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Application of engine intelligent start-stop system technology for heavy vehicle fuel saving

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Abstract. Diesel consumption costs are currently among the three main expenses in heavy vehicle fleets in Brazil, strongly affecting the total cost of ownership (TCO - Total Cost of Ownership). This work aims to present a case study of a start-stop system tested in a vehicle and a dynamometer engine developed by a company in the mechanical metal sector in partnership with the university. After interviews conducted during the customer discovery phase for this system, was possible to validate fuel consumption as the main expense within large urban bus fleets. An urban bus equipped with a manual transmission and a turbocharger, a diesel cycle engine with 7.2 liters of displacement, was defined as an object for a case study to prove the value proposition that the start-stop system about the fuel consumption e reduction. The urban bus would meet the limit of atmospheric emissions PROCONVE P7. The bus was subjected to tests in an urban cycle in the city of Curitiba under operating conditions in normal traffic. The results did present a reduction of 4,8% in diesel consumption, validating the hypotheses previously raised. The cycles ETC, WHTC, and urban performed on the vehicle were chosen for dynamometer tests. The engine was installed on the dynamometer without an after-treatment system and the results in the urban cycle present a reduction of 3,1% in CO2 emissions and 57,1 % of particulate matter. The result of this study shows the importance of concurrent engineering in product development, enabling the development of prototypes in conjunction with customer discovery studies.

Keywords: Start-Stop system, fuel economy, emissions, product development, usability.

1 Introduction

Being developed by a team in a start-up model in a metal mechanic industry, a Start-Stop system project for buses and urban cargo vehicles is under development. Within the validation period of the project, about 140 interviews were conducted by the project team in the Brazilian territory to assess the needs and concerns of the managers of large fleets of buses. During these interviews, it was found that the three largest fleet expenditures are in a row: vehicle maintenance, the cost of managing tires, and

especially fuel consumption, the latter being the largest market demand for the generation of new technologies of the economy.

During the research, there was a period in the validation process that needed to be contextualized about the scope to be addressed, short-distance transport in an urban cycle or long-distance transport encompassing the rural perimeter. Since the Start-Stop system is defined as a system that switches off the engine after a few seconds of idle and automatically turns it back on, for the definition of this scope the challenge was to find evaluation criteria that justified the most profitable cycle for the product.

Therefore, three evaluation criteria were determined: the number of vehicles per km² in the region, the number of inhabitants of the perimeter, and the percentage of traffic in the environment, and the product. The greater the traffic the greater the number of stops that will be subject to the vehicle and consequently more benefits will be produced by the system.

Thus, the problematization that addressed this research was the high expenses of the urban bus fleets about the fuel consumption, promoting a product that helps in saving diesel and consequently reducing TCO. Combined with the market's need, technologies favorable to the reduction in fuel consumption, and the urban scene as a promising environment for product development, there is also the issue of environmental and energy efficiency laws as beneficial aspects for this project. Examples of Brazilian legislation can be cited:

- Law 13.775 or ROTA 2030, a national incentive program for R&D projects to stimulate the development of energy efficiency solutions in vehicle production. [1]
- PROCONVE P7, equivalent to the European standard EURO 5, establishes further reductions in the emission of gases from the burning of diesel such as nitrogen oxides (NO_x), hydrocarbons, and carbon monoxide (CO), and particulate materials. [2]

Within the context presented above, it is justified the use of a Start-Stop system as a TCO optimization tool with application in the retrofit system of trucks and buses of the urban cycle. Therefore, we proceed to the prototyping and experimentation phases of the system through case studies, objects of research in this article.

