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Effectiveness of engine start stop systems on real world driving conditions in United States

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Abstract

Start-stop systems are expected to gain prominence in US market in the next few years [1-2]. The extent of benefits of this technology is well demonstrated on standard test cycles, but the estimates on real world benefits have been largely inconclusive. Real world driving in US has longer idling time than the regulatory test cycles, hence it is widely believed that this technology will offer better fuel savings in real world driving conditions than on regulatory testing [3]. Wishart et.al [4] showed consistent fuel savings due to start-stop systems in regulatory cycles from US and Europe, however the real world tests were termed inconclusive in their report. Drive behavior, route selection were factors that prevented a conclusive real world benefit estimation. This study uses vehicle simulation to eliminate those uncertainties, and quantify the fuel saving potential of the engine start-stop system in a mid-size passenger car. Real world cycles recorded from multiple locations in US are used to represent the driving conditions.

Keywords: real world, start-stop

1 Introduction

Real world driving offers a variety of challenges and opportunities to demonstrate the benefits of a vehicle technology. Fuel economy benefits from engine start-stop technology will vary depending on the factors such as driver behavior, idle time, distance, traffic conditions, ambient temperature, cabin cooling requirements etc. This study estimates the maximum benefit that can be expected from an engine start-stop system, while assuming no change in driver behavior or driving patterns. Cabin cooling is assumed to be turned be off, and the vehicle controller can turn off the engine whenever the desired speed demand is zero.

1.1 Approach

Vehicle system simulation will be used to quantify the impact of start-stop system across multiple technology implementations. Three midsize vehicle models were built in Autonomie [5] using the same component models to compare their relative fuel saving potential. The vehicles are identical except for the battery and electric machine specifications.

1. The conventional vehicle has an alternator to keep the 12V battery charged and the engine idles when the vehicle is not moving. This vehicle is considered as the baseline.
2. The micro-hybrid uses the same engine and other components as the conventional vehicle, but it turns the engine off when vehicle comes to a stop, and restarts the engine when the driver releases

the brake pedal. This vehicle uses the regular starter to restart the engine. There is no regenerative braking in this vehicle.

3. The third vehicle is a Belted Integrator Starter Generator (BISG) with a 7kW motor and li-ion battery pack. This vehicle can do regenerative braking and assist, but the smaller motor limits the hybrid operation.
4. The fourth vehicle is Crank Integrator Starter Generator (CISG) with a 15kW motor and li-ion battery pack.

These vehicles will help quantify the improvements due to idle reduction, regenerative braking and launch assist for engine.

1.2 Vehicle models

The default vehicle and component models in Autonomie are validated against test data recorded at Argonne National Laboratory [6]. The various implementation of start stop technologies were modelled and simulated on UDDS cycle. The observed benefits vary based on motor power and battery size. Micro hybrids demonstrated a 4% improvement, BISG provided close to 7% improvement and the CISG system with a larger battery and motor provided 9% reduction in fuel consumption. This is close to the improvements observed during actual vehicle tests on UDDS cycle.

