

A Large Scale Simulation Process to evaluate Powertrain Technology Targets with Real World Driving

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Short Abstract

System Simulation is an accepted approach to evaluate the fuel economy potential of advanced (future) technology targets. Many technological advancements in vehicles result in ‘real world benefits’ which may not be adequately captured by the standard procedures and drive cycles. It is becoming increasingly important to evaluate the technologies on real world drive cycles. Generally, the approach for real world evaluation has been to synthesize a limited number of representative cycles from a large dataset, in order to limit the number of system simulations.

This paper will present an approach based on a large scale simulation process, where simulations will be performed over thousands of real world drive cycles. An important qualification for the choice of real world drive cycles is the unbiased or representative nature of the drive cycles. The paper will detail a process to randomly down-select from the thousands of simulations to a (large) subset of simulations which represent the distribution of daily driving as per the NHTS survey of 2009 [1]. Multiple such drive cycle sets will be randomly generated to show the variance in benefits for a single distribution curve.

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1 Introduction

Based on targets defined for advancements in powertrain technology (e.g. engine efficiency, battery energy density, light weighting, fuel cell efficiency), by U.S. Department of Energy’s Vehicle Technologies Program[2], vehicle system simulation models have been generated in Autonomie [3], to reflect potential midsize vehicles in 2025. These simulation models cover multiple powertrain types, like conventional, hybrid, PHEV, and electric vehicles. Current and future vehicle models will be evaluated for their fuel economy potential on standard and real world drive cycles and several steady state speeds. The paper analyses the differences in fuel economy benefits between standard and real world driving. The impact of technology targets on fuel economy improvements on standard and real world drive cycles will be analysed. The sensitivity of the real world benefits to the choice of real world drive cycles, and categories (e.g. low speed cycles) is quantified.

Real World impact is evaluated by simulating vehicle models on a prescribed set of real world drive cycles. These real world drive cycles are generally generated from real world GPS data logging on sample vehicles. Two important aspects of evaluating real world fuel economy impact using real world drive cycles are:

1. The validity of the set of real world drive cycles to statistically represent real world driving in terms of distance, average speed, acceleration and other parameters to represent driving in a particular region, or a country.
2. The comparison between fuel economy impact due to real world drive cycles and the standard drive cycles. The difference in fuel economy impact of advanced technology depends on the choice of real world drive cycles and the difference in vehicle operation, component utilization due to the choice of drive cycles.

2 Vehicles

The powertrain types considered in this paper include conventional, power split hybrid (HEV), 100 mile battery electric vehicle (BEV100) and a BEV capable of 300 mile range (BEV300)

Two mid-size vehicles are designed for each powertrain type. Baseline vehicle uses the technologies available in 2015, and the future vehicle considers the new technologies and efficiency improvements possible by 2025. Some of the major assumptions for the vehicles are shown in Table 1. Both sets of vehicles are required to meet the same vehicle performance requirements like acceleration and range.

Table1: List of major assumptions that changes from Model Year 2015 to Model Year 2025

Component	Parameter	2015	2025	Units
	Transmission	6 spd AT	8 spd DCT	
Vehicle	Glider Mass	1000	746	kg
	Cd	0.31	0.3	
	Frontal Area	2.4	2.3	m ²
	Rolling Res	0.008	0.007	
SI engine	Peak efficiency	36	45	%
CI engine	Peak efficiency	42	50	%
Motor	Specific Power	1080	1440	W/kg
Battery	Specific Power	2000	4000	W/kg

The changes made in the technology assumptions could affect the mass of the vehicle, which helps the 2025 vehicles achieve the same performance as 2015 vehicle with smaller component power rating values. The power rating of all the vehicles assumed in this study is shown in Table 2.

Table 2: Vehicle component specifications for Model Year 2015 & 2025 vehicles

Vehicle Type	Parameter	2015	2025	Units
SI Conv	ICE Power	123	107	kW
CI Conv	ICE Power	108	91	kW
SI Split HEV	ICE Power	90	70	kW
	Integrated Traction Drive #1	69	52	kW
	Integrated Traction Drive #2/Generator	52	40	kW
	Battery	32	27	kW
BEV 100	Integrated Traction Drive #1	114	84	kW
	Battery	164	101	kW
BEV 300	Integrated Traction Drive #1	152	99	kW
	Battery	203	127	kW

Such a change in vehicle components would result in fuel economy improvements in both regulatory and real world cycles. However, the magnitude of improvement in regulatory cycles could vary from those observed in real world cycles.

