

Start/Stop Test Drive Cycle Design and Implementation in Challenging Markets: A Mexico City Case Study

Andres Toledo and Rodrigo Felix
 Ford Motor Company

ABSTRACT

Political and social trends in the automotive industry production and consumption have changed in the last decade, driving a demand for more efficient, low-fuel consuming, clean vehicles in most markets nowadays. Recently the demand for such vehicles has been increasing and emerging markets are no exception; automakers all around the world have invested heavily in developing new electrification technologies that would comply with the newer and stricter regulations and environmental policies, being Start-Stop systems one of the preferred approaches due to their lower complexity and cost compared to full and mild hybrids. Mexico stands out as a challenge for the implementation of this technology due to its wide range of altitudes, temperatures, traffic jams, and some other contributing factors that can hinder this type of application – especially in its bigger and more populated cities. Specifically, Mexico City and its Metropolitan Area - where more than three million people travel from the suburbs into the city, suffering up to six hours of travel each day - account for more than 50% of hybrid and electric vehicles sold in the entire country. This paper proposes a specific drive cycle for vehicles with a Start/Stop system, based on data collected from different vehicle classes driven under different conditions in Mexico City, with the objective of assessing the correct scope, design, and implementation of Start/Stop strategies in similar markets. The conditions under consideration could impose a challenge in the different subsystems that interact during an automatic shutdown and restart of an engine, such as climate control, injectors, battery, and transmission.

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INTRODUCTION

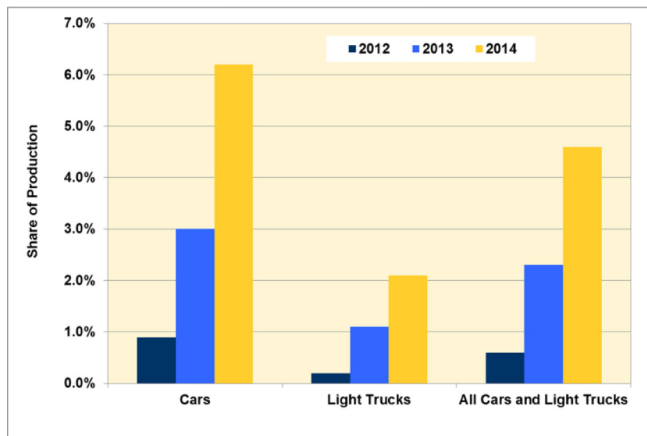
In recent years, OEM's have invested a great share of resources in order to develop newer technologies that meet the more stringent regulations that have been implemented due to newer environmental policies, which are commonly associated to concerns such as Global Warming and emissions of Green House Gases (GHG). Being reduction of exhaust emission gases and a better fuel consumption the main objectives of these regulations, automakers have taken great interest in the partial and total electrification of automotive subsystems as a mean of alternative propulsion that complies with these policies, while remaining cost effective, safe and easy enough to be driven by the common customer.

Start-Stop systems are one of the main strategies in production for current cars to meet these regulations. An automatic Start-Stop system allows the vehicle to automatically stop and start the engine during predetermined conditions with minimal intrusiveness from the driver during idling events in which fuel consumption can be reduced. Nowadays, this is commonly achieved by installing a more robust starter motor that can withstand a higher number of cycles; a higher performance battery is needed as well, being the glass-mat (valve-regulated) lead-acid batteries the preferred option due to their tolerance to deep discharges without reducing the useful life of the battery [4]. This allows the vehicle to handle electrical accessories,

the restart of the engine, and still remain with a healthy battery state of charge. Although it is commonly installed in mild and full hybrid vehicle, due to its lower complexity of implementation and lower associated costs it is currently being included as a feature in several standalone ICE powertrains with stop-start (known also as micro-hybrids), thus enabling this option to a broader widespread of customers. As of December 29, 2014, this feature was available in almost 5% of all new light vehicles being produced in the U.S. [Figure 1](#) shows a breakdown of hybrid vehicles production, with stop-start, percentages between model year 2012 and 2014.[5]

Despite being simpler than hybrid and electric powertrains, vehicles must meet specific conditions in order that the Start-Stop system operates correctly. From the simpler and more logical conditions of a car speed being zero, idle speed being nominal and brake pedal being pressed to a far more complex self-diagnosis [2] on several interacting subsystems provided by the PCM – such as Climate Control heating and/or A/C request, engine coolant temperature, battery charge and temperature, a minimum speed after the initiation of the system and every restart, no faults in fueling subsystem, etc. –, the vehicle must fulfill every single requirement in order to ensure that the feature will be capable of stopping and starting the vehicle smoothly, safely, and transparently enough without affecting drivability, meanwhile achieving the objective of reducing emissions and fuel consumption during idling.

PENETRATION OF NON-HYBRID STOP/START TECHNOLOGY IN NEW LIGHT VEHICLES



Note: 2014 estimates are preliminary.