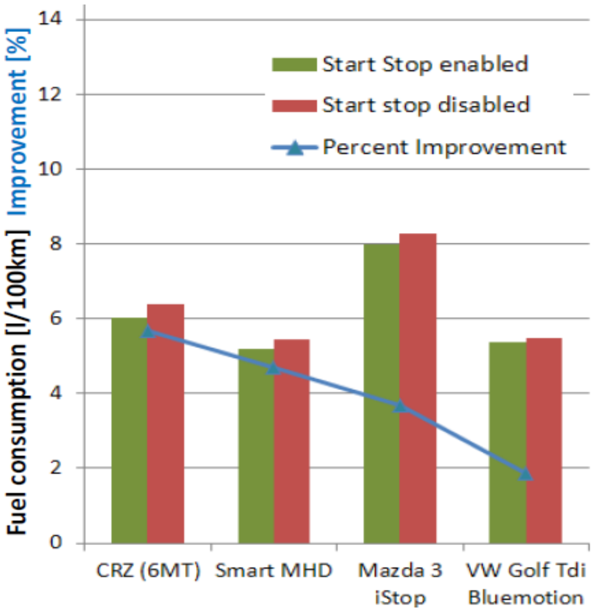

Figure 1. Test data showing the benefit of start stop systems on UDDS cycle

1.3 Drive cycles

The real world cycles for this study were obtained from the Transportation Secure Data Centre (TSDC) [7]. Over 8000 daily cycles were recorded from 6 different locations. This data is from various transportation studies in cities and suburbs, it may not reflect the driving distance across United States. Some of the important drive cycle properties from these cycles are shown in Figure 2. The parameters that are most interesting for this study are driving distance and idle time in the real world cycles.

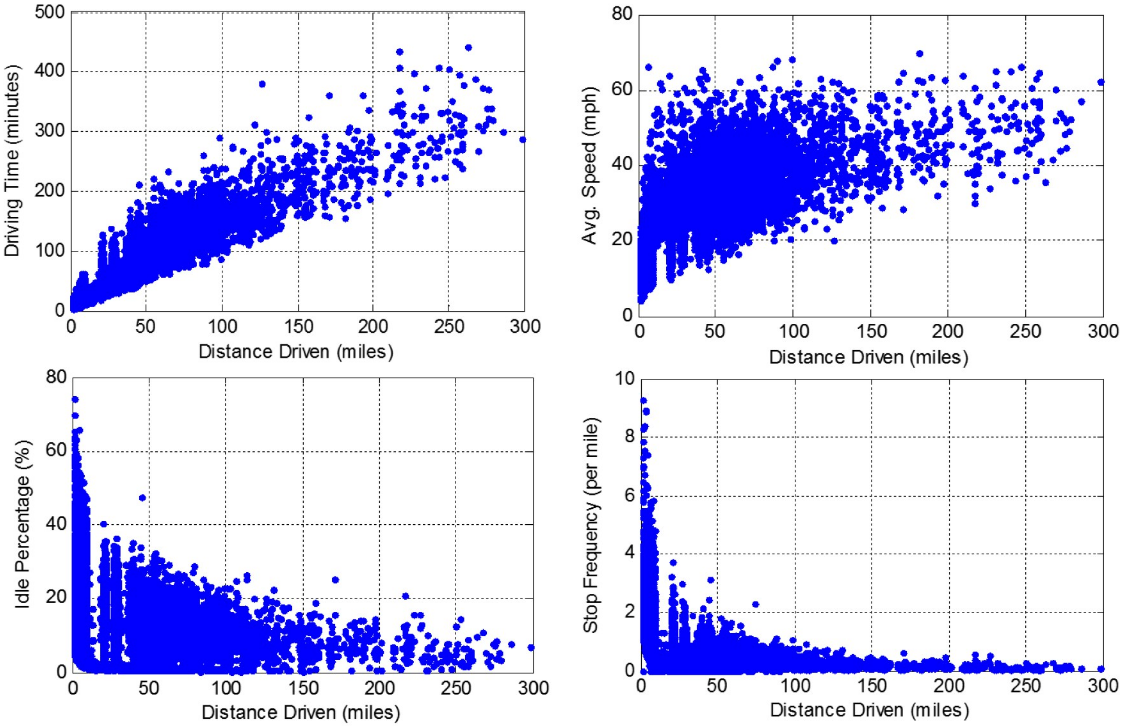

Figure 2. Driving distance has a good correlation to many other drive cycle properties.

National Household Travel Survey (NHTS) provides an insight on the driving behaviour of people in this country [8]. By sampling the TSDC data to match the driving distances observed in NHTS, we can get a fair representation of the national driving behaviour [9]. The red line in figure 3 shows the fraction of cycles that fall under the driving distance shown as x axis.