3 Drive cycles

National Renewable Energy Laboratory's (NREL's) Transportation Secure Data Centre (TSDC) [4] has a large database of real world cycles recorded from various cities in United States. When various characteristics of these cycles are analysed, we see that all the locations have some unique characteristics. Chicago may have shorter trips more stops per mile, and California ones may have trips with higher average speed. A sample across all these cycles will be needed to represent the general driving characteristics of the United

States. NHTS data characterise the vehicle use scenario across US. NHTS curve in Figure 1 shows that nearly half the daily drives are under 40 miles, and nearly 90% of the daily drives in US are under 300 miles.

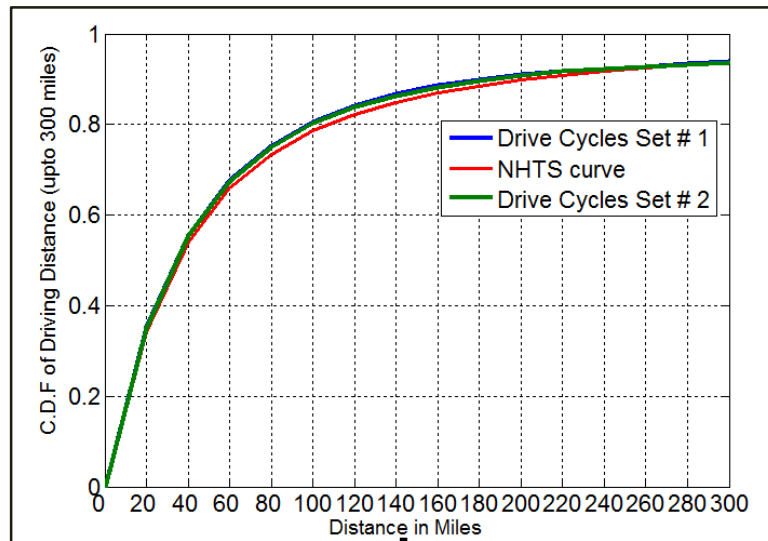


Figure1: Generation of set of daily driving trips to match the NHTS distribution on average daily driving distance

For this study, we use a sampling technique where we divide the drive cycles into multiple bins based on distance, and the number of random samples picked from each bin is changed to ensure that the overall distance covered by those sampled cycles is similar to the NHTS curve.