Figure 1. Hybrid Vehicle Penetration 2012-2014 [5]

The main potential benefits of a Start-Stop system depend heavily of the time the vehicle spends at idling conditions. Regulatory drive cycles are enforced on production vehicles all around the world in order to comply with governmental regulations on emissions and fuel economy; however, since the markets vary from region to region, these drive cycles are not designed the same, which means that different drive cycles will follow different speed traces that resemble more their local market driving habits. All of this affects how much Start-Stop can contribute in terms of fuel consumption reduction for each drive cycle, depending on the number of stopping events and idle-off time during a specific cycle. For a NEDC cycle which has 22.6% idle time this would result in a predicted 3.3% reduction of fuel consumption in a mid-sized vehicle, but this benefit is reduced to a mere 1.6% on a FTP-75 cycle [6]. This is even further reduced to 1.1% in CAFÉ since it also takes into account the HWFET cycle results, which follows a highway speed trace with no idle stops.

MEXICO CITY CAR OWNERSHIP DEMOGRAPHICS

Studies from the last couple of decades have shown that there is a strong correlation between high income and urbanization of cities and their suburbs; this means that the more the habitants of certain city earn, the more prone they are to rely on private transportation. High income also leads to larger homes and larger parcels of land, which causes that suburban areas increase in size surrounding main urban centers. Although there are some clear exceptions in which cities rely more on public transport and/or alternate methods of mobility rather than car-ownership, such as New York and Zurich, the global trend leans towards an increased rate of private transportation due to decreasing prices and rising incomes, with more distances to be driven to the main central areas of cities. This is particularly exacerbated in the developing-world where there has also been a continuous population growth. In China, the number of cars per thousand people increased fivefold between 1991 and 2003, meanwhile in Latin America the number of registered cars increased by 8.4% between 2009 and 2010, compared to only 0.2% in the U.S. and 1.2% in Western Europe [9].

Mexico City Metropolitan Area – commonly known as MCMA, covering Mexico City and the surrounding 17 municipalities – has followed similar trends in terms of suburban area growth and vehicle availability. Both commercial housing and the vehicle fleet have increased and grown faster than the population itself. Population in the MCMA has increased during the last 50 years in such a way that it has led to an increase in the suburban area. During the 1950's and 1960's the majority of people lived in the central boroughs of the city, but between 1960 and 1970 other concentric areas increased their population numbers dramatically, such as Nezahualcóyotl and Ecatepec which went from 40,000 to 800,000 habitants in that lapse. Between 1990 and 2010 the Mexican national population experienced a growth of 38.26% – about 31 million people; however, the growth in the MCMA was rather uneven: while Mexico City (originally Federal District) increased its population numbers in 615,000 habitants, the State of Mexico (which is the main surrounding state and whose 17 of its municipalities are considered part of the Metropolitan Area) did the same with 5,360,000 new habitants [10]. In percentage, while Mexico City lagged behind the national population growth with 7.47%, State of Mexico surpassed it with 54.61%. If this trend continues for the present decade, estimates show that by 2020 the MCMA will have a population of more than 21 million people and expand itself between 38,000 and 56,000 hectares [1]. This inevitably derives in larger distances to be covered for those who must travel to the central areas of the city for their daily activities, which also increase the time spent travelling: just between 1972 and 1994 the travel time in the MCMA increased 12%, with 17 million hours daily [8]. That amounts to more than 2 million 8-hour work shifts spent on transportation.

Private car ownership in the region has grown as well: between 1980 and 2010 the number of cars and light-duty trucks has more than doubled, and between 2000 and 2010 that accounted for an increase of 2.4 million cars. Nevertheless, the distribution of this fleet remains concentrated in the center part of the city, where more than a half of the registered cars are owned by a third of its habitants. According to data from 2001, there were approximately 2.3 million registered private vehicles in the MCMA – 1.7 million registered in Mexico City and the rest in the State of Mexico. This total accounts for 71.81% of the total number of vehicles circulating throughout the region, although they only account for 16% of total trips performed each day. This means that the wealthiest areas in the western part of the city own most of the private vehicles been driven in the city. Despite the fact that there is a centralized concentration of vehicles, during that same time lapse the number of registered cars in 5 of the poorest municipalities augmented five times; this fact reasserts that potential drives will most probably increase in the areas that surround the city, many of them having the central urban areas as their destination.

Mexico City Driving and Environmental Conditions

Data gathered by the Mexican Association of Automotive Industry (AMIA) shows that Mexico City alone accounts for 43.20% of the total sales of electric and hybrid vehicles in the country between January and May of 2016 [7]. If we were to include the State of Mexico, then this number increases to 52.59% of the total sales during this same period. Although no distinction is made between

which types of hybrid (micro, mild, or full) is being sold, this data clearly shows that the MCMA is the region in which more than half of the total units of electric and hybrid vehicles are being sold; since hybrid vehicles tend to include Start-Stop applications as a default, there is a great opportunity of study in this specific region due to its complexity caused by diverse factors such as pollution, time spent in traffic, and driving habits, among others. All of these aspects have to be taken into consideration for a correct design and robust implementation of this feature into this intricate market. The full hybrid vehicle sales distribution in Mexico is shown in [Figure 2](#).

