DEPARTMENT OF TRANSPORTATION

Techno-Economic Analysis of Implementing Hybrid Electric Utility Vehicles in Municipal Fleets

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Final Report 2020-25

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16. Abstract (Limit: 250 words)

This research quantified fuel economy improvements by implementing hybrid electric utility vehicles in municipal fleets. The research team analyzed utility vehicle data and built computer vehicle simulations of utility trucks with three powertrain types: conventional, charge sustaining hybrid, and charge depleting hybrid plug-in hybrid vehicle (PHEV). Driving cycles were recorded from three vehicle groups, ¾-ton pickup trucks, ½-ton pickup trucks, and SUVs using portable onboard diagnostics loggers. Collected data were used in vehicle simulations to determine the fuel economy improvement possible when implementing hybrid powertrain architectures in municipal fleets. The magnitude of benefits from implementing hybrid vehicles was highly dependent on driving cycles and the electric motor/battery combination of the PHEV. The highest kinetic intensity (KI) values, representing urban driving, were found to lead to the greatest fuel economy improvements for hybrid vehicles over conventionally powered vehicles. The results depended heavily on the electric motor/battery combination, with the higher battery capacity plug-in hybrid vehicles yielding the highest levels of fuel economy improvement. It is recommended that fleets consider driving cycle as the primary factor for determining the economic benefits of purchasing alternative powertrain vehicles. Hybrid vehicles should be placed on routes that are more urban, while rural/highway routes would be better served by conventionally powered vehicles. Idling time was also calculated for all the drive cycles and needs to be separately accounted for when analyzing driving cycle data. Idling for over 50% of the driving cycle can lead to about a 10% reduction in fuel economy based on the modeling conducted for ¾ ton pickup trucks in this study. The research team further recommends that aggressive driving be reduced as it will negate the fuel economy advantages possible from hybrid powertrain architectures.

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TECHNO-ECONOMIC ANALYSIS OF IMPLEMENTING HYBRID ELECTRIC UTILITY VEHICLES IN MUNICIPAL FLEETS

FINAL REPORT

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EXECUTIVE SUMMARY

The central aim of this project is to quantify fuel economy improvements by implementing hybrid electric utility vehicles in municipal fleets. Although municipal fleets are starting to implement hybrid electric vehicles for selected applications, fuel economy benefits and corresponding fuel cost savings are not always easy to determine. Further, with an increasing number of hybridized vehicles available on the market, comparing fuel economy benefits on the diverse driving cycles used by utility vehicle fleets is difficult. Municipatilies collect extensive in-use telemetry data from their fleet vehicles but analyzing large quantities of data is time consuming and labor intensive. Therefore, most county fleet managers often do not fully utilize available data to make vehicle purchasing or operational decisions. In this project, we analyze utility vehicle data and build computer vehicle simulations of utility trucks with three powertrain types: conventional, charge sustaining hybrid, and charge depleting hybrid plug-in hybrid vehicle (PHEV).

The research objectives of the project were to: 1) determine what routes and duty cycles result in high fuel consumption, 2) determine which powertrain results in lower fuel consumption on chosen routes through vehicle simulation, and 3) determine the most cost-effective powertrain choice for a given vehicle duty cycle through a basic economic analysis.

Driving cycles were recorded from three vehicle groups, ¾-ton pickup trucks, ½-ton pickup trucks, and SUVs using portable onboard diagnostics loggers. Collected data were used in vehicle simulations to determine the fuel economy improvement possible when implementing hybrid powertrain architectures in municipal fleets. The most on-road data were collected from the ¾-ton pickup trucks, resulting in a more complete analysis that included seasonal variation. The kinetic intensity (KI) was found to be a suitable metric for comparing driving cycles. The logged cycles were divided into three ranges: KI≥1, 0.4≤KI>1, and KI<0.4 representing highway/mixed, arterial/mixed, and urban types, respectively.

The magnitude of benefits from implementing hybrid vehicles is highly dependent on driving cycles and the electric motor/battery combination of the plug in hybrid electric vehicle (PHEV) . In this study, through the simulation work, the highest KI values, representing urban driving, were found to lead to the greatest fuel economy improvements for hybrid vehicles over the conventionally powered vehicles. The results depended heavily on the electric motor/battery combination, with the higher battery capacity plug-in hybrid vehicles yielding the highest levels of fuel economy improvement. Colder weather was found to lead to greater fuel economy improvements for mild hybrid architectures in the ¾-ton pickup trucks most likely due to lower average speeds and more regenerative braking. It is recommended that fleets consider driving cycle as the primary factor for determining the economic benefits of purchasing alternative powertrain vehicles. Hybrid vehicles should be placed on routes that are more urban, while rural/highway routes would be better served by conventionally powered vehicles.

Idling time was also calculated for all the drive cycles and needs to be separately accounted for when analyzing driving cycle data. Idling for over 50% of the driving cycle can lead to about a 10% reduction in fuel economy based on the modeling conducted for ¾ ton pickup trucks in this study. The research team further recommends that aggressive driving be reduced as it will negate the fuel economy advantages possible from hybrid powertrain architectures.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Although municipal fleets are starting to implement hybrid electric vehicles for selected applications, fuel economy benefits and corresponding fuel cost savings are not always easy to determine. Further, with an increasing number of hybridized vehicles available on the market, comparing fuel economy benefits is difficult over the diverse driving cycles used by utility vehicle fleets.

Fuel use costs in Minnesota counties and cities are significant. For example, the Dakota County utility vehicle fleet consumes 216,705 gallons of fuel per year. This corresponds to a cost of $541,763 per year assuming fuel costs at $2.50 per gallon. Even a slight decrease in fuel consumption will provide tremendous benefit to county taxpayers. In addition, a reduction in the use of fuel will reduce the negative environmental impacts of fuel combustion through emissions of products like oxides of nitrogen, carbon monoxide, and carbon dioxide.