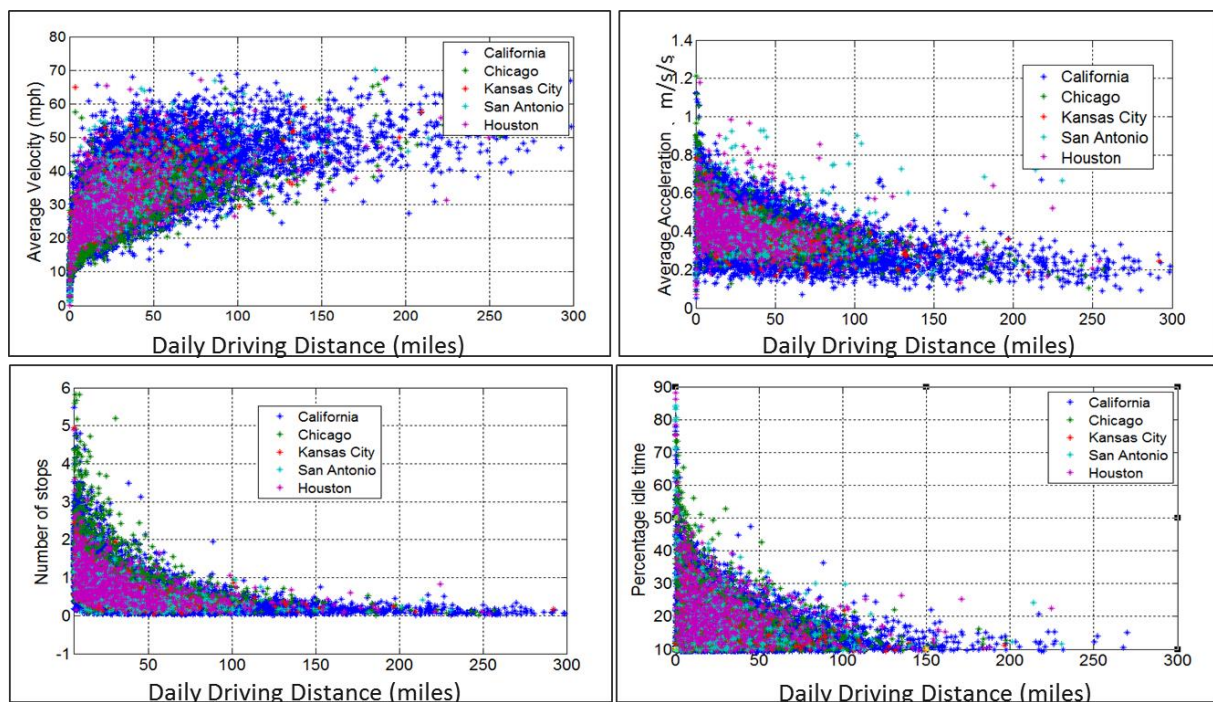


Figure 2. Characteristics of drive cycles taken from TSDC.

The relative distribution of daily driving distance of the sampled cycles is also shown in Figure 1. This ensures that the cycles we pick for this study match closely with the national driving behaviour in terms of driving distance.

When we analyse the TSDC data based on the distance driven, we see that many other drive cycle characteristics, tend to have a loose correlation with distance. From Figure 2, we see that longer trips tend to have higher average speeds, fewer stops per mile, lesser idle time and lower average acceleration.

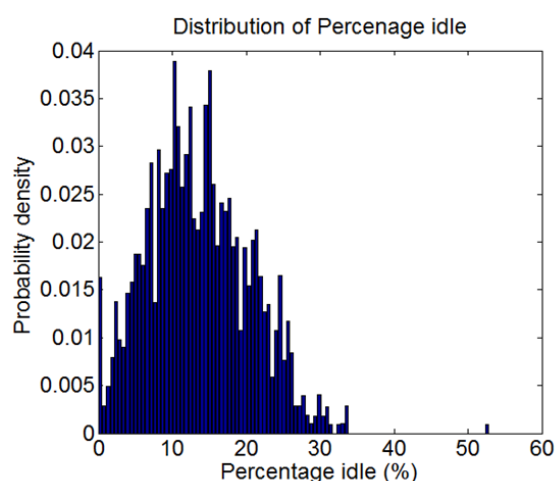


Figure 3. Percentage of idling time in Real world drive cycles

In addition to the factors shown in Figure 2, one of the major factors that separates the real world driving from the regulatory cycles is the duration of the idling time. While city cycle has about 4% idle time and highway cycle has little idling time, the real world driving has an average idling time of about 15%. In general, the real world cycles require more energy as they operate at higher speeds and have higher acceleration rates, than the regulatory cycles.

Since the TSDC data represents various large as well as small cities in US, it can be considered as a fair cross section of the drive characteristics across the country. As the database of drive cycles increases in the future, the result of this sampling process will get better in representing the national driving behaviour.

4 Simulation

All vehicles are simulated over all the sampled cycles and on several regulatory cycles. Autonomie was used to do this simulation. The vehicles that represent each powertrain technology and their default control logic are available in Autonomie as Simulink models. The component sizing was done as explained in Table 2.

Each simulation recorded the fuel consumption, electrical energy consumption, drive cycle trace adherence, in addition to many other vehicle simulation results. Fuel consumption on individual cycles are averaged to form the real world fuel consumption value. This average value is then compared against the fuel consumption observed in regulatory cycles to evaluate the impact of real world driving.

There are some differences in the way official test procedures are done on different kinds of vehicles. Eg. Hybrids are always tested in a charge sustaining mode, ensuring that the electrical consumption is negligible. For real world tests, we let the vehicle controller keep the SOC close to the initial value, but it may not be completely charge sustaining. For BEVs and PHEVs, it is expected that they start with a charged battery and based on the distance they actually drive, they may or may not consume fuel. Utility factor (UF) is not considered for real world analysis, as the variety of the samples available in the database will bring in the same impact as envisaged in the UF calculations.

