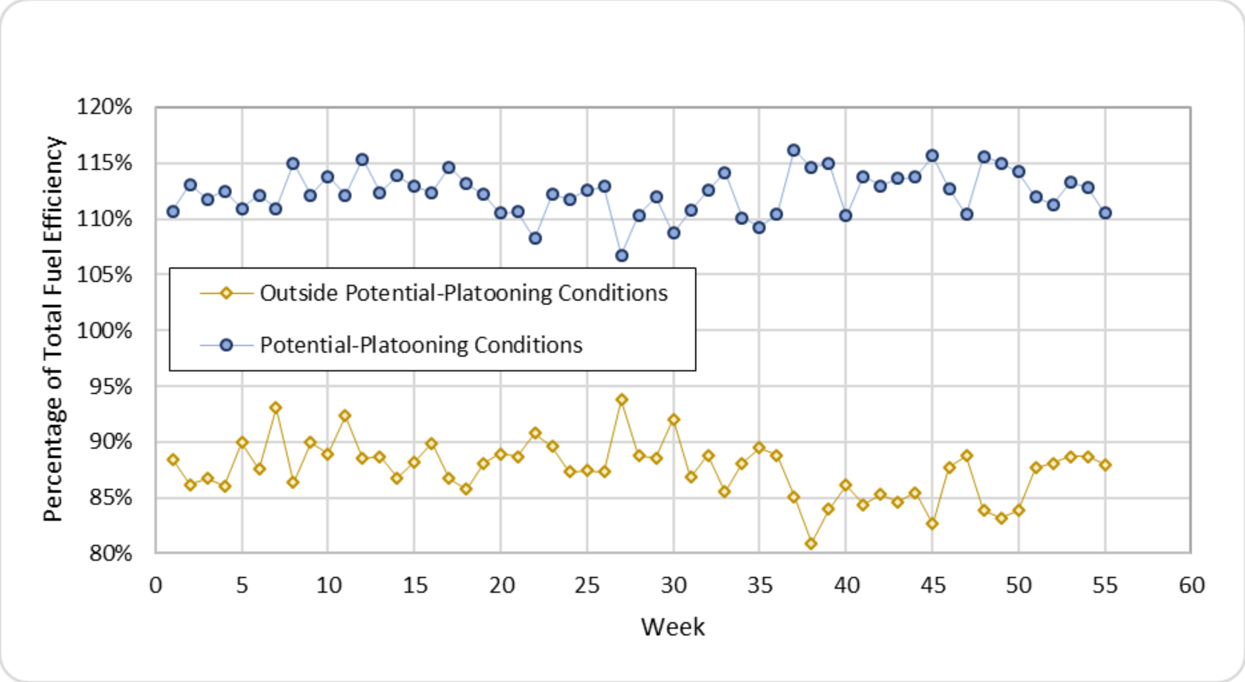

**FIGURE 7 Potential-Platooning Conditions Fuel Efficiencies and Outside Potential-Platooning Conditions Fuel Efficiency as Percentage of Total Fuel Efficiencies by Week.**

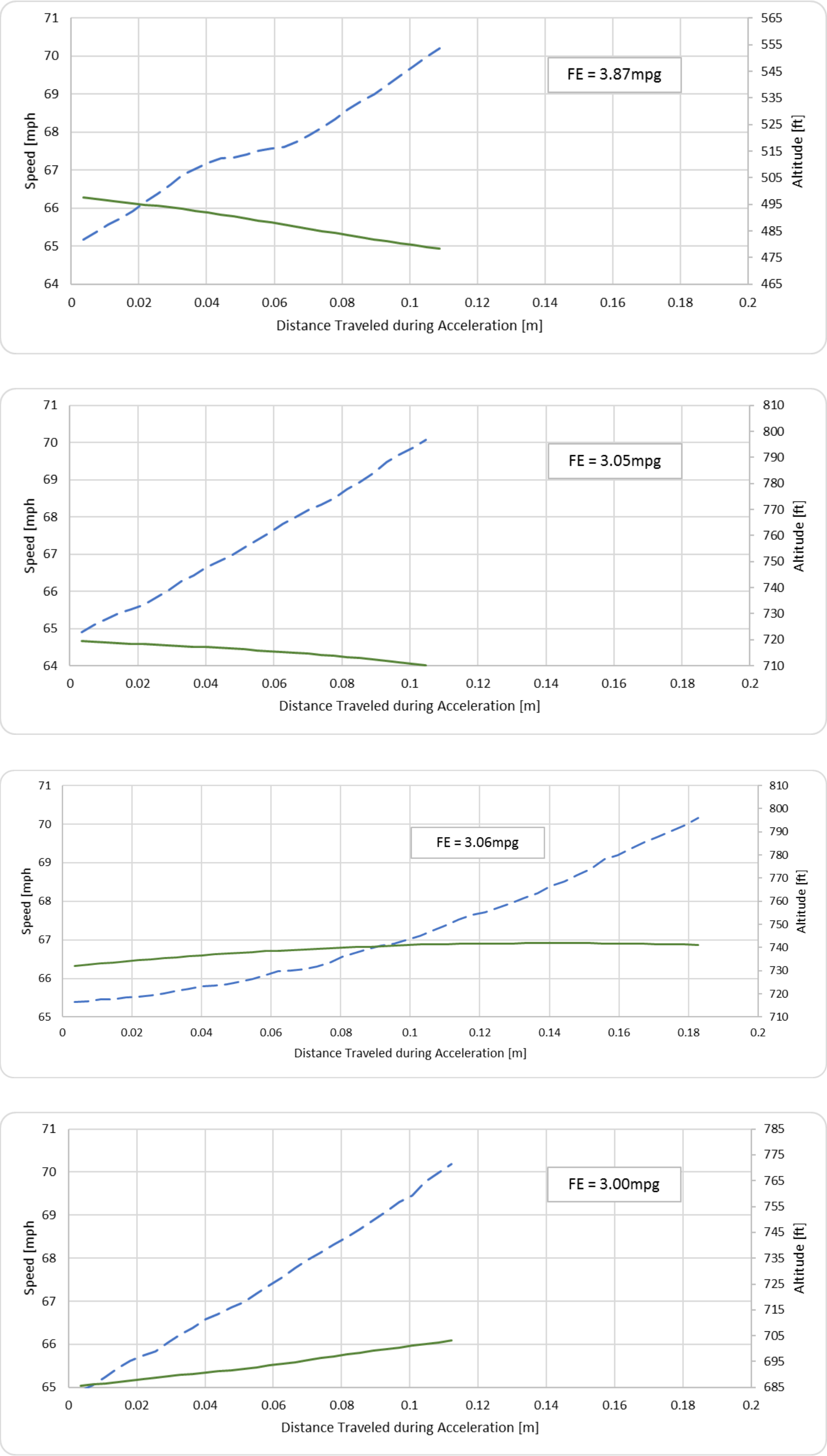

**FIGURE 8 Four Acceleration Events from 65 mph to 70 mph -Vehicle 4/Week 17.**