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ACCURACY OF IN-DASH FUEL ESTIMATES

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ABSTRACT

This study examined the accuracy of fuel economy and range estimation displays for a selection of passenger vehicles. These tools are intended to help the driver make decisions about refueling and to understand how their driving behavior impacts fuel economy. AAA responded to over 488,000 out-of-fuel calls in 2019, suggesting these tools may be misunderstood or not utilized to their full benefit.

Sixteen vehicles of different brands were subjected to simulated drive-cycle tests using a specialized dynamometer allowing for accurate control of drive cycles, calculation of fuel consumption, and control of ambient temperature. Vehicles' displayed fuel economy and range values were compared to those calculated based on the collected dynamometer and emissions data.

Research Questions/Key Findings:

1. ***How accurate is the fuel economy displayed by passenger vehicles?***

   The average absolute difference between a vehicle's displayed fuel economy and its lab-measured fuel economy was 2.3% (0.7 mpg) over the entirety of testing, ranging from 0.0% to 6.4% for individual vehicles. Examination of error for individual drive cycles showed that error varied significantly over short distances, even when accurate over long distances.

   Despite variability in accuracy, a vehicle's fuel economy display can provide useful information to drivers. Resetting the vehicle's trip data at the beginning of long trips or after filling the gas tank can provide drivers with a better understanding of their vehicle's typical range and how driving conditions affect their vehicle's fuel economy.

2. ***How accurate is the range (miles-to-empty) displayed by passenger vehicles?***

   The accuracy of the vehicles' range estimations varied significantly as they progressed through the cycles. Specifically, the range estimates seemed to react based on the fuel economy of the recent drive cycles, suggesting that the accuracy of the range display at a given point is affected by changes in driving conditions.

   In general, the displayed range became more accurate as vehicles got closer to the end of their range. However, all of the tested vehicles had some amount of remaining range at the point when they displayed a range of zero. This may suggest that manufacturers utilize some amount of built-in underestimation to reduce the risk of an empty fuel tank.

   While a vehicle's miles-to-empty display may not be highly accurate at a specific point in time, it can be useful for long-distance planning of fuel stops and for understanding how driving style affects fuel economy.

GLOSSARY

Absolute difference – In this text, refers to the difference between the estimated value and measured value regardless of whether the difference is positive or negative. For example, for two cases where difference is +2.0% and −2.0%, the absolute difference will be +2.0% for both.

Drive cycle – A controlled driving procedure of a certain time and distance that specifies the vehicle’s speed, acceleration, and braking throughout.

Emissions – The contents of the vehicle’s exhaust, which (in this study) are used to calculate vehicle fuel economy.

Fuel economy – Measure of the distance traveled by a vehicle per unit of fuel used. Commonly presented in terms of miles per gallon (MPG).

Range – In this text, refers to the potential remaining distance that a vehicle can travel with the fuel remaining in the tank.

Road-load – The forces acting against the movement of a vehicle while driving on a smooth level road, such as tire rolling resistance and wind resistance.

CONTENTS

I. INTRODUCTION

Modern vehicles are often equipped with in-dash fuel efficiency and range displays within the instrument cluster to help the driver make informed decisions about refueling and how their driving behavior may impact the fuel economy of the vehicle. If the displayed range or fuel efficiency are inaccurate they could do more harm than good, leading to driver frustration or even stranded motorists (AAA assisted over 488,000 out-of-fuel cases in 2019). This project examines the accuracy of these in-dash range and fuel efficiency displays for a selection of vehicles.

A. Research Question #1: How accurate is the fuel economy displayed by passenger vehicles?

The fuel economy displayed by the instrument cluster of test vehicles was compared to lab-measured fuel economy during a series of controlled driving cycles. Tests were performed on a climate-controlled four-wheel chassis dynamometer so that drive cycles were accurately repeated for each vehicle.