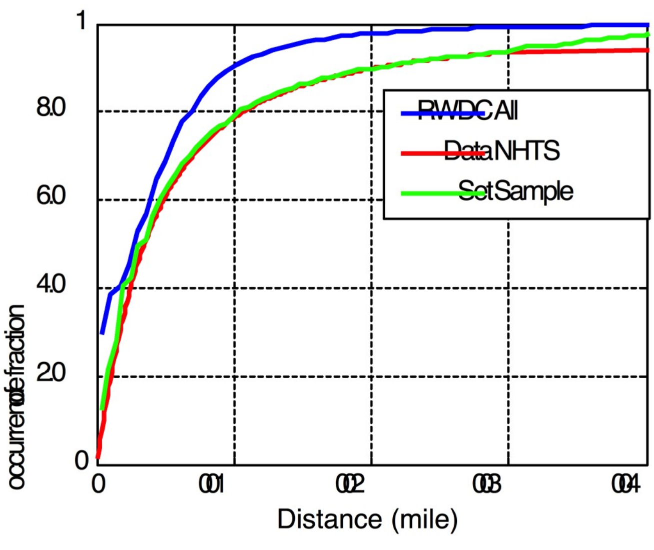

Figure 3. Sample sets that conform to the NHTS drive pattern are taken from the pool of real world driving cycles

Simulating the four different vehicles on thousands of real world driving cycles yield the real world fuel consumption estimates for these vehicles. The benefits attributable to start-stop technology can then be derived by analysing the results

2 Simulation Process

All vehicles were simulated in all cycles as the first step. This is a time consuming step, but once this large database is built, it enables the result analysis with respect to various drive characteristics.

Each sample taken from the pool of real world cycle results represent 1000 cycles with driving distances following the same distribution as the NHTS driving distance profile, as shown in figure 3. While the real world cycles ensure that the actual driver behaviour is considered, the sampling to match the driving distance distribution from NHTS ensures that the national driving pattern is factored in.

For each of these samples the fuel consumption obtained for the four vehicles can be computed. To consider variation between samples, 100 such samples were taken. For each sample the weighted fuel consumption is computed from the total distance and fuel consumed by all those sampled cycles. The fuel economy observed on individual cycles as well as the weighted fuel economy for the samples is shown in Figure 4.

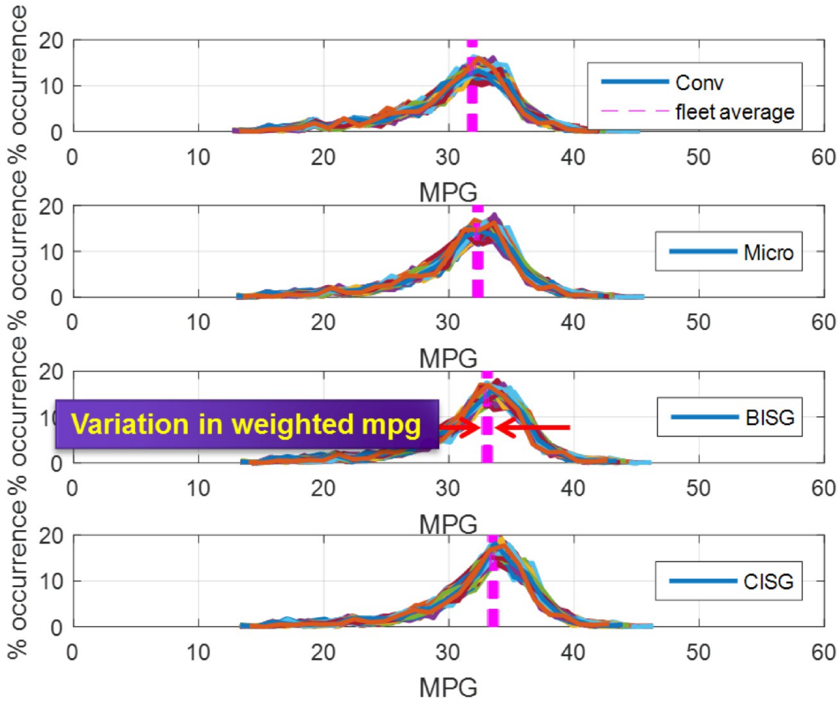

Figure 4. Distribution of fuel economy values for four vehicles over 100 sample sets