The methodology addressed in this article aims to present the Start-Stop system for use in buses and urban cargo vehicles as a TCO optimization tool. Additionally, the research exposes the results obtained in experiments with the dynamometer and test performed with a bus in the urban cycle. To this end, the document is structured into three main topics: (i) This introductory chapter containing the context of the project, the motivations that led to the development of the research, the objectives; (ii) A literature review for structure the technological background; (iii) the structure development for the system (iv) A topic exposing the experimental procedures developed in a dynamometer and the case study with a bus in an urban cycle; (v) An item with the discussion about the results obtained from the experimental procedures; (vi) And the conclusions and suggestions for next searches.

2 Technological Background

Studies of technologies in commercial vehicles aimed at reducing fuel consumption began in the 1990s; primarily with strategies to reduce engine use over long periods at idle. Among the harms of the gradual use of idling in vehicles without load can be highlighted: the reduction of the useful life of the internal lubricants of the engine leading to an increase in the frequency of oil change. The emission of pollutants such as particulate materials, nitrogen oxides (NOx), and carbon dioxide (CO₂) [3].

Over time, more robust systems have been developed to minimize these problems, with the introduction of ECUs (Engine Control Unit) and sensors in the market more variables have been able to be integrated, improving the performance of projects. Currently, the Start-Stop systems, in general, are controlled by an electronic central, which modifies the functions of the alternator for the starter when requested by the system, in addition to these instruments, the system also requires a differentiated battery from the conventional ones. In addition to allowing, the driver inactivates the system and uses the vehicle in the usual way, pressing only one button on the panel [4].

The system operating logic starts from the identification by the Start-Stop of some factors: if the vehicle is at rest; if the driver has his foot on the brake and without activating the clutch or accelerator, if the gear is in neutral, if the battery level is suitable for a new start and depending on the system, other variables, such as belt buckling. With all these situations occurring, the engine is turned off until the clutch pedal is pressed again, or when the driver removes his foot from the brake pedal, depending on the product algorithm [4][5].

Coupled with the harms of the gradual use of idling vehicles, there is the factor of congestion in the urban perimeter as an impact on excessive fuel consumption. In research carried out by Samaras et al., a method was implemented to study the impact of traffic jams on fuel consumption for diesel-powered cars. For this, the traffic simulation tools CRUISE and TSS AIMSUM were used to analyze pollutant emissions and fuel consumption. Such tools allow the creation of detailed vehicle simulations to predict fuel consumption and emissions according to the second, considering the standard gear change speed. The implementation of the platform revealed that about fuel consumption in a normal congestion scenario adopted by the software, in the situation of free traffic there was a saving of 25.8% in fuel consumption, whereas in the situation of high congestion there was an increase of 20.9% in this consumption. This result demonstrates a needy scenario in the development of technologies that allow optimizing this scenario of fuel consumption in congestion situations. [6]

Other research approaches using the Start-Stop system as an economic tool and it has pointed out its benefits, both financial and environmental. In a simulation study on a diesel engine carried out by the technical university of Istanbul, it was possible to prove a reduction in fuel consumption of 0.16 liters for every 100 km traveled, in addition to a benefit of 4 gr / 100 km of particulate matter emitted [7].

In the research carried out by [8] from the Polytechnic University of Madrid, using two vehicles with a diesel engine, some results are more expressive. A reduction of up to 20% in CO₂ emissions in urban traffic at a speed of 15.5 km / h, in addition to an estimated reduction in fuel consumption of 12%. To reach these conclusions, tests were

carried out on two urban circuits, simulating the traffic of the city of Madrid. The tests used two SUV (Sport Utility Vehicle) vehicles, a conventional model and a model equipped with a Start-Stop system [8].

Another example was presented at the sixth international conference on measurement technology and mechatronics automation. The research highlighted the advantages of using the system in an urban cycle. In the experimentation, a sedan model vehicle was used, traveling along a path following the guidelines of the NEDC (New European Drive Cycle. It is a driving cycle designed in 1997 to assess the emission levels of engines and the economy of fuel and passenger cars (excluding light and commercial trucks). The test was carried out in 1,180 seconds, including the 14 times the engine was stopped by the Start-Stop system, resulting in a vehicle standby time of 280 seconds. As a result, the study was able to prove the fuel economy of 8.31% [9].