B. Research Question #2: How accurate is the range (miles-to-empty) displayed by passenger vehicles?

Vehicles were driven on a controlled drive cycle until lack of fuel caused the engine to stall. The range (distance to empty) displayed by each vehicle was recorded at specified intervals throughout the drive and compared to the measured distances to engine stall.

Figure 1: 2019 Ford Escape on dynamometer during fuel efficiency testing. Image Source: AAA.

II. BACKGROUND

A. Vehicle Fuel Economy Displays

Many modern vehicles are equipped with a fuel economy estimation feature that provides the driver with a calculated miles-per-gallon value, which is typically displayed alongside related information, like trip distance and remaining range. The means by which the vehicle determines its estimation could (and likely does) vary by manufacturer. This study examines the accuracy of the displayed fuel economy values for a selection of vehicles from a variety of manufacturers.

B. Vehicle Range (miles-to-empty) Displays

Commonly displayed along with fuel economy is a range value, providing an estimation of the miles until the vehicle runs out of fuel. Calculation of remaining range relies on a projection of the vehicle's fuel economy into the future. Like the estimation of past fuel economy, manufacturers could use varying means to determine this projection. This study examines the accuracy of displayed vehicle range for a selection of vehicles from a variety of manufacturers.

Figure 2: Example of fuel economy and range on vehicle display. Image source: AAA.

III. METHODOLOGY

A. Dynamometer

All testing was performed at the Automobile Club of Southern California's Automotive Research Center (ARC). Drive cycles were performed using a pair of AVL 48-inch diameter electric chassis dynamometers. The front dynamometer is rated for 150 kW while the rear dynamometer is rated for 220 kW. The dynamometer is used to simulate the same tractive forces that a vehicle encounters when it is driven in real-world driving environments and is located inside of a temperature- and humidity-controlled chamber.

B. Vehicle Selection

Vehicles of model year 2018 to 2020 were selected to represent the majority of automobile manufacturers based on availability. In order to be considered for testing, a vehicle had to have at least 4,000 miles on its odometer to ensure adequate break-in, be in proper operating condition (run and drive well, no warning lights illuminated), have matched tires in good condition, and be in original condition (no modifications). Each selected vehicle was equipped with a display that provided fuel economy information.

Year	Make	Model
2019	Hyundai	Elantra
2019	Toyota	Tacoma
2019	Mazda	CX-5
2019	Ford	Escape
2019	Nissan	Sentra
2019	Dodge	Grand Caravan
2018	Mercedes-Benz	CLA 250
2019	MINI	Cooper
2019	Chevrolet	Malibu
2019	Volkswagen	Jetta
2018	Subaru	Outback
2019	Honda	Accord
2019	Kia	Optima
2020	BMW	740i xDrive
2020	Volvo	XC90 T6 AWD
2020	Land Rover	Range Rover Sport

Figure 3: List of Test Vehicles. Image source: AAA.

C. *Driving cycles for fuel economy testing*

Each vehicle performed seven different drive cycles (see table below), and each drive cycle was repeated four times. The drive cycles represent a variety of driving scenarios, from high-traffic city driving to steady-speed highway driving. Two of the cycles (HWFET and US06) are standard drive cycles developed by the EPA for fuel economy testing. The other five were developed by the ARC research team by recording driving parameters during real-world trips. The “Modern UDDS” drive cycle, which is an updated version of the EPA city route, better represents modern driving along the route on which it is based. Cycles 4 through 7 were developed to simulate common driving scenarios not represented in the EPA cycles.