Hybrid vehicle technology for municipal vehicles is available for light-duty cars through heavy-duty trucks. Companies like XL Hybrids and some original equipment manufacturers (OEMs) like Ford are promising significant savings in fuel cost through hybridization of work trucks, some including plug-in capability for some portion of all electric driving. These vehicles are costlier to purchase than their conventionally powered equivalents. However, higher efficiency powertrains and use of grid electricity may result in net savings through reduction in fuel costs.

Although fuel costs are generally accepted to be lower for hybrid vehicles, the benefit over conventionally powered vehicles is dependent on both driving style and the driving “cycle,” or speed versus time profile along a route. Work trucks including ½ and ¾ ton pickup trucks are commonly used vehicles in municipal fleets. New options exist for hybridized versions of work trucks, ranging from charge sustaining hybrids that do not require external charging to plug-in vehicles that allow charging to further reduce fuel use in exchange for facility electricity. Beyond the capital costs for purchasing the hybrid vehicles and for installing charging infrastructure, not much is known about the actual fuel economy benefits of implementing these vehicles beyond what is advertised by OEMs.

1.2 PROJECT GOALS AND IMPACTS

The central aim of this project was to quantify fuel economy improvements achieved by implementing hybrid electric utility vehicles in municipal fleets. The research involved collecting in-use vehicle data from three internal combustion engine powered vehicle types in different municipal fleets, ¾ ton pickup trucks, ½ ton pickup trucks, and light-duty SUVs. These data were fed into a vehicle simulation to predict the impact of two hybridization levels on fuel economy over varying routes. The two hybrid types considered included non-plug in (i.e., charge sustaining) and plug-in models (i.e., charge depleting). The main impacts of the project were as follows:

Material Cost Savings: Fuel savings are identified for real driving cycles through simulations of hybrid vehicles. The fuel savings for each vehicle type and driving cycle can be balanced by capital and maintenance costs for the vehicles known by fleet managers.

Reduce Environmental Impact: Emissions will be reduced proportional to gallons of fuel saved by municipal fleets. Reducing fuel use also decreases the need for fossil fuel production, further benefiting the environment.

1.3 REPORT ORGANIZATION

This report is organized into five chapters. The first chapter provides background information, motivating the study that was undertaken. The second chapter describes the research approach and methodology. Analysis and results are provided in the third chapter, and the fourth chapter provides additional discussion and relevance of the results including economic analysis. Conclusions are given in the last chapter.

CHAPTER 2: RESEARCH APPROACH AND METHODOLOGY

2.1 VEHICLE DATA COLLECTION

During the project, in-use vehicle data were collected from three vehicle classes; ¾ ton pickup trucks, ½ ton pickup trucks, and light SUVs. Project Technical Advisory Panel (TAP) members, many of whom manage municipal fleets, offered candidate vehicles from their organizations to a spreadsheet shared in Google Drive, from which ten vehicles of each class were selected. The project aimed to collect ten work days for each of the vehicle classes in two seasons representing different work tasks. These seasons included a warmer weather period in the fall of 2019, and a colder weather period during the winter of 2019-2020.

Table 2.1 lists the number of drive cycles collected during each season for each vehicle. Due to logistical concerns and scheduling, the original plan of 10 vehicles for 10 days/season vehicle was not achieved. Data from ¾ ton pickup trucks for the fall season was the exception. Issues with the data loggers running the vehicle battery down over time when installed on some Ford manufactured pickup trucks. If the logger was left installed over the weekend, this was enough to cause the vehicle to not start on Monday morning. This limited our ability to find ½ ton pickup trucks for data logging as most of them are Ford F150 models. The group also had a very limited selection of SUVs from which data could be logged. Those that were logged were Ford Escapes. For the above reasons, the most data were collected from ¾ ton pickup trucks. These vehicles consisted of Ford F250 and Chevrolet 2500 trucks. Driving cycles ranged in length from 10 to 190 miles. Drive cycles of less than 10 miles were excluded from the analysis.

Table 2.1 Vehicle type, model, and number of driving cycles greater than 10 miles collected in project

¾ Ton			½ Ton			Light SUV		
Model	**Fall**	**Winter**	**Model**	**Fall**	**Winter**	**Model**	**Fall**	**Winter**
F250	8	5	F150		5	Escape	5	
F250	6		F150		1	Escape	5	
F250	9	15	F150		7	Escape	6	
2500	10	5	F150		8	Escape		6
2500	11	3				Escape		5
2500	13	4						

F250	8							
F250	8	7						
2500	5							
2500	13	5						

Vehicle data were collected at 1 Hz from the vehicle's OBD port. Any installed telematics systems were removed and a standalone data logger was installed. CL2000 data loggers from CSS Electronics were used in the study. The loggers recorded data directly to a 32 GB SD card and did not collect any vehicle location data. Loggers split the data into 20 MB data files to minimize any data loss if the logger failed for any reason. Parameters requested from the vehicles included vehicle speed, engine RPM, Mass Air Flow (MAF) and fuel consumption; however, none of the spark-ignition vehicles reported fuel consumption. The data collected was backed up to a UMN Google Drive folder.

The data was initially processed using the CSS Electronics CANvas software. This software allowed us the merge all the data files from one vehicle into a single file and to down sample the data to 1 Hz.

2.2 DATA PROCESSING AND KINETIC INTENSITY

To analyze collected data as composite drive cycle data files, a script program was written in the Python programming language to calculate daily metrics including average speed, fuel consumption and kinetic intensity (KI), which is the ratio of characteristic acceleration to aerodynamic velocity. [1,2,3] Kinetic intensity is a factor used to define routes when comparing conventional and hybrid drivetrains. Higher KI indicates a route with frequent acceleration events and slower speeds, which are known to be favorable for hybrid vehicles due to their ability to capture regenerative braking energy. In lieu of showing the direct calculation for KI in this report, Table 2.2 provides a useful key for relating KI to practical driving cycle types. These ranges should be considered when looking at plots contained in this report.