In the context of the Start-Stop system on urban buses, research was developed to predict the damage that can occur in the starter motor in the thermal field, since the abrupt and repeated thermal variation that the Start-Stop system imposes could cause future problems in the component. To this end, a thermomagnetic model was developed to study the three scenarios that thermally damage the starter motor: the loss of copper generated by the current in the windings, the reduction of the ferromagnetic core from the floating main magnetic field, and the mechanical loss caused due to ventilation defects and friction between the bearings.[10] The study concluded that the main cause of these component damages is linked to the high-frequency on-off conduction signal produced by the Start-Stop system. With this, the proposed analysis method will serve as an aid in the optimization of the control algorithm to avoid future wear and this element [10]. The main results of studies carried out proving the benefits of the start-stop system are presented in Table 1.

Table 1. Main Start-Stop studies results.

| Study origin | Used vehicle model | Main results |
|---|---|--|
| Technical University of Istanbul - Turkey | A simulation of a diesel engine via software | Fuel economy of 0.16 liters.[7] |
| Polytechnic University of Madrid – Spain | Sport Utility Vehicle (SUV) - diesel engine | A reduction of up to 20% in CO2 and fuel economy of 12% [8]. |
| Conference of Measuring Technology and Mechatronics Automation - China | A sedan model passing vehicle – a hybrid engine | A fuel economy of 8.31%. [9] |

Another methodology that was also used in Start-Stop studies is the User Experience (UX) application validation process, to develop a product tailored to the customer's needs. A study developed was used or the same method of adapting system improvements to start based on feedback received by users [11]. According to this study, how the driver behaves in the controls of a vehicle, such as pedals and gearshift are not uniform and concerning the region of study. For the authors, the use of the Start-

Stop system is very well adapted to the driving standards, but it must undergo changes to be used in the Indian scenario. There is no ideal definition for the concept of User Experience, there are several accepted explanations. In summary, UX can be collected as a collection of information about the user's internal state (expectations, needs, and motivations), system resources (objective, complexity, and functionality), and the context in which the interaction occurs [11].

In this context, a survey uses findings from previous work carried out by the same authors and surveys using questionnaires used in UX, improving the system based on the user's needs and still guaranteeing the benefits of the system. However, the actual benefits from the Start-Stop system in real-time vehicle driving conditions in the city can deviate from the estimated/validate range, due to the various design factors like a design for safety and design for functionality [12].

Regarding the Brazilian scenario in the use of this product, there are many advantages which the main one is the reduction of fuel and tends to the immediate interest. In addition to the benefits to the end-user, this system also generates advantages for companies about tax incentives since it is a product favorable to environmental issues. Among them, consideration can be given to obtaining carbon credits. Besides, the technology has the advantage of not requiring training or differentiated behavior from the user, because once driven inside the vehicle, the driving behavior follows the guidelines of a conventional car [13].

3 Engine intelligent start-stop system technology for heavy vehicle fuel saving

The Start-Stop prototype installed in the vehicle consists of a control unit, battery sensor, on/off button, an ignition activation box, and an electrical harness for connecting the components (detail in Fig 1.).