Order	Drive Cycle	Distance	Time	Description
1	**HWFET**	10.3 mi	12:45	Original EPA Highway cycle. Mild accelerations and speeds. (Industry standard)
2	**US06**	8.0 mi	9:56	Original EPA Aggressive cycle. Higher accelerations and speeds. (Industry standard)
3	**Modern UDDS**	7.5 mi	25:42	Same route as EPA UDDS (city) cycle through Los Angeles, but with updated start/end points and modern traffic, speeds, and accelerations. (Non-standard)
4	**Fast Freeway**	18.9 mi	18:00	Freeway drive cycle in Los Angeles with high speeds and minimal traffic. (Non-standard)
5	**Traffic Jam**	3.0 mi	16:11	Very low speed “crawl” on Los Angeles freeway during rush hour. (Non-standard)
6	**65 MPH Cruise**	5.0 mi	5:00	Cruise control drive at 65 mph with a single, moderate acceleration and deceleration. (Non-standard)
7	**80 MPH Cruise**	6.0 mi	5:00	Cruise control drive at 80 mph with a single, moderate acceleration and deceleration. (Non-standard)

Figure 4: List of drive cycles used for dynamometer fuel economy testing. Image source: AAA.

D. *Test Procedure*

1. *Vehicle Preparation*

Before testing was started for each vehicle, cold tire pressure was adjusted to match the door placard after a 4-hour (minimum) soak period at constant temperature. Then a warm-up drive (consisting of two consecutive HWFET cycles) and dynamometer road-load derivation were performed. A road-load derivation is a process where the dynamometer adapts to the real-world forces that act upon the specific vehicle under test.

Fuel was then drained from the test vehicle’s fuel tank, which was refilled with certification gasoline containing 10% ethanol (E10). Most of the vehicles were given regular octane (87 minimum), but premium octane (91 minimum) was used for the Mercedes Benz, MINI, BMW, Volvo, and Land Rover according to the manufacturers’ requirements.

The vehicle was then placed onto the dynamometer and the fuel economy and range information display was reset. Most of the test vehicles had a “Trip A” (reset before each drive cycle) and “Trip B” (cumulative, reset once at the beginning of testing) display for distance and fuel economy, but four vehicles only had one display: Toyota Tacoma, Dodge Grand Caravan, BMW 740i, and Volvo XC90. In these cases, cumulative data was calculated based on individual “Trip A” values. All testing was performed at a controlled 75°F and 40% relative humidity.

2. *Emissions Measurements*

Vehicle emissions were measured with an AVL i60 Series II Constant Volume Sampler (CVS) and emissions bench. The vehicle exhaust pipe was connected to a mixing unit where fresh air is used to dilute the exhaust. The CVS blower pulls the diluted exhaust through heated lines and calibrated Venturi tubes to maintain constant flow and avoid condensation.

A small portion of the diluted exhaust is stored in sample bags and is later analyzed by the emissions bench. The emissions bench measures hydrocarbons, oxides of nitrogen, carbon monoxide, and carbon dioxide. Knowing the emission contents and exact fuel specifications, the system then calculates fuel economy based on the carbon balance and the calculated distance traveled on the dynamometer. This procedure aligns with official fuel economy testing methods used by the EPA.

E. Data recording

After each drive cycle was completed, the engine was shut off and the fuel economy, trip distance, and range were recorded from the display, as was the dynamometer distance and emissions analyzer data.

F. Distance-to-empty measurement

Once the final drive cycle of the procedure (Table 1) was complete, the vehicle was driven on the dynamometer according to the final drive cycle (80 MPH Cruise) until the engine stalled, at which point the vehicle was braked to a stop. Display range and total distance traveled were recorded at each 10-mile interval of the display range. Upon completion, the distance traveled (to the point of engine shut-off due to lack of fuel) was used to calculate actual vehicle range at each data point.

IV. RESULTS

A. Research Question #1: How accurate is the fuel economy displayed by passenger vehicles?

Figure 5 provides a summary of the totaled results (all drive cycles) of the fuel economy testing for each vehicle tested. It includes the vehicle’s displayed fuel mileage estimation, the lab-measured fuel mileage, and the difference between the two. It also includes the displayed and dynamometer-measured distance traveled during testing.