3 Results

The mean value of the fuel economy observed from these samples is taken as the representative fuel consumption for each type of vehicle. Conventional vehicle is taken as the baseline and the improvements observed in all vehicles are computed as a percentage of the baseline fuel consumption. In figure 5, it can be seen that the increase in the degree of hybridization leads to greater reductions in real world fuel consumption. This is expected, as the larger motor and battery allows for more regenerative braking, and use of that energy to reduce the load on the engine. The improvement seen for micro hybrids is entirely attributable to the idle reduction by the start-stop system. From the 100 samples taken for each vehicle, the minimum and maximum values observed are used form the error bar around the mean value of fuel consumption reduction. It is not surprising that the improvements observed are not as high as what was seen from UDDS cycle (4%-9%). Real world cycles contain highway driving too, where little improvement should be expected from a start stop system.

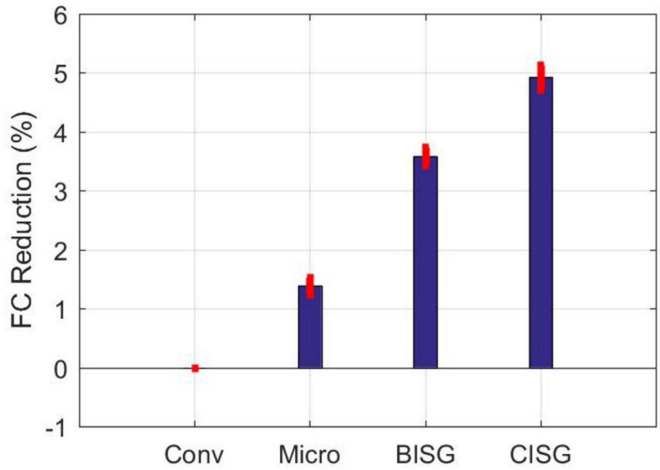

Figure 5. Fuel consumption reduction observed in real world cycles due to micro/mild hybrid technologies on a generic midsize passenger car

3.1 Comparing real world benefits against 2 cycle procedure

The regulatory testing in US involves both city and highway cycles and then adjusted with correction factors to reflect the real world fuel economy. The simulation results show that the fuel consumption reduction due to start stop system observed in the 2 cycle procedure exceeds the benefits observed in real world driving. This comparison is shown in Figure 6.

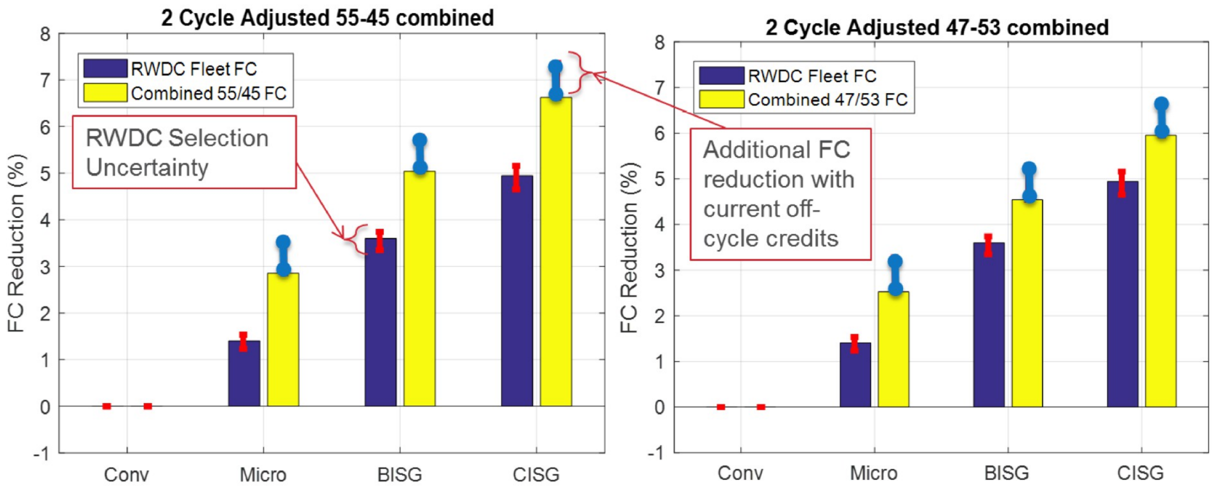

Figure 6. Real world benefits compared against the improvements observed in regulatory cycles.