5 Results

This paper puts forth a process to evaluate vehicle performance on samples of real world cycles to the performance observed on regulatory cycles. The analysis of each technology and its contribution to vehicle performance improvement is beyond the scope of this paper.

Both MY15 and MY25 cycles were tested on the same set of real world drive cycles, so the energy consumption differences between them are entirely due to the technology improvements in the vehicle, mainly reduced weight and increased component efficiencies.

The technology improvements benefit both real world cycles as well as regulatory cycles. For this paper, the comparison of real world cycle and the regulatory test procedures followed in US are compared, and shown in Table 3.

Table 3. Fuel and energy consumption for MY15 and MY25 vehicles

Vehicle	fuel/energy consumption estimate				% difference in RW estimate
	Year	Regulatory	Real world	Units	
Conventional SI	MY15	35	33	mpgge	-6%
	MY25	53	48	mpgge	-8%
Improvement MY 15 to MY 25		50%	47%		
Conventional CI	MY15	44	40	mpgge	-8%
	MY25	61	55	mpgge	-11%
Improvement MY 15 to MY 25		40%	36%		
Split HEV SI	MY15	57	50	mpgge	-12%
	MY25	78	72	mpgge	-8%
Improvement MY 15 to MY 25		37%	44%		
BEV100	MY15	261	279	Wh/mile	7%
	MY25	186	206	Wh/mile	11%
Improvement MY 15 to MY 25		-29%	-26%		
BEV300	MY15	382	378	Wh/mile	-1%
	MY25	216	223	Wh/mile	4%
Improvement MY 15 to MY 25		-44%	-41%		

There is improvement from MY15 to MY25 in both regulatory cycles and real world cycles. The percentage improvement values are slightly higher in regulatory cycles than in real world cycles. This is mostly due to the drive cycle characteristics. The real world cycles have consistently higher energy consumption than the regulatory cycles. The mix of the cycles in this study could have more aggressive stop and go trips, as most of the data is from cities.

This trend can be seen in Figure 4 to 6 as well, where the normalized distribution of fuel or energy consumption for all the real world cycles are shown against the regulatory values.

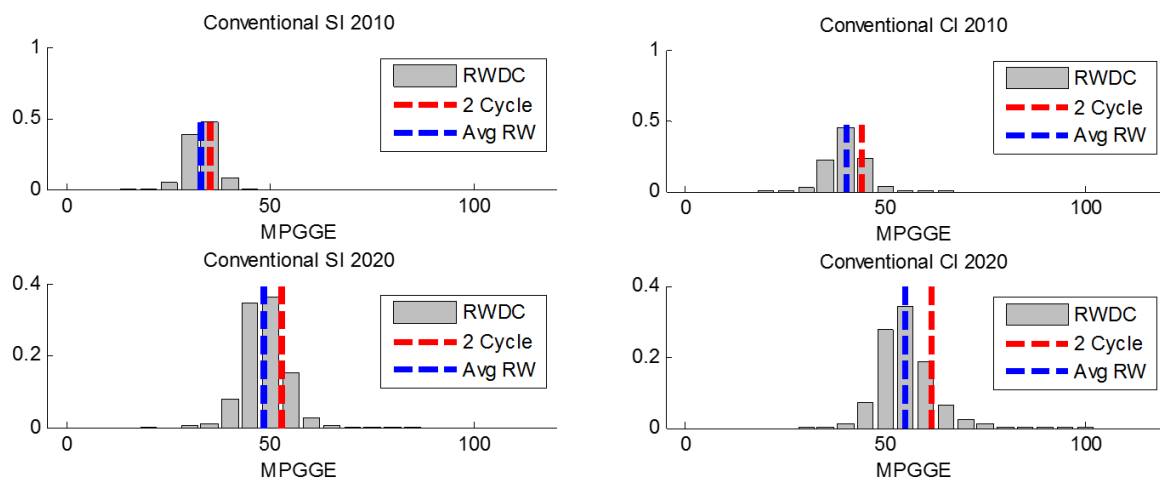


Figure 4. Normalized distribution of the fuel economy on conventional vehicles over real world cycles