Summative Fuel Efficiency Data							
	Vehicle Display		Dyno Calculated		Difference		
Test Vehicle	Trip Dist. (mi.)	MPG	Trip Dist. (mi.)	MPG	Distance Diff (mi.)	MPG Diff.	MPG % Diff.
2019 Hyundai Elantra	317.8	39.2	316.52	37.7	-1.3	-1.5	-4.1%
2019 Toyota Tacoma	255.9	21.0	253.42	21.4	-2.5	0.4	1.7%
2019 Mazda CX-5	233.9	26.7	234.40	26.8	0.5	0.1	0.2%
2019 Ford Escape	246.3	24.5	240.73	24.7	-5.6	0.2	0.7%
2019 Nissan Sentra	235.0	37.6	234.85	35.9	-0.2	-1.7	-4.7%
2019 Dodge Grand Caravan	235.7	23.0	232.87	22.6	-2.8	-0.4	-1.8%
2018 Mercedes-Benz CLA 250	232.0	34.4	233.73	34.4	1.7	0.0	0.0%
2019 MINI Cooper	241.0	36.0	234.43	33.8	-6.6	-2.2	-6.4%
2019 Chevrolet Malibu	251.6	34.3	248.59	35.1	-3.0	0.8	2.3%
2019 Volkswagen Jetta	237.0	38.3	234.23	39.2	-2.8	0.9	2.4%
2018 Subaru Outback	235.7	30.3	233.87	30.2	-1.8	-0.1	-0.2%
2019 Honda Accord	233.9	35.2	234.44	35.4	0.5	0.2	0.4%
2019 Kia Optima	232.6	33.3	234.96	34.2	2.4	0.9	2.8%
2020 BMW 740i xDrive	233.3	25.9	234.23	26.0	0.9	0.1	0.4%
2020 Volvo XC90 T6 AWD	243.9	22.2	235.04	22.8	-8.9	0.6	2.7%
2020 Land Rover Range Rover Sport	229.4	23.9	233.72	22.5	4.3	-1.4	-6.1%
Note: Positive difference indicates that actual fuel economy exceeded vehicle's displayed economy. Note: Averaged resuts represent absolute error, disregarding whether the error is high or low.					Avg Absolute Diff.	0.71	2.32%

Figure 5: Fuel mileage results from start to finish of all drive cycles - displayed vs measured. Image source: AAA.

On average, tested vehicles' fuel economy estimations showed an absolute error of 2.3% (0.7 mpg) compared to their lab-measured fuel economy from start to finish of testing. Though the average error was relatively low, some vehicles were more accurate than others. The most accurate display was that of the Mercedes-Benz CLA 250, which showed no significant difference between displayed and measured fuel economy. On the other hand, the MINI Cooper displayed a fuel economy that was 6.4% (2.2 mpg) better than calculated from the lab data.

A look into fuel economy results for individual drive cycles shows that, while displayed fuel economy through all drive cycles may have been relatively accurate, the accuracy for individual trips varies. The example plot below displays the individual fuel economy error for each drive cycle for the Mercedes-Benz CLA 250, the vehicle with the most accurate fuel economy display when considering the all drive cycles together. Note that each of the seven drive cycles was repeated four times. In the plot below, each consecutive series of four dots represents one drive cycle. (See Methodology section)