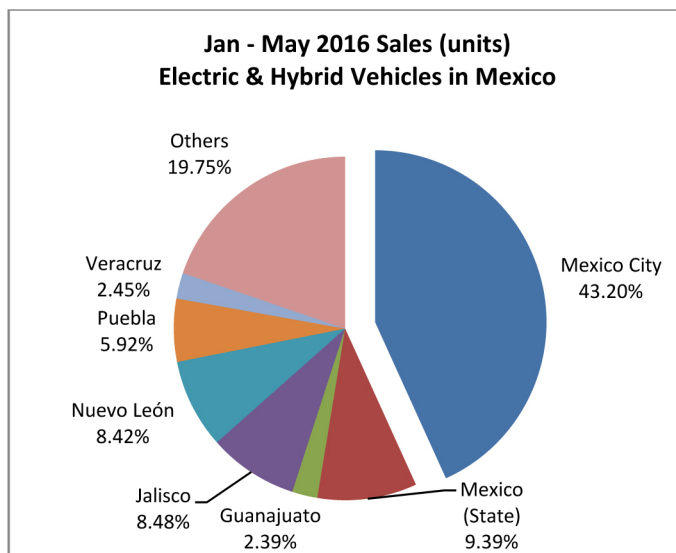


Figure 2. Hybrid and Electric Vehicles Sales for Mexico for the 2016 calendar year.[7]

Regional Drive Cycle Review

The justification for the crafting of a representative drive cycle is clear. If the cycle closely mimics the key aspects of vehicle operation within a given environment it will be a better tool for assessing the real world impact of its operation in terms of pollutant emissions and fuel consumption. For years the standardized EPA[11] and EU [12] drive cycles have been the work horse of the automotive industry, but they have been shown to not fully represent the realities of markets different to those which they represent [13]; furthermore the benefits of region specific drive cycles has been discussed extensively in literature [14] [15] [13] [16]. These works share common ground on the fact that each region, with its unique conditions and driving habits of their population, require cycles to inform governing authorities of the realities local vehicle-borne pollution. With this in mind a need to create a Mexico City Metropolitan drive cycle has been identified and already discussed [15].

Within this context it is necessary to mention that an in-use emissions drive cycle for Mexico already exists and is regulated by Mexican law through the instrument NOM-047-SEMARNAT-2014 [17], known as NOM-047 for short. The norm describes two different in-use emissions tests, a dynamic one meant for single driven axle vehicles (RWD or FWD) and a stationary one for all-wheel drive powertrains. These test procedures are used in the Mexico City Metropolitan Area (MCMA) and surrounding states, a region known

as CAME. This region and metropolitan area include within their territories mountain chains which impose additional loads on a vehicle which would then put NOM-047 under scrutiny in terms of a static test yielding representative emissions results. All of this considering that an analysis conducted in [18] concluded, albeit by means of numerical simulation, that road grades can impose an additional 1%-3% energy consumption penalty.

In parallel to the drive cycle state of affairs is the introduction into the Mexican market of hybrid and micro-hybrid vehicles; the latter being part of the subject matter of this work as their Stop-Start functionality is intended to cut down pollutant emissions whilst the engine is idling. Yet any benefit coming from such functionality is dependent on vehicle type and drive cycle [19] predicted that the benefit from Stop-Start, in terms of fuel economy, can be as much as 3.3% over NEDC, but only 1.1% for FTP/CAFE, due to differences in cycle idle time. The authors also elaborate on platform class being a factor since each one has its own defining traits.

In summary for a drive cycle to be representative of local conditions it must consider a myriad of factors to be truly representative of regional vehicular pollutant emissions. This work will focus its scope on considering powertrain technology, stop-start specifically, vehicle class, B through D, topography and urban, suburban and extra-urban traffic conditions during the drive cycle derivation process.

REAL WORLD DRIVE CYCLE DATA ANALYSIS

Once the governing factors to be used to rule over the design process were determined a specific review of the art was conducted. It was found that current efforts in the area of regional drive cycle creation employed the micro-trips methodology [16][20] and in some cases this was enhanced by the use of intelligent algorithms, such as Markov processes [21][22].

A micro-trip is defined as a segment of a drive cycle or trip where the vehicle is travelling. This segment has its boundaries set by a couple of idling periods which precede and follow the micro-trip. By dissecting a given full length trip into its micro-constituents it can be statistically analyzed in depth. Literature suggests using metrics such as average speed and acceleration, average micro-trip duration, percentage composition of the trip like percentage of time spent driving or at idle [20][16]. For this work an additional set microhybrid specific parameters were added to account for stop-start which resulted in the following list of parameters to be considered:

1. Average micro-trip driving speed
2. Average full cycle speed
3. Full cycle distance traveled
4. Peak driving micro-trip speed
5. Average driving micro-trip launch acceleration
6. Average driving micro-trip braking deceleration
7. Number of stop-start micro-trips
8. Duration of stop-start micro-trips
9. Average full cycle idle segment duration