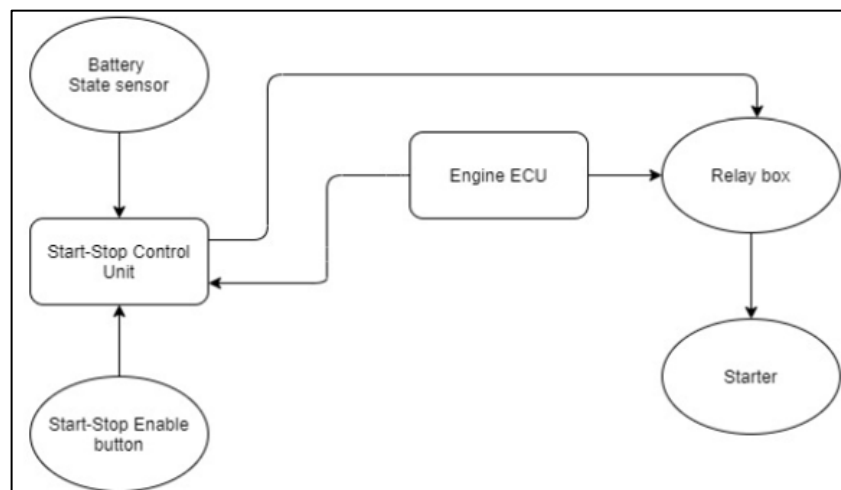


Fig 1. Start-Stop Architecture.

The Start-Stop control unit “works” in parallel with the diesel engine control unit. It exchanges information with the vehicle's ECUs to manage Start-Stop's operating actions. The battery sensor monitors the current, voltage, and temperature and, using an algorithm applied to the control unit software, evaluates the battery charge conditions to perform the next start on the diesel engine in case the battery is not fit (not OK) to perform the next engine start, the Start-Stop does not stop the diesel engine. The Start-Stop on/off button is intended to turn the Start-Stop off and return the vehicle to its original operating condition. The Start-Stop's operating principle is as simple as it is effective when the vehicle stops, and the diesel engine is automatically switched off. To move forward simply press the clutch pedal. For the Start-Stop to start operating, the engine cooling temperature must be above 60 °C. Five variables were necessary to be validated to turn off the diesel engine, they were: engine temperature above 60°C, battery condition available, diesel engine rotation at idle, vehicle speed equal to zero, and the gear in a neutral position. More specifically about the state of the Kivik battery, discusses this topic considering the monitoring of its state of charge as a preponderant factor to determine the normal conditions of its status. The state of charge can be determined from the measurement of voltage, current, or impedance [14]. Therefore, after these five conditions were met, the Start-Stop waited 4 seconds for the diesel engine to reach idle speed, and thus shut down safely. For the engine to start, it was only necessary to activate the clutch pedal. If the vehicle stayed more than 10 minutes in this condition, it was necessary to start the engine with the ignition key.

4 Validation of Engine intelligent start-stop system technology for heavy vehicle fuel saving in an urban public transport vehicle

4.1 Vehicle

An instrument for the case study was defined as an urban bus (shown in Fig 2.) with the date of manufacture in 2013 and model 2014. Containing a total load capacity equal to 16,000 kg, equipped with a manual transmission and a diesel engine turbocharged with 7.2 liters of cylinder capacity, meeting the limit of atmospheric emissions PROCONVE P7. The vehicle used in the test had already covered approximately 250.000 km. Before running in, instrumentation of the important features for evaluating the Start-Stop system was performed. To assess the possible deterioration of the starter and batteries, these components were replaced with new parts before the start of tests on the vehicle. In tests where the bus needed to be loaded, the vehicle was weighted with 2,200 Kg.

For data collection, the following equipment was used

- Temperature: ETAS ES420.1 – Thermo Module
- Current, voltage and pressure: ETAS ES 410.1 – A/D Module
- CAN line: ETAS ES592.1 – Interface Modules

Vehicle speed and engine speed were also recorded using the CAN line. A visual fuel level indicator was installed through a transparent flexible tube connected to the fuel tank and affixed to the side of the bus near the vehicle's fuel nozzle. This tube

contained a mark, which was the reference for the full tank. In this way, it was possible to standardize the fuel supply process.