Table 2.2 Relationship between kinetic intensity and driving type

Kinetic Intensity Range	Driving Cycle Type	Characteristics
$KI \geq 1$	Urban	frequent start/stop
$1 > KI \geq 0.4$	Arterial/Mixed	some start/stop
$0.4 > KI$	Highway/Rural	constant high speed

The amount of idle time during the drive cycle does not impact the KI since the vehicle is not moving. If the gasoline engine powered vehicles are operating with a stoichiometric air-fuel ratio, which is a reasonable assumption, and a gasoline density, the MAF and vehicle speed data can be converted to fuel consumption in miles per gallon. The average speed calculated in this initial step excludes idle time. The Python script also exported the speed trace for each of the days data was logged to a file for use in the modeling software.

2.3 VEHICLE SIMULATION

The project team decided to use the Future Automotive Systems Technology Simulator (FASTSim) provided by NREL to model vehicle fuel consumption for different powertrain types. [4,5,6] This simulation tool is freely available and is more suited to the tasks we are performing for this project. It provides a simple yet powerful way to compare powertrains and estimate the impact of technology improvements on vehicle efficiency, performance, cost, and battery life using the collected driving cycles as input. NREL provides an overview of FASTSim on their website. [2] FASTSim is packaged with more than 20 common vehicles types which provided the baseline for the modified models developed for this work.

FASTSim uses a simpler vehicle/powertrain model than the AVL Cruise software originally envisioned for use in this project, but it provides a more robust interface for running the model over multiple drive cycles with low computational requirements. Running the model over all of the collected drive cycles allowed the research team to determine which type of routes are best suited to hybrid vehicles. The project team decided on running the reduced FASTSim model over all the driving cycles over developing a composite driving cycle for each cycle type, as would be typical of AVL Cruise analyses. Parameters needed to model a given vehicle included engine power, frontal area, tire size, vehicle weight and cargo amount. One limitation to FASTSim is that it does not properly account for fuel consumption during idling during the driving cycles as it applies a constant auxiliary load during idle. Actual engine load during idle is highly variable depending on the season, the vehicle use, etc.

Models of three hybrid powertrain types were created for both types of pickup trucks: conventional, charge sustaining hybrid, and charge depleting hybrid as depicted in the Figure 2.1 and Table 2.3 below. The conventional vehicle was modeled using a FASTSim template and validated using in-use collected data. A mild electrified mild hybrid electric vehicle architecture was modeled after the XL hybrid system. This system uses a small traction motor and battery but retains the original internal combustion engine. The system allows regenerative braking to recapture vehicle energy and improve fuel economy, with manufacturer claims of up to 50% improvement in fuel economy. The third vehicle architecture analyzed is the Workhorse (WH) hybrid system which is a plug-in hybrid vehicle (PHEV). A strong electrification strategy, the WH W-15 pickup truck uses a large battery pack and a small internal combustion range extender (REx) engine-generator.

Simulations were run over in-use driving cycles recorded during data logging sessions. The drive cycles consisted of all the driving a given vehicle did during a 24-hour period. Fuel economy was compared between the three vehicle types. Cost information collected from project partners is used to complete the techno-economic analysis along with known fuel costs.

Conventional Vehicle	**XL XL-3 Hybrid Vehicle**	**Workhorse W-15 Hybrid Vehicle**
		
No electrification	Mild electrification	Strong electrification
Gasoline engine with differential	Small battery pack, Integrated motor with existing gasoline engine	Large battery pack with small gasoline powered range extender

Figure 2.1 Vehicle powertrain types considered in the study in terms of vehicles available in the marketplace.

Table 2.3 Model specifications for the three powertrains; Baseline conventional, PHEV and W15

Baseline – pickup with 250 kg (550 lbs) cargo for the ¾ ton and 136 kg (300 lbs) for the ½ ton
PHEV – 40 kW motor, 45 kW batt, 15 kWh batt, add 340 kg (750 lbs), same IC engine as pickup
W15 – 50kW gas, 344 kW motor, 360 kW batt, 40 kWh batt, same weight/cargo as baseline

For the SUVs, the FASTSim software included models of a 2016 Ford Escape, a 2016 Ford C-Max PHEV with a 19-mile all-electric range and 2016 Toyota Highlander hybrid. These three vehicles were run over the collected SUV drive cycle data.

CHAPTER 3: ANALYSIS AND RESULTS

3.1 ANALYSIS

FASTSim simulation software from NREL was used to simulate vehicle operation over driving cycles using logged data as input. For most driving cycles, the simulated fuel consumption results accurately matched with the logged fuel consumption data. However, very close matching of simulated results to logged data for all vehicles was not possible due to vehicle-to-vehicle differences. Further, it was difficult to match the model to the collected because vehicle weight, ambient temperature and other parameters varied between driving cycles day-to-day. Exact matching was not necessary to meet the primary goals of the project because so long as the vehicle modeled was representative of the fleet, observed changes in fuel economy when simulating different powertrains are comparable. The ½ ton pickup trucks and the SUVs did not report fuel consumption or mass air flow to the OBD logger, so collected idling data could not be used to calibrate their models.

Since FASTSim could not accurately estimate fuel use during idling, the time each vehicle spent idling in the logged data was removed for separate analysis. The identification of idling time enabled analysis of the impact of idling on vehicle miles per gallon. Figure 3.1 shows the modeled improvement in fuel consumption in MPG after removing idling from the drive cycles for the ¾ ton pickup truck warm weather dataset.