The combined adjusted values are calculated by simulating the fuel consumption observed in UDDS and HWFET cycle and then weighing those values based on the EPA's 2 cycle procedure. Both 55-45 weighting and the 47-53 weighting are considered in this case. Unadjusted values show lightly larger improvements than the adjusted values.

The red error bars on the real world fuel consumption reduction estimate show the variation that is observed between multiple samples. The blue bar on top of the improvement observed on combined 2 cycle estimates are the additional off-cycle credits offered for the start-stop systems. Based on this sample of real world cycles and for this particular type of vehicle, it is observed that the real world benefits are lower than the ones for the standard driving cycle.

In order to fully understand the results, it is necessary to look at various types of real world driving. In the following sections, we look at real world cycles that are sampled based on specific characteristics which affect the operation of the start-stop systems.

3.2 Impact of driving distance

The real world fuel savings on shorter drive cycles (<10 miles) was analyzed for measuring the impact on city driving. Shorter cycles are more likely to be from city driving, based on the stops per mile, idling time, average speed, and other characteristics. This is seen from the cycle characteristics shown in Figure 2.

When cycles under 10 miles are considered, we see that the real world benefits match closely with the improvements observed in UDDS cycle. If a vehicle is mostly driven in urban conditions, then the benefits observed due to start-stop systems will be greater that the improvement observed in the combined 2 cycle procedure.

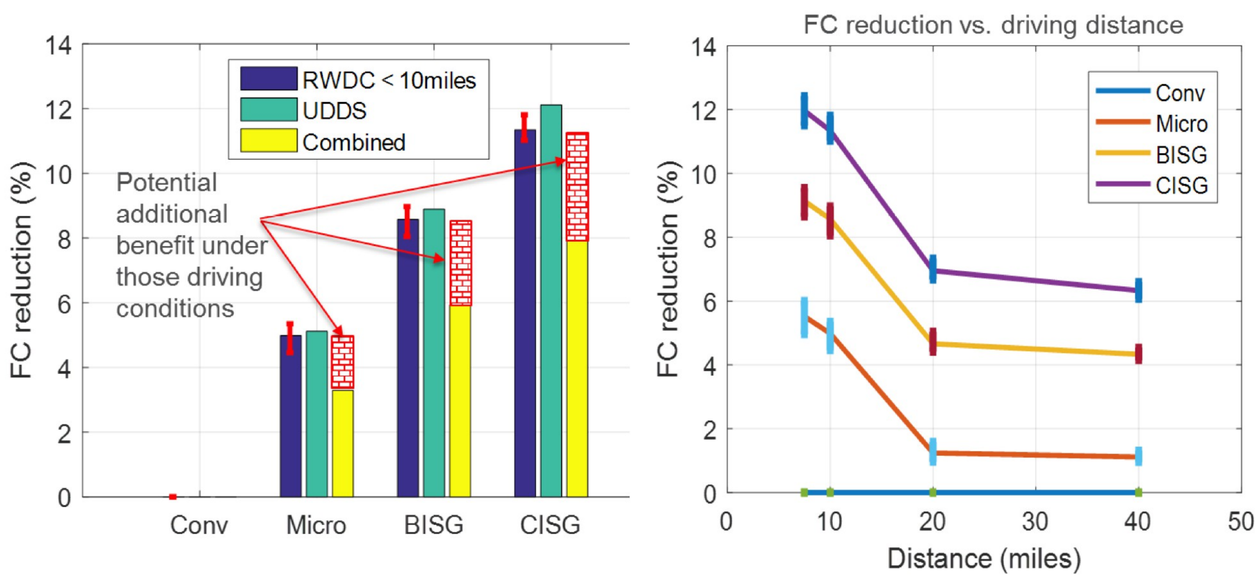

Figure 7. Driving distance has a good correlation to many other drive cycle properties.