Fig 2. Urban Bus for Prototyping

4.2 Dynamometer

For the dynamometer tests, a diesel engine turbocharged with 7.2 liters of the same engine family as the vehicle was used. This engine had a compression ratio of 16.9: 1, with peak pressure in the cylinder of 180 bar. Its maximum power was 165kW at 2200 rpm and the maximum torque was 861 Nm at 1400 rpm, idling around 700 rpm. The diesel injection system used was from the Bosch brand, consisting of a CP3.3NH pump, a CRIN3 injector with a maximum injection pressure of 1800 bar, and an EDC7 control unit. The Dynamometer tests were carried out at the Robert Bosch LTDA Engine Laboratory, located in Curitiba, which has an asynchronous alternating current dynamometer with induction control technology, commonly known as an active dynamometer (detail in Fig 3.).

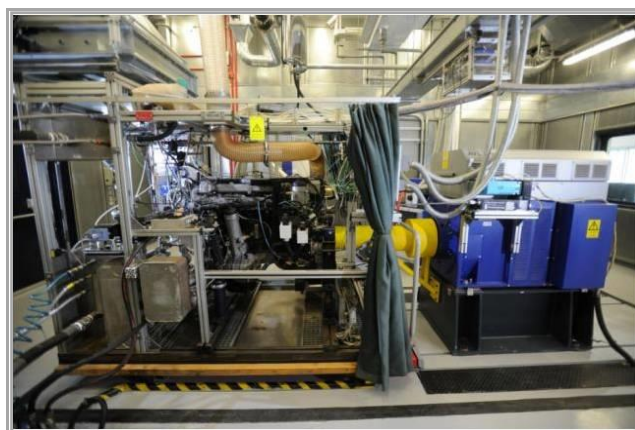


Fig 3. Engine assembled on a dynamometer

The first one is an analyzer that contains a flame ionization detector, intended for the analysis of total hydrocarbons (THC), the principle of which is the measurement by ionization of carbon atoms in a lit hydrogen flame exposed to an electric active field. The second analyzer is intended for the analysis of nitrogen oxide (NO_x), where there is a chemiluminescence detector. The measurement principle is by emitting light from NO₂ molecules that return to a lower energy state. A photomultiplier counts the number of photons, which are proportional to the amount of NO in the sample. The third analyzer is intended for the analysis of carbon dioxide (CO₂) and carbon monoxide (CO), it contains an infrared detector whose measurement principle is the absorption of non-dispersive infrared.

4.3 Test validation methodology

This research was divided into two distinct stages, the first stage being carried out on the vehicle to evaluate the functioning, the reduction of fuel consumption, and the wear of the starter. The second stage was performed on a diesel engine installed in the dynamometer for a detailed evaluation of the effect of the Start-Stop on the engine emissions, as well as measuring with the aid of specific equipment the fuel consumption in test cycles widely used for homologation of cycle engines diesel.

The first stage. Initially, five measurements of fuel consumption were performed on the vehicle with the aid of a graduated burette. We prepared an apparatus to introduce the diesel supply hoses to the engine and return to the tank in a properly calibrated graduated burette. We fill the burette and with a vehicle parked inside the Laboratory, we start the engine. We leave it idle, waiting for it to reach a temperature of 60°C. We turn on the headlights to consume electricity during the tests. When the diesel level reached the 500ml mark, we started the stopwatch. When the diesel level reached 200ml, we stopped the timer, so it was possible to measure diesel consumption at idle.

Following, an external route of 20 km was defined in the city of Curitiba (detail on Fig 4.). This city was chosen because it is considered a large metropolis in the southern region of the country (it has more than 1,900,000 inhabitants) [17]. It has a city with relevant vehicle traffic, and it has the highest concentration of interviews carried out in the customer discovery phase. In addition, a partnership was established with an urban bus fleet company in the city, which provided one of its vehicles for the tests to be carried out. Thus, we travel 6 times a day in a period of 32 working days, which allowed us to cover different traffic times and traffic conditions. We ran alternately 24 days with the Start-Stop running, 6 of which with the vehicle loaded. We traveled 8 days with the Start-Stop off, 2 of these days with the vehicle loaded, to compare fuel consumption modes.