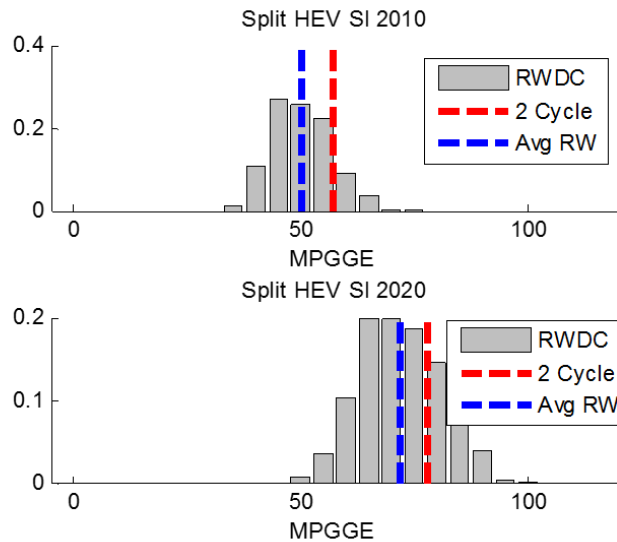


Figure 5. Normalized distribution of the fuel economy for split hybrid vehicles on real world cycles

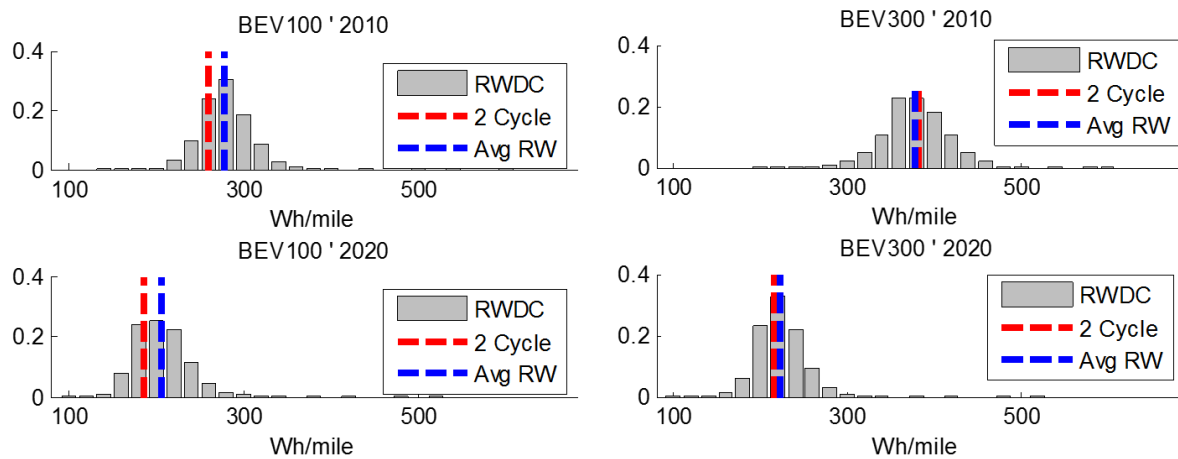


Figure 6. Normalized distribution of the fuel economy for battery electric vehicles on real world cycles

6 Summary and Conclusion

The paper presents a large scale simulation process used for the evaluation of advancements in powertrain technology on real world driving, and compare the real world benefits to the benefits with standard drive cycles. The paper also details the process used to select the real world drive cycles to generate daily trips to match the NHTS daily driving distribution. Following conclusions can be drawn from the analysis.

Real world cycles considered in this study

- Matches the NHTS average daily miles travelled
- Have higher energy consumption and fuel consumption than the regulatory cycles.
- Shows similar fuel and energy consumption benefits as the regulatory cycles.

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Aymeric Rousseau is the Manager of the Vehicle Modelling and Simulation Section at Argonne National Laboratory. He received his engineering diploma at the Industrial System Engineering School in La Rochelle, France in 1997. After working for PSA Peugeot Citroen in the Hybrid Electric Vehicle Research Department, he joined Argonne National Laboratory in 1999, where he is now responsible for the development of Autonomie. He received an R&D 100 Award in 2004 and a 2010 Vehicle Technologies Program Award in 2010. He has authored more than 40 technical papers in the area of advanced vehicle technologies.