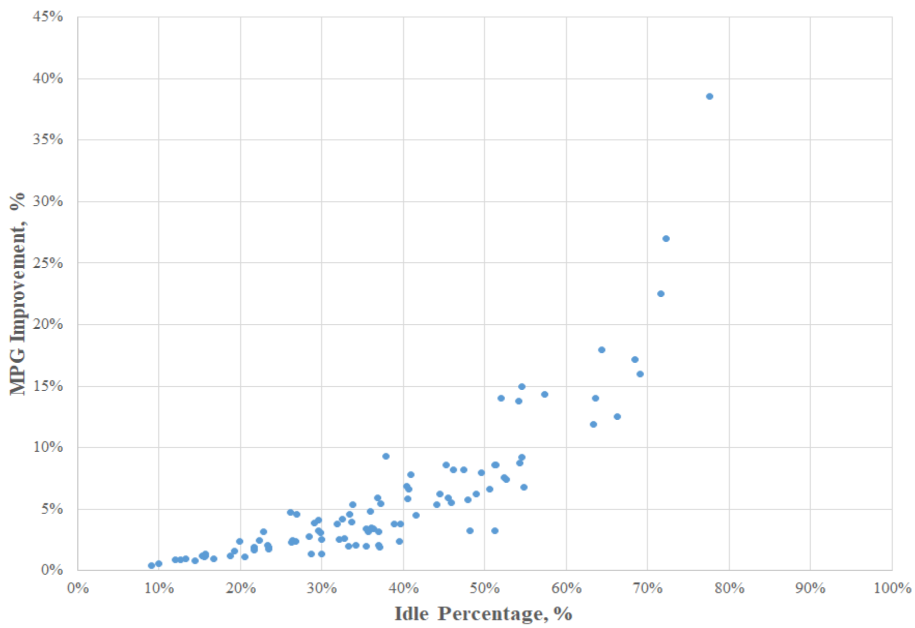

Figure 3.1 Modeled improvement in fuel economy with idling periods removed for the ¾ ton pickup trucks

The average amount of idle time for ¾ ton pickups during the warm weather period was 38%. Idle time increased to 58% for the winter data. From Figure 3.1, we can see that we would expect about a 5% fuel economy penalty for spending 38% of a day idling and approximately 10% increase in MPG for 58% idle time. Although idle reduction is a known strategy for improving fuel economy, the data presented here reinforces this point quantitatively for ¾ ton pickup trucks used in municipal fleets. Such analysis for the other two vehicle types was not possible due to insufficient logged data, though similar results are expected. Additional discussion about idling is provided in Section 4.1.

3.2 RESULTS

Simulation results comparing different powertrains indicate that vehicle fuel economy improvement is highly dependent on driving cycle. Kinetic intensity (KI) is the metric used to provide an indication of the relationship between drive cycle and fuel economy improvement expected with different hybrid powertrains. Higher KI indicates a route with frequent acceleration events and slower speeds which would be favorable for hybrid vehicles. Table 2.2 provides a guide for how KI relates to driving type. KI is defined in a way that makes it most useful for cycles where the amount of fuel used for driving is large compared to fuel consumed while idling.

In this section, results for the ¾-ton pickup trucks are presented first, followed by the results for the other two vehicle types. The analysis of the warmer, fall drive cycle data yielded KIs with a range of 0.08 to 3.34 with an average of 0.76, while the winter data yielded KIs with a range of 0.16 to 2.26 with an average of 1.0. Lower KI correlated to longer average trip distance as shown in Figures 3.2 and 3.3. The figures also show that higher average speed correlated to lower KI. These trends were not as obvious during the winter, when some short distance drive cycles had very low KI. This is likely due to adverse driving conditions affecting distance traveled and the amount of idling found in winter as discussed in Section 3.1.

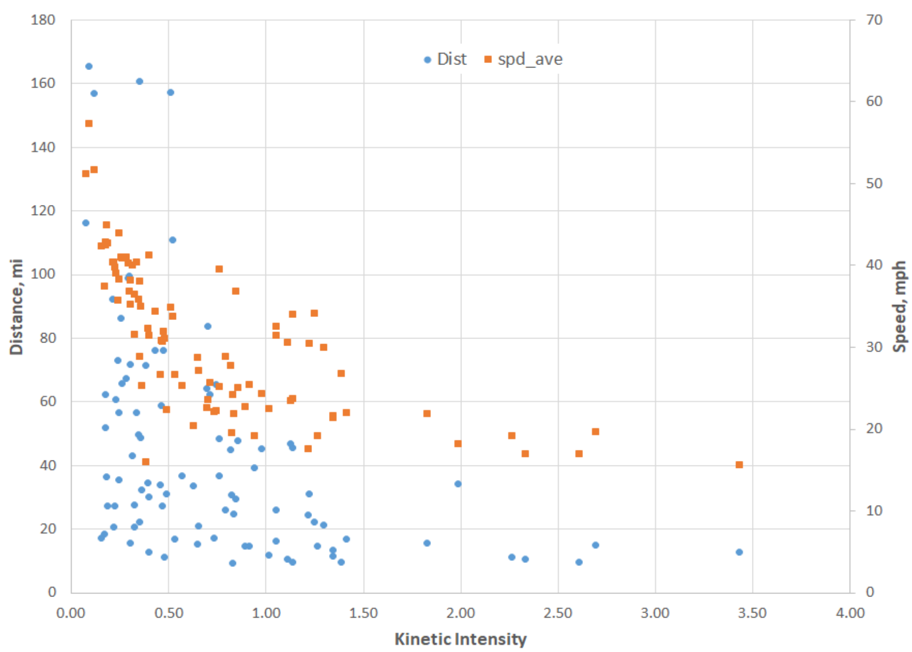

Figure 3.2 Fall drive cycle distance (circles) and average speed (squares) versus KI for ¾-ton pickup trucks