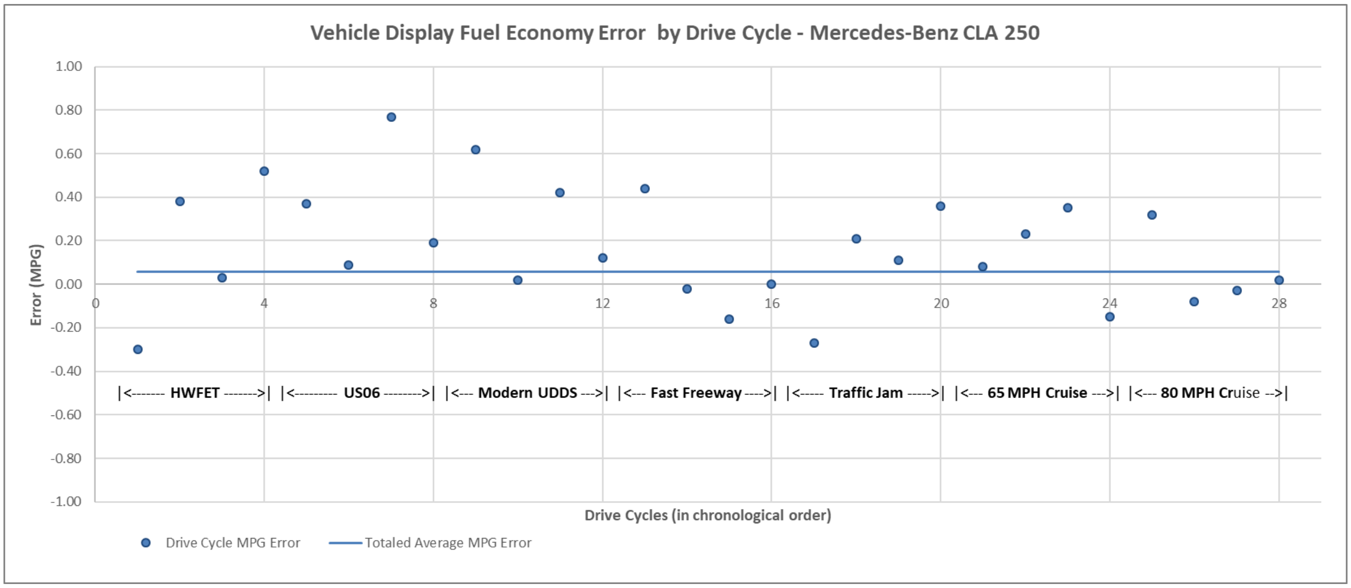

Figure 6: Fuel economy error by drive cycle – Mercedes-Benz CLA 250. Image source: AAA.

The fuel economy display error was only +0.1 mpg for the complete series of cycles, but the error for individual cycles varied from −0.3 mpg to +0.8 mpg. While the error was highly variable from one cycle to the next, it never exceeded one mile-per-gallon for this vehicle.

The next plot is that of the MINI Cooper, whose total averaged error was highest among vehicles tested at 2.2 mpg. Individual cycle error varied from -0.3 mpg to -4.1 mpg. Note in this plot how the error appears to trend based on the drive cycle (groups of four) while the error in the previous plot seemed to be more random.