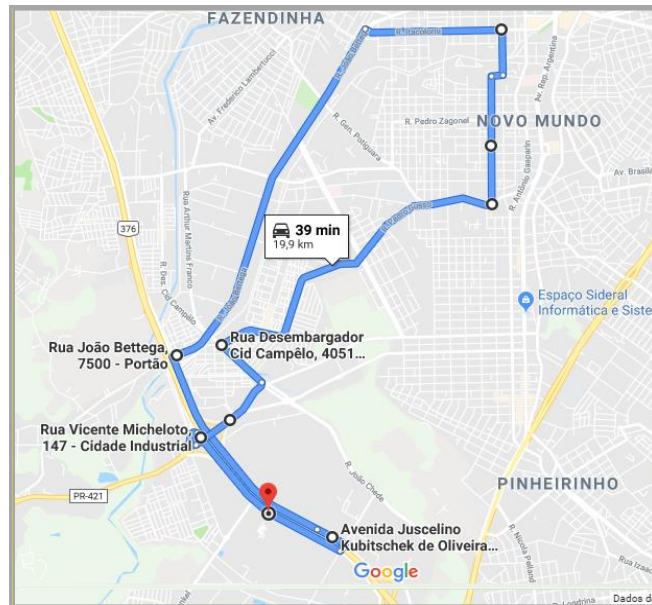


Fig 4. External Route

After tests on the external route, we created a cycle in severe operation in a controlled environment. In this way, we defined three equidistant stops at the test track, which is 784 meters long. The cycle consisted of thirty laps of the test track, stopping at each point, and following the door opening process described above. We performed this procedure with the vehicle loaded, which allowed us to evaluate the Start-Stop functioning under a condition of use very similar to that of a mining company.

Second Stage. The diesel engine was mounted on the dynamometer installation trolley, following the internal procedures of the Engine Laboratory. In this case, the starter, battery, and vehicle components were not installed, as they are not necessary for the diesel engine to operate on the dynamometer. In addition to the various instrumented characteristics required by specific standards, we added for monitoring the reading of pressure and temperature of lubricating oil before the turbocharger and temperature of this same oil after the turbocharger. In the dynamometer, there was no need to install the components of the Start-Stop, because the asynchronous dynamometer allows applying the stops/starts in the diesel engine via the equipment control software. The choice of dynamometer test cycles for statistical evaluation considered the need for the cycle to go through the idle condition. Thus, the following cycles were chosen:

- **World Harmonized Transient Cycle (WHTC):** is the cycle intended for the EURO VI level of emissions, it is based on the world standard of the real use of heavy commercial vehicles. The total cycle time is 1800 seconds, 296 seconds of idling speed corresponding to 16.44% of the total time.[15]
- **European Transient Cycle (ETC):** is used for emissions approvals for the PROCONVE P7 (EURO V) limits, the cycle is divided into three parts, the

first part being the simulation of the urban cycle, the second rural cycle, and the third part motorway cycle. The total cycle time is 1800 seconds, with 118 seconds in idle speed corresponding to 6.55% of the total time.[16]

- **Curitiba urban cycle:** based on tests carried out on the 20 km external route with the loaded prototype vehicle. This cycle was recorded and transposed to the dynamometer programming. It corresponds to the initial 1800 seconds of the route, with 499 seconds in the idle rotation that corresponds to 27.72% of the total time. Ten tests were defined for each cycle, five tests with Start-Stop on and five tests with Start-Stop off.

5 Discussion of results

5.1 Fuel consumption results applied in the physical Vehicle

The results obtained during the tests on the 20 km urban cycle in the city of Curitiba are shown in the table below. Table 1 contains split data for the external route and the internal test track. The first line corresponds to the data with the vehicle empty. The second line presents the data with the loaded vehicle and finally, in the third line the results with the loaded vehicle in the tests carried out on the proving ground.