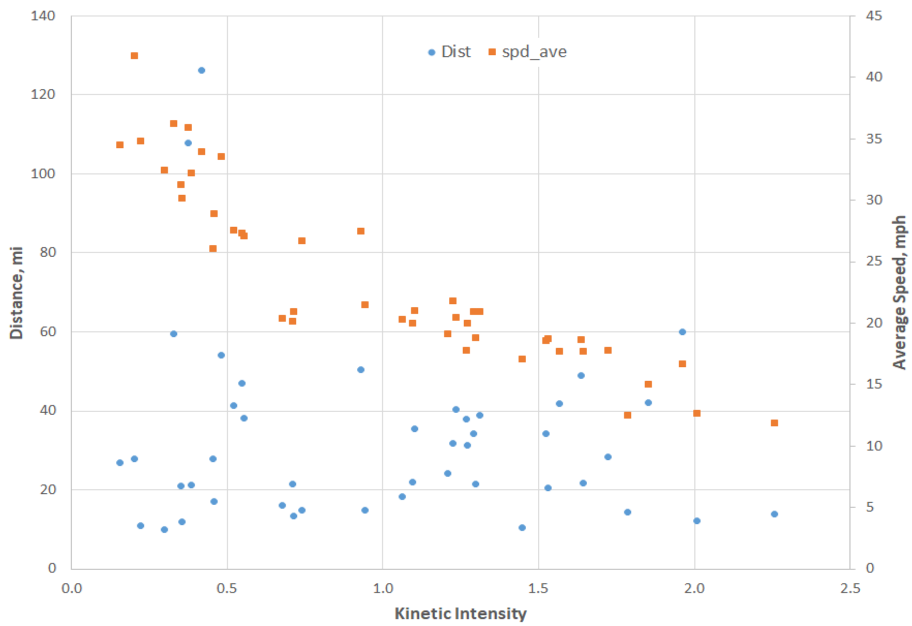

Figure 3.3 Winter drive cycle distance and average speed versus KI for ¾-ton pickup trucks

The estimated fuel economy improvement from switching to the XL Fleet PHEV powertrain for the fall and winter seasons is shown in Figures 3.4 and 3.5. The circled portion of the data shown in Figure 3.4 represents data from a single vehicle that does not follow the general trend. This vehicle exhibits much lower fuel economy improvement for a given KI than would be expected. This is most likely due to the driver of the vehicle having aggressive driving habits, a factor known to have a large influence on fuel economy, independent of powertrain.

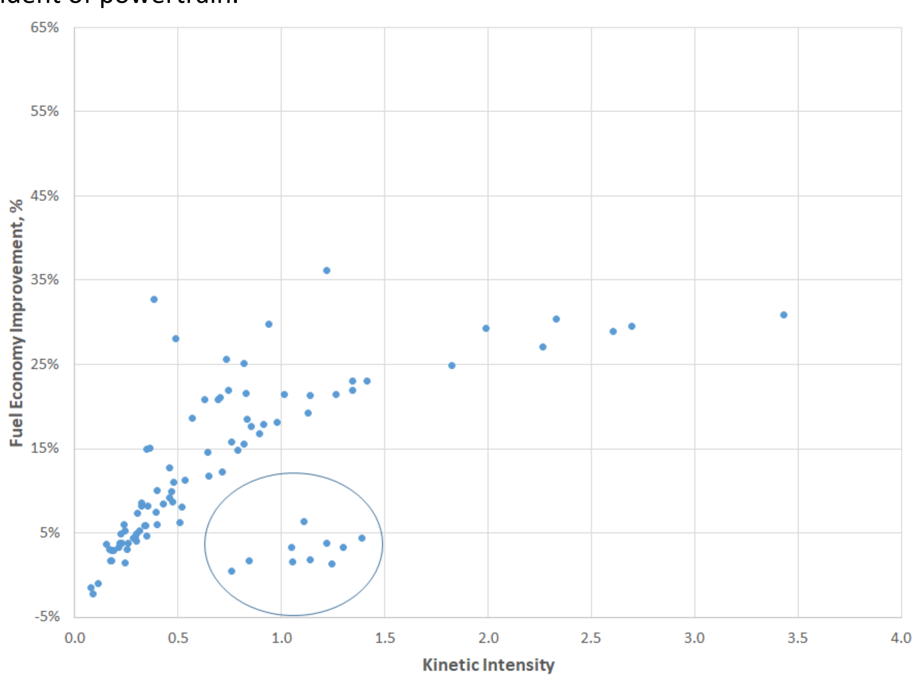

Figure 3.4 ¾ ton pickup truck fall fuel economy improvement versus kinetic intensity. Circled region are data points from a single vehicle with anomalous behavior

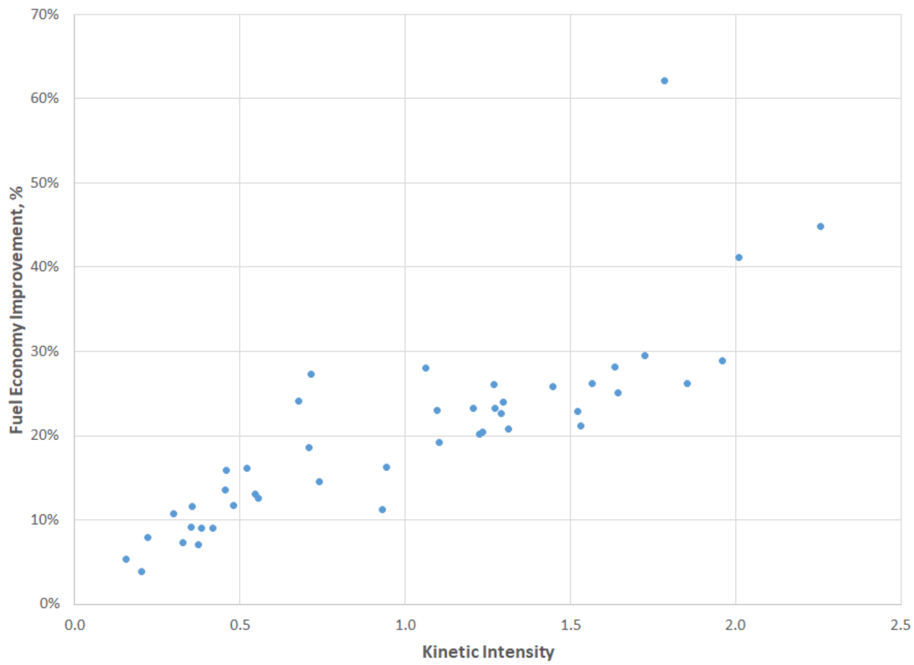

Figure 3.5 ¾-ton pickup truck winter fuel economy improvement versus kinetic intensity

The average improvements in fuel economy for the XL Fleet-type mild hybrid electric powertrains over the baseline conventional vehicles for the fall and winter are shown in Table 3.1 for three ranges of KI. One standard deviation of the improvement is also indicated.