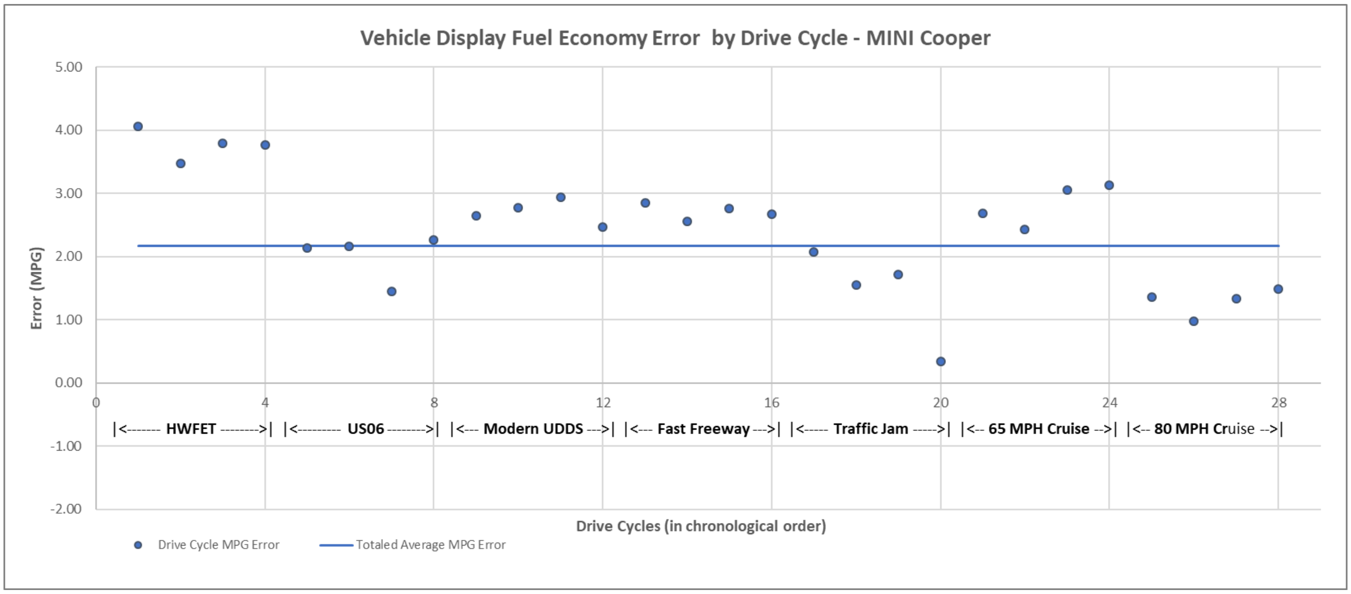

Figure 7: Fuel economy display error by drive cycle - MINI Cooper. Image source: AAA.

This trend in the error may suggest that the vehicle's algorithm is reacting to changes in driving factors that affect fuel economy, such as speed and acceleration. The vehicle's computer may adjust its estimations over time based of the recent driving history. If the vehicle's driving style remains consistent over time, the estimation is likely to become more accurate. When the driving conditions change (such as going from city to highway driving) the estimation will likely lose accuracy until it adjusts to the new driving conditions.

B. Research Question #2: How accurate is the range (miles-to-empty) displayed by passenger vehicles?

For five of the sixteen test vehicles, an additional step was added to the dynamometer procedure. After the fuel mileage testing was completed as prescribed, the vehicles were allowed to repeat the final drive cycle (80 mph cruise) until the vehicle ran out of fuel and came to a stop. During this cycle, the vehicle's displayed range (miles until empty) was recorded in ten-mile increments along with its dynamometer distance driven at each increment. When the vehicle ran out of fuel, the distance driven (measured by the dynamometer) was recorded. This was used to calculate the actual range (to engine stall) corresponding to the displayed values that were recorded.

Miles to Engine Stall									
Dash Range Displayed	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**	**0**
Subaru	73.6	72.7	64.7	55.8	44.9	36.8			
Honda					66.7	57.4	46.8	35.2	30.6
Kia						88.7	76.3	62.2	48.9
BMW								32.9*	23.2
Land Rover								67.7	54.4
Average	73.6	72.7	64.7	55.8	55.8	61.0	61.6	49.5	39.3

*This data point was actually taken at 11 miles (instead of 10) since that was the the BMW's range at the beginning of the runout cycle.

Figure 8: Actual & displayed range during run-out.

The collected display range data is provided in Figure 8. Due to differences in fuel economy, the test vehicles had varying amounts of fuel remaining at the beginning of the run-out cycle. Therefore, the amount of data collected for each vehicle varies. Additionally, the Subaru system stopped displaying range before reaching 20 miles and displayed a fuel level warning instead. In order to expand the scale of the data used for this analysis, the data in Figure 8 was combined with the data collected in the fuel economy portion of this study (Research Question #1).

The total miles driven parameter from the fuel economy data, along with the measured miles-to-empty from the range data, was used to determine the measured range (to empty) at each data point through the entirety of dynamometer testing. With the combination of both data sets, the estimated range (miles-to-empty displayed) and actual range (measured by dynamometer) were available at each data point from the start of the first drive cycle.