The red textured region shown in Figure 7 shows the potential additional benefits of start-stop vehicles when driven on short trips.

As distance increases, the overall fuel consumed increase, and the fuel saved by avoiding idling will become a smaller percentage of the overall fuel consumption. Statistically significant parameters of the drive cycles are known to have clear trends with respect to driving distance based on previous work [10]. For this particular technology it would be relevant to specifically verify the impact of idle time on fuel consumption reduction.

3.3 Impact of Idle time

The percentage of idle time in a cycle is a good indicator whether the cycle is from urban or rural area. It will also indicate the usefulness of start-stop systems for that cycle. Idle time is expressed as a percentage of the total driving time, for various standard drive cycles in Figure 8. It also shows the cumulative fraction of idle percentage in the real world cycles considered for this study. Highway cycle has almost no idling time and UDDS cycle has close to 19% idle time. All standard cycles from US falls between these two cycle in terms of idle percentage. Almost 80% of the real world driving cycles from US too is within this range. Real world driving in US has a little over 12% idle time. This is computed by considering the total idle time against the total driving time recorded in the real world data sets. It should be kept in mind that long distance drives over interstates can significantly impact the overall idle percentage.

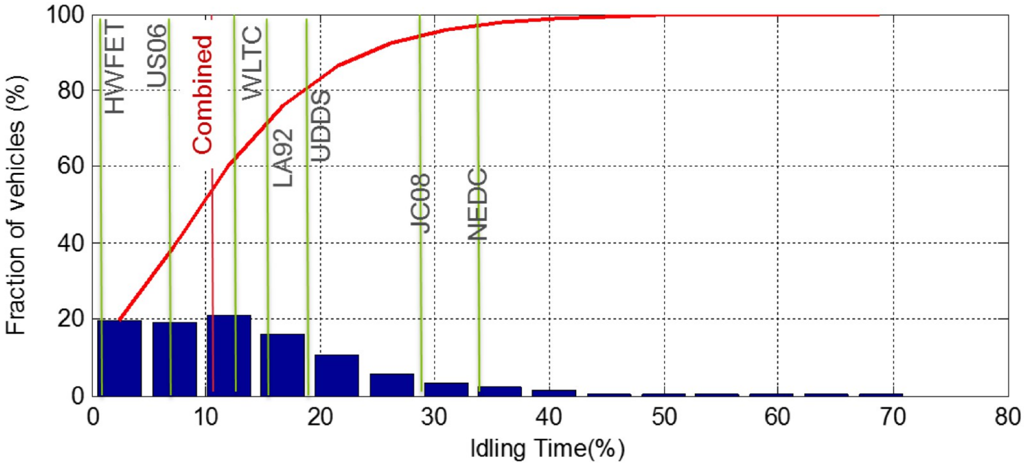

Figure 8. Idle-time of various standard cycles compared against that of real world driving data

The figure 9 shows the variation in fuel consumption reduction when drive cycle samples are chosen based on the overall idle percentage. Drive cycles that have longer idle times demonstrate significant fuel consumption reduction. However those cycles with very long idle percentages tend to be shorter, hence the quantity of fuel consumed is small.