Table 3.1 ¾-ton pickup truck fall percent MPGe improvement versus cycle type for both tested seasons

Cycle Type	Mild Hybrid fall	Mild Hybrid winter
Urban	18% ± 12%	28% ± 10%
Arterial/Mixed	15% ±7%	16% ±5%
Highway/Rural	6% ± 6%	8% ± 2%

Table 3.2 compares the average drive cycle speed and distance for the same range of driving cycles as shown in Table 3.1. This data generally fits expected results that higher KI values correspond to lower speeds. The lower average speeds correspond to more urban drive cycles where the distance traveled would be less. This was the case for the fall data but in the winter, we see the distance traveled are all very similar. However, the speed trends follow the expected result.

Table 3.2 ¾-ton pickup truck average speed and distance versus cycle type for both seasons

	Fall		Winter	
Cycle Type	Speed mph	Distance mi	Speed mph	Distance mi
Urban	24	19	18	30
Arterial/Mixed	27	44	26	37
Highway/Rural	39	59	34	33

With further model optimization, it may be possible improve the variability illustrated in Table 3.1, but significant variance from parameters such as driver behavior, vehicle load, weather, and etc. are highly influential. The results for the Mild hybrid show that we can expect improvement up to approximately 40%, slightly less than the published manufacturer value.

The modeling results from the W15 type plug-in hybrid (PHEV) are more difficult to interpret as the drive cycles were often short enough that the vehicle was modeled to run entirely off the battery and use little to no gasoline. The data will be included in the appendix for further review. In Figure 3.6 the W15 type powertrain data is presented as the reduction in equivalent gallons of gasoline used over the drive cycle as compared to the baseline case.

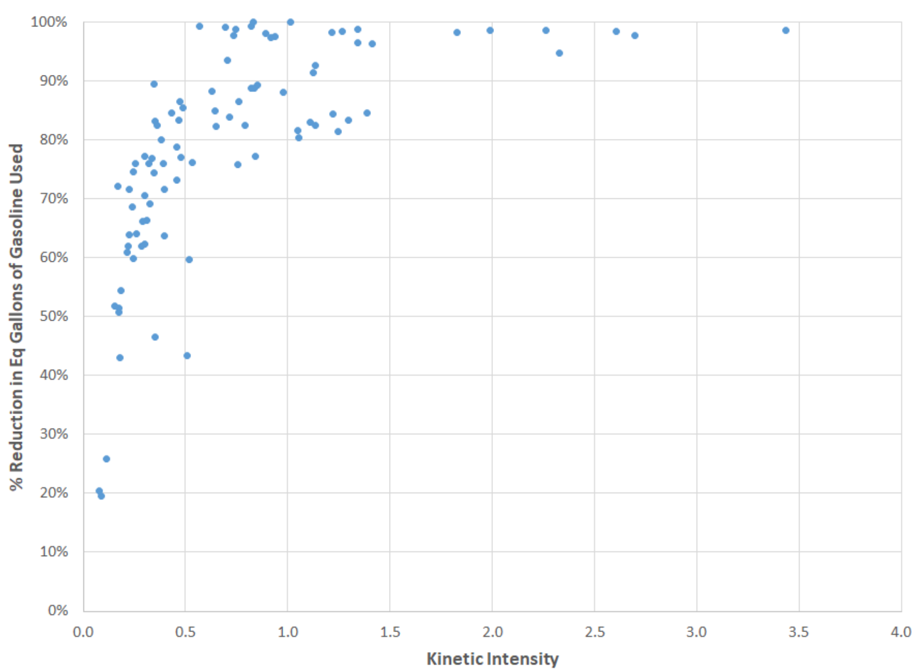

Figure 3.6 ¾ ton pickup trucks fall reduction in equivalent gallons of gasoline used

If we look at the percent reduction in gallons in table form similar to the fuel economy improvement for the PHEV versus the baseline we see the larger improvement for the pHEV vehicle as shown in Table 3.3. For the more urban cycles, where KI ≥ 1, we that the vehicle is operating completely on battery power.

Table 3.3 ¾-ton pickup truck percent reduction in fuel used versus cycle type

Cycle Type	PHEV fall	PHEVwinter
Urban	92%	98%
Arterial/Mixed	86%	87%
Highway/Rural	63%	70%

Data collected for ½-ton pickup trucks was more limited than for ¾-ton, with only 21 drive cycles available for analysis, all from April 2019. The data was from Dakota County and outstate Minnesota and was all of suburban/rural type. The results reflect that the driving was mostly on the highway, with KIs that ranged from 0.06 to 0.81 with an average of 0.36. These are all lower than the ¾-ton pickup truck data and none were greater than 1.0, the highest of the three categories used to compare the ¾-ton pickup trucks. The overall average speed and distance traveled were both higher as well. The results for the ½-ton pickup trucks can be seen in Table 3.4. The results are quite similar to the ¾-ton pickup truck results. We again see that the higher KI drive cycles with lower speeds and shorter distances lead to better hybrid performance.

Table 3.4 1/2-ton pickup truck results versus cycle type

Cycle Type	Speed mph	Distance mi	Mild %inc	PHEV %red
Urban	--	--	--	--
Arterial/Mixed	25	29	30%	83%
Highway/Rural	44	93	5%	50%

The average idle time for the ½ ton pickup trucks was 33% which was even lower than the ¾ ton pickup trucks in the fall and much lower than the winter. In Figure 3.7, the fuel economy improvement seen from switching to the XL Fleet PHEV powertrain for the ½ ton pickup trucks for all the drive cycles is provided. Results as a function of KI were largely similar to the ¾-ton pickup trucks with slightly higher improvement in fuel economy for a given KI.