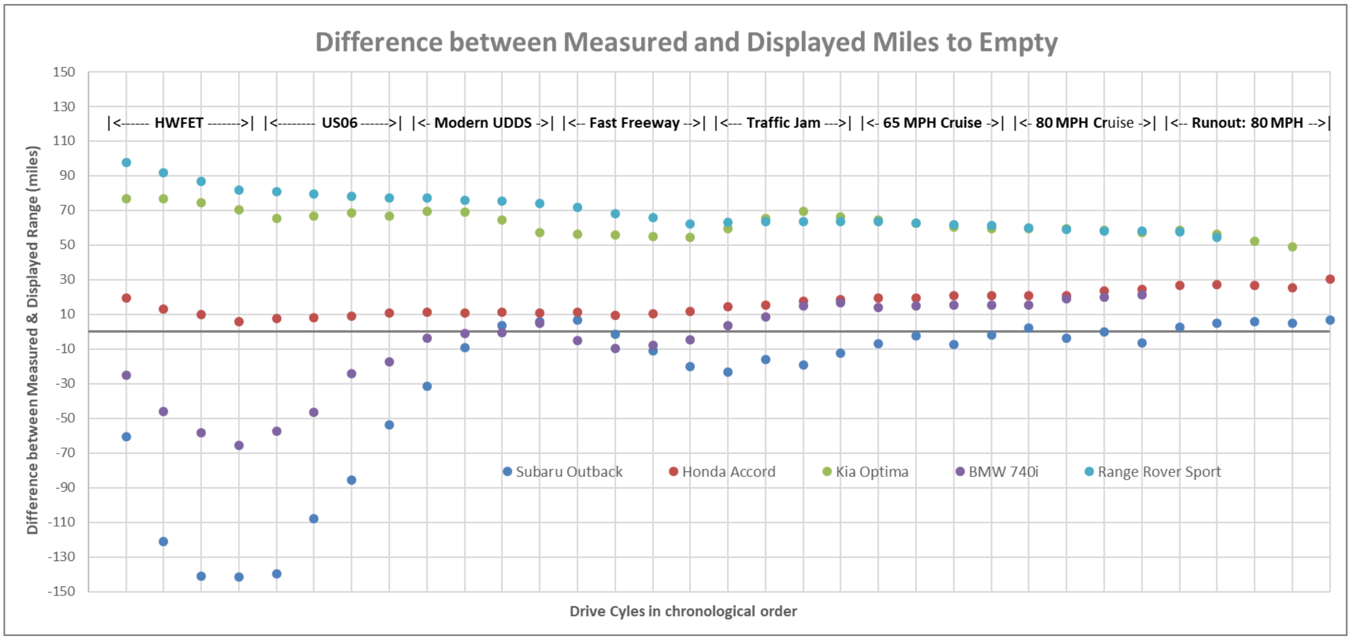

Figure 9: Difference between measured and displayed range for all drive cycles.

Figure 9 illustrates the difference between the measured and displayed range at each data point throughout testing. For clarification, positive values (above the zero line of the chart) indicate that the actual range of the vehicle exceeded the range displayed by the vehicle at that specific point. Negative values indicate that the displayed range overestimated the actual range. As can be seen, the accuracy of the vehicles' range estimations varied significantly throughout the series of drive cycles, and accuracy improved in general as testing proceeded.

The accuracy of the vehicles' range estimations varied significantly from cycle to cycle. Though each manufacturer likely uses a unique algorithm to estimate vehicle range, it can be assumed that some amount of historical driving data is used to estimate the vehicle's fuel efficiency for future driving. Therefore, the accuracy of the range estimation at any given point is affected by the vehicle's recent driving conditions.

This can be seen clearly in the cases of the Subaru Outback and BMW 740i through the first two drive cycles. Through the four repetitions of the HWFET cycle (mild accelerations and speeds) the range estimations increased with each cycle (increasing the error). This suggests that the range estimation adapted to the higher fuel economy of the HWFET cycle compared to overall fuel economy (15.3 and 8.4 MPG higher, respectively). Through the next cycle (US06), the range estimations decreased with each of the four iterations, likely due to the comparatively lower fuel economy.