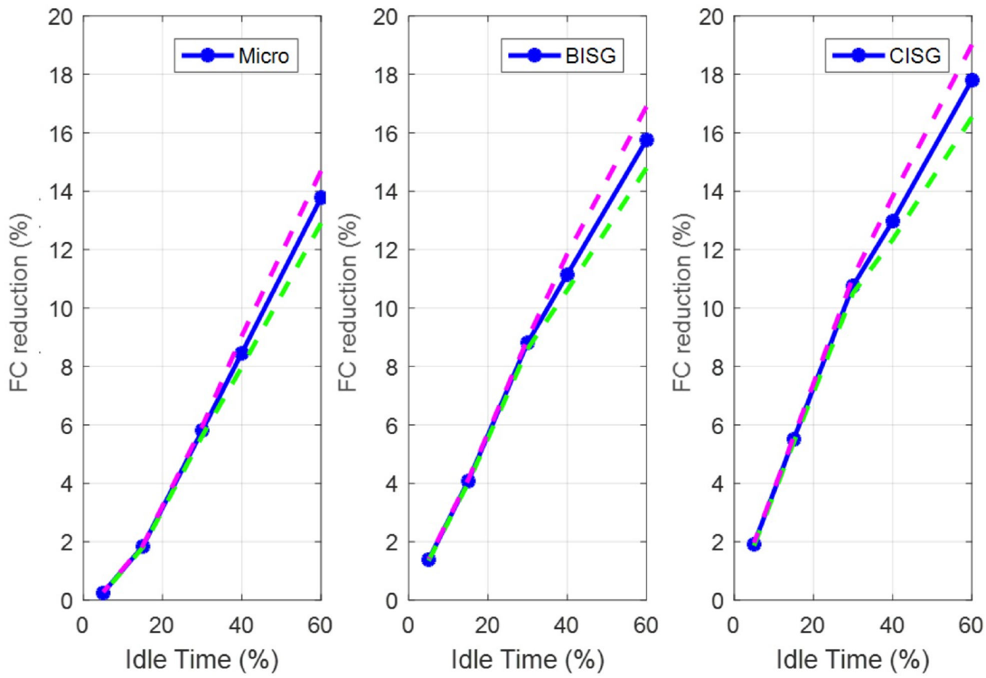

Figure 9. Fuel consumption reduction plotted against the percentage idle time for various start-stop technology implementations.

With these parametric sweeps, it is shown that start-stop systems are capable of fuel savings in drive cycles that have more idle time.

3.4 Comparing idle time percentages from other sources

EPA estimates 13.7% idle time in the fuel economy prediction tool named MOVES [11]. The combined two cycle procedure has 10.7% of idle time. For both these estimates, EPA assumes that the start-stop systems will be effective for only 67.3% of the time. Many vehicles will avoid start-stop functionality if engine is not completely warmed up, or if air conditioner or heating loads are above certain threshold levels. Some drivers might even manually disable the start-stop systems.

Data provided by Mercedes Benz to EPA for off-cycle credits shows close to 23% idle time for the vehicles that were recorded under that program [12]. However that data shows 52% usage for the start-stop system. The annual distance travelled by the vehicles in that dataset was about 30% lower than the typical distance driven by vehicles in US, which might suggest that it had more city driving than the NHTS driving. This comparison is shown in Table 1.

Table1: Various estimates for the fraction of time spent during idling in real world driving

Idle % estimates	Idle %	Usage %	Total (%)
EPA 2 cycle	10.7	67.3	7.2
EPA MOVES	13.7	67.3	9.2
Mercedes Benz	22.7	52	11.8
RWDC weighted average	12.1	100	12.1

In this study it is assumed that the start-stop systems can be effective at all times. Although the real world driving has higher idle time than the standard test cycles, a lower percentage reduction in fuel consumption is observed.

4 Conclusions

This study estimates the maximum fuel consumption benefits of idle reduction technologies in a midsize sedan, when simulated over drive cycles recorded from various parts of US. While there is no doubt that quantify of fuel saved by a start-stop system could increase as idle time increases, the percentage reduction is computed by considering the total fuel consumed during the drive. Fuel consumption is determined by a lot more factors than just driving time or idle time. The parametric sweeps of fuel consumption reduction against idle time and driving distance gives a good estimate of the real world fuel saving potential of start-stop systems.

A generic process is developed to estimate the real world energy impact of advanced technologies on a wide range of real world driving cycles. It is shown that the results are consistent across large number of drive-cycle samples. Real-world distribution for driving distances is considered to reflect the US driving behaviour. Based on this analysis, the real-world benefits of start-stop systems may actually be lower than the observed benefits on the regulatory drive cycles.

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