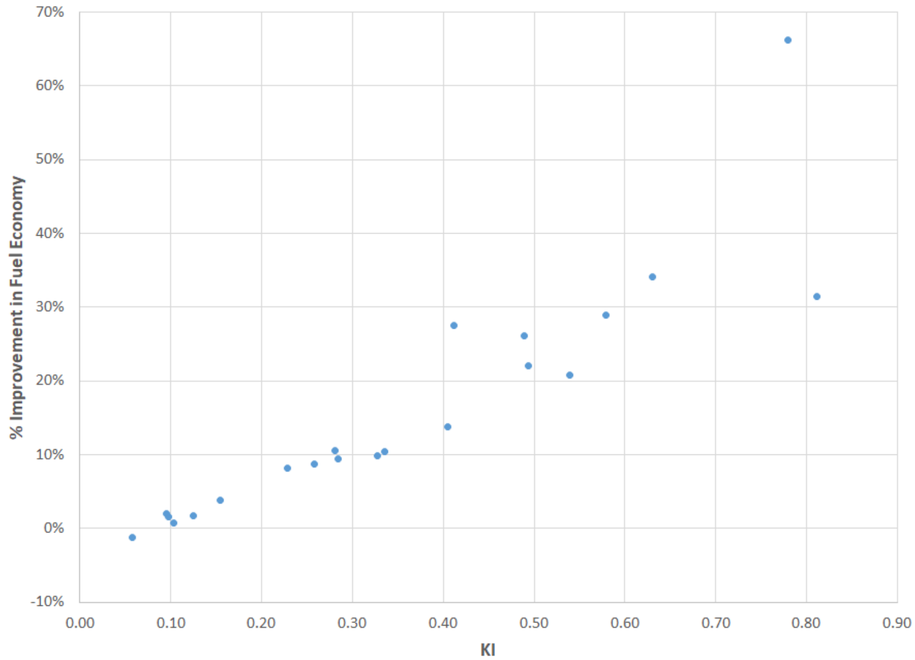

Figure 3.7 ½ ton PHEV pickup truck fuel economy improvement over conventional baseline powertrain versus KI

The data for the SUVs comprised 27 drive cycles from November 2018 and March 2019, all from the City of Minneapolis fleet. There did not appear to be any weather based trends in the data, so all the drive cycles were analyzed together. It was originally hoped to get the spring 2019 data earlier, but inclement weather at that time limited the access to the vehicles. As these were all urban vehicles, the KIs were higher, ranging from 1.1 to 4.0 with an average of 2.2. Compared to the pickup truck results, all these drive cycles were of the urban nature with an average speed of 17 mph and distance of 30.7 miles. The average idle time for the Ford Escape SUV's was 63%, slightly higher than the ¾ ton pickup trucks in the winter. The results for the SUVs can be seen in table 3.5. We see a large increase in fuel economy for the switch to a Toyota Highlander hybrid powertrain and an even larger increase for switching to a C-Max PHEV as indicated by the large reduction in fuel used over the modeled drive cycles. These results are as expected for these high KI values.

Table 3.5 Ford Escape SUV results vs kinetic intensity

Cycle Type	KI	Speed mph	Distance mi	T.H. %imp	C-Max %red
Urban	KI≥1	17	30.7	73%	91%
Arterial/Mixed	1>KI≥0.4	--	--	--	--
Highway/Rural	0.4>KI	--	--	--	--

In Figure 3.8, the fuel economy improvement seen from switching to the Toyota Highlander hybrid powertrain for the SUVs is presented. Even at relatively low KI, the improvement in fuel economy is significant. It is advantageous to implement hybrid technology for municipal vehicles, like SUVs, that operate at high KI.

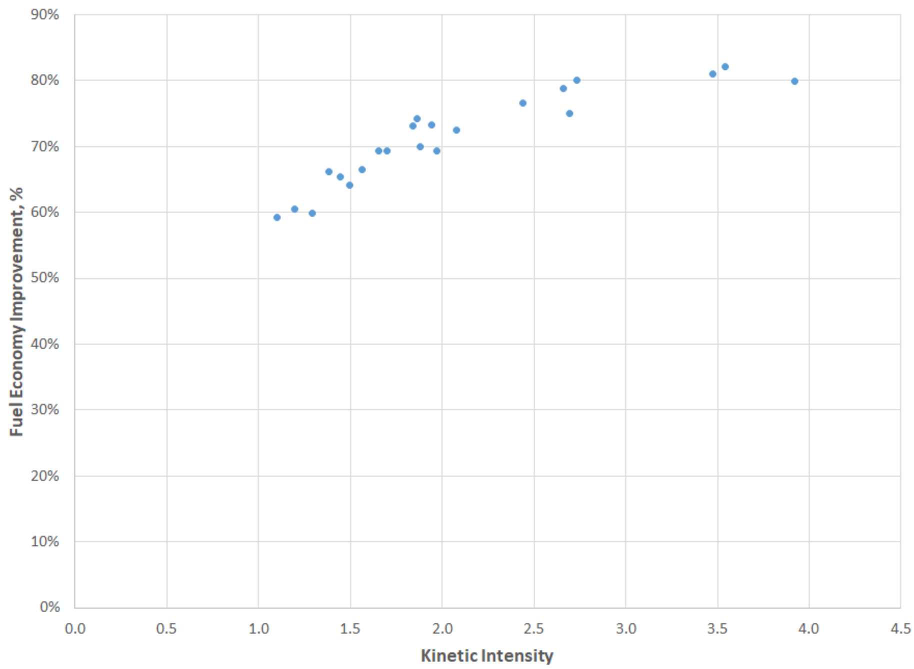

Figure 3.8 SUV Fuel Economy Improvement versus KI

CHAPTER 4: DISCUSSION

4.1 FACTORS INFLUENCING FUEL ECONOMY

A KI for a specific route along with the amount of idling time is needed to determine the fuel economy improvement using the modeling developed in this project. If a fleet manager does not have the resources or opportunity to perform a modeling study like that done here, an average KI for a vehicle or fleet could be used to determine the potential fuel economy improvement for switching to an alternative powertrain. On an even more basic level, Table 4.1 shows a scaled ranking of potential improvement expected from implementing mild and PHEV vehicles over baseline engine-powered vehicles. A score of "1" means that negligible fuel economy improvement is expected and a score of "10" means that a vehicle can drive almost on battery power alone, and not consume any fuel. Clearly from the ranking table, all vehicles score highly when operated on urban driving cycles. Mild hybridization of vehicles used on the highway shows very low improvement (1-6%) in fuel economy.