Vehicle	Cycle	Avg MPG
Subaru Outback	HWFET	45.5
	US06	26.9
	All Cycles	30.2
BMW 740i	HWFET	34.4
	US06	23.2
	All Cycles	26

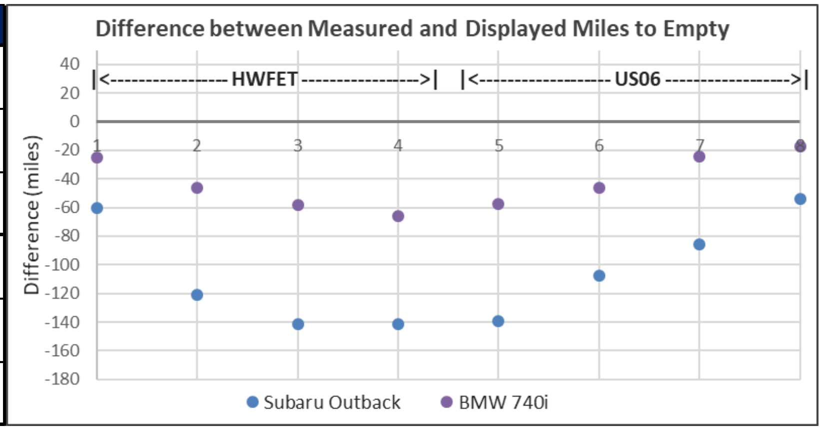

Figure 10: Fuel Economy & Range Accuracy for Subaru Outback & BMW 740i during HWFET & US06 cycles.

As the test vehicles approached the end of their range, they all underestimated the miles-to-empty, having between 6 and 55 miles remaining when the display said zero (See Figure 9). While the algorithms used are not clear, it may be common practice for manufacturers to include a built-in underestimation of range. This would help protect the fuel pump, which can be damaged when the fuel level is too low. This could also be done to benefit the driver, reducing the risk of running out of gas.

This underestimation of range could also be due to the difference in fuel economy during the final cycles as compared to the average fuel economy during testing. If the vehicle's economy increases near the end of its range, it would expectedly be able to drive further on the remaining fuel. It is possible that a different selection or order of drive cycles would have produced a different result.

V. CONCLUSION

A. Research Question #1: How accurate is the fuel economy displayed by passenger vehicles?

On average, the absolute difference between a vehicle's displayed fuel economy and the measured fuel economy was 2.3% (0.7 mpg). Of the sixteen vehicles tested, nine of them underestimated their fuel economy, ranging from 0.1 to 0.9 more miles per gallon than displayed by the vehicle. Six vehicles overestimated fuel economy, ranging from 0.1 to 1.7 fewer miles per gallon than displayed. One vehicle showed no difference between displayed and measured values.

Results varied significantly by vehicle, with absolute error ranging from 0.0% to 6.4% for the cumulative miles per gallon. Examination of individual drive cycles showed that error can vary significantly over short distances, even if it is accurate over longer distances.

Despite variability in accuracy, a vehicle's fuel economy display can provide useful information to drivers. Resetting the vehicle's trip data at the beginning of long trips or after filling the gas tank can provide drivers with a better understanding of their vehicle's typical range and how driving conditions affect their vehicle's fuel economy.

B. Research Question #2: How accurate is the range (miles-to-empty) displayed by passenger vehicles?

Based on the results of these tests, a vehicle's displayed range may not be accurate at a specific point in time. It is reactive to changes in the many driving factors that affect fuel mileage (such as speed and acceleration), and its accuracy is dependent on the consistency of these factors. A vehicle's miles-to-empty display may not be a precise representation of their vehicle's remaining range at a specific point in time, but it can be useful for long-distance planning of fuel stops and for understanding how driving style affects fuel economy.