Table 4.1 Fuel economy improvement ranked on a scale from 1-10 with "1" being negligible improvement to "10" meaning almost no fuel was used to complete driving cycles

Vehicle		3/4 Ton Pickup				1/2 Ton Pickup		SUV	
Weather		Warm		Cold		Warm		Warm	
Hybrid Type		Mild	PHEV	Mild	PHEV	Mild	PHEV	Mild	PHEV
Driving	Characteristics								
Urban	frequent start/stop	4	10	5	10	--	--	8	10
Arterial/Mixed	some start/stop	3	9	4	9	4	9	--	--
Highway/Rural	constant high speed	2	7	2	7	1	5	--	--

In general, colder weather resulted in higher improvement in fuel economy for mild hybrid vehicles. The cause of this could have been lower average speed during the winter testing, which allowed the hybrid powertrain to yield more benefits due to additional regenerative braking.

Idle time was analyzed separately from the drive cycle data and is discussed in more depth here. Table 4.1 shows the percent idle versus KI for the three vehicle types. The ½-ton pickup trucks had essentially no difference between the two lower KI ranges, but, in general, the higher the drive cycle KI value, the more time was spent at idle. It is clear that more urban driving leads to greater time spent idling.

Table 4.2 Percent Idle versus KI and cycle category for the different vehicles. ¾-ton pickups are split into fall and winter testing seasons.

Cycle Type	KI	¾-ton f	¾-ton w	½-ton	SUV
Urban	KI≥1	45%	71%	--	63%
Arterial/Mixed	1>KI≥0.4	39%	58%	32%	--
Highway/Rural	0.4>KI	30%	38%	34%	--

Understanding the reason for the time spent idling is an important factor that needs to be considered when deciding about hybrid vehicle purchases. The increase in idle time between fall and winter may be due to the need for cabin heating, but it might be due to operator behavior. For hybrid vehicles, fuel used in the engine for heating may be similar to conventional vehicles.

Vehicle weight is also a key issue. If the hybrid weighs more, which is the case for the XL conversions, it is somewhat easy to lose the hybrid advantage if the driver is overly aggressive. The advantage also goes away as the distance traveled increases, especially in the case of more constant speed highway type driving. Aggressive driving like that seen in Figure 3.4 should be avoided, or the advantages of implementing alternative powertrain vehicles will be reduced.

4.2 PRELIMINARY ECONOMIC ANALYSIS

This study shows that improvement in fuel economy will lead to savings when switching to a PHEVs to an extent dependent on vehicle type and driving cycle. The analysis conducted did not consider operating and maintenance cost estimations for different electrification technologies. For ¾-ton pickup trucks, a KI of greater than 1 implies that the average speeds over the cycle will be less than 35 mph while the average cycle distance will be less than 50 miles during the fall with the average speed decreasing to less than 22 mph during the winter. In this case, with gas at $2.00/gallon and driving 18,000 miles per year, savings up to $900/year fuel per vehicle are possible. Anecdotal information from XL Hybrid customers, including TAP members, has stated that the amount saved on maintenance with the XL Fleet type system is minimal to none.

The ½-ton pickups did not have any drive cycles with a KI of over 1 while all the SUV drive cycles had a KI of over 1. However, the SUVs were split into two groups, with one group having a significantly higher improvement than the other. Until more data is collected or a determination is made as to the reason for these two groups, it is not useful to calculate cost savings.

The improvement in fuel economy seen switching to the PHEV at the lowest KI levels for both types of pickups was minimal and would not lead to a positive outcome if a switch was made. This is due both to the generally higher speed and longer routes as well as the increased weight of the PHEV.

The fuel savings seen when switching to a PHEV with a larger capacity battery is most significant in all cases. It is difficult to determine the actual savings for the pickup truck drive cycles with the highest KI values as essentially no gasoline was used as the distances driven were quite short and electricity cost was not estimated in this work.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this research, driving cycles were recorded from three vehicle groups, ¾-ton pickup trucks, ½-ton pickup trucks, and SUVs using portable onboard diagnostics (OBD) loggers. Collected data were used in vehicle simulations to determine the fuel economy improvement possible when implementing hybrid powertrain architectures in municipal fleets. The most on-road data were collected from the ¾-ton pickup trucks, resulting in a more complete analysis that included seasonal variation. The kinetic intensity (KI) was found to be a suitable metric for comparing driving cycles. The logged cycles were divided into three ranges: KI≥1, 0.4≤KI>1, and KI<0.4 representing highway/mixed, arterial/mixed, and urban types, respectively.

The magnitude of benefits from implementing hybrid vehicles is highly dependent on driving cycles and the electric motor/battery combination of the PHEV. Through the simulation work, the highest KI values, representing urban driving, were found to lead to the greatest fuel economy improvements for hybrid vehicles over the conventionally powered vehicles. The results depended heavily on the electric motor/battery combination, with the higher battery capacity plug-in hybrid vehicles yielding the highest levels of fuel economy improvement. Colder weather was found to lead to greater fuel economy improvements for mild hybrid architectures in the ¾-ton pickup trucks most likely due to lower average speeds and more regenerative braking. It is recommended that fleets consider the driving cycle as the primary factor for determining the economic benefits of purchasing alternative powertrain vehicles. Hybrid vehicles should be placed on routes that are more urban, while rural/highway routes will be better served by conventionally powered vehicles.

Idle time was also calculated for all the drive cycles and needs to be separately accounted for when analyzing driving cycle data. Idling for over 50% of the driving cycle can lead to about a 10% reduction in fuel economy based on the modeling conducted for ¾ ton pickup trucks in this study. The research team further recommends that aggressive driving be reduced as it will negate the fuel economy advantages possible from hybrid powertrain architectures.

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