Table 2. Fuel Consumption results

| Place | Load | Start/ Stop | (Km) | (L) | (L/ 100Km) | Dif. | Dif(%) |
|-------------------|-------|----------------|-------|--------|---------------|------|--------|
| External Route | Empty | OFF | 434.1 | 177.75 | 40.95 | 2.41 | 5.9% |
| | | ON | 884.3 | 340.8 | 38.54 | | |
| | Full | OFF | 85.5 | 36.6 | 42.81 | 1.92 | 4.5% |
| | | ON | 500.9 | 204.8 | 40.89 | | |
| Indoor Track | Full | OFF | 21.9 | 11.8 | 53.88 | 2.08 | 3.9% |
| | | ON | 22.2 | 11.5 | 51.80 | | |

The results show that with an empty vehicle in urban traffic it is possible to achieve a significant reduction of 5.9% in diesel consumption. This is a great example of low-occupancy city bus lines. Another significant aspect is the reduction of 4.5% in diesel consumption for the loaded vehicle. This is a typical example of urban bus lines with an occupancy rate above 70%. In a correlated and referential way, it is possible to compare this consumption reduction to urban delivery trucks that have similar diesel engines. The internal cycle carried out on the proving ground can be compared to the cycle of a mining company, which has several stops, in short, traveled spaces. In this cycle, there was a 3,9% reduction in diesel consumption. Calculating the average reduction in diesel consumption of the three cycles performed, the value of 4.8% is obtained. Transposing this result to a vehicle that travels 300 km/day with a consumption of 2.34 km / l, we would have savings of 2.215litress per year. Extrapolating this result to a fleet of 100 vehicles, we would obtain an annual reduction

of approximately 221.538 liters of diesel, which makes the solution a great option for reducing total costs of ownership (TCO).

5.2 Fuel consumption results applied in the Dynamometer

In dynamometer tests, was possible to verify the Start-Stop impact of about five pollutants, in addition to fuel consumption. The emissions data are presented in grams per kilowatt-hour (g/kWh) and the mass consumption of diesel (kg).

- **Idling fuel rate** - Through a database, it was possible to survey the diesel consumption rate measured in a dynamometer concerning the engine capacity. It is worth mentioning that there is a difference between the reading of this consumption rate in the vehicle and the dynamometer. Normally the engine is not installed with all components on the dynamometer, such as a compressor. This fact makes the consumption measured in a dynamometer normally lower than the consumption measured in a vehicle.
- **WHTC Cycle Results** - Table 2 detailed the results obtained in the WHTC tests. The “On” column represents the average of the five tests performed with the Start-Stop in operation. The “Off” column represents the average of the results with Start-Stop off. The last column corresponds to the difference between the results. In this cycle, there was a significant reduction of 12.1% in the emissions of particulate matter (PM), 1.3% in the emissions of carbon dioxide (CO₂), and 8.2% in the emissions of total hydrocarbons (THC).

Table 3. WHTC Emission Results

| Gas | Unit | On [avg] | Off [avg] | Dif [%] |
|-----------------|---------|----------|-----------|---------|
| CO | [g/kWh] | 1.3262 | 1.3828 | - 4.1 |
| CO ₂ | [g/kWh] | 676.8292 | 685.8236 | - 1.3 |
| THC | [g/kWh] | 0.2154 | 0.2346 | - 8.2 |
| NOX | [g/kWh] | 7.5472 | 7.7910 | - 3.1 |
| PM | [g/kWh] | 0.0245 | 0.0278 | - 12.1 |
| Fuel cons. | [kg] | 3.2810 | 3.3520 | - 2.1 |

- **ETC Cycle Results** - Table 3 detailed the results obtained in the ETC tests. The “On” column represents the average of the five tests performed with the Start-Stop in operation. The “Off” column represents the average of the results with Start-Stop off. The last column corresponds to the difference between the results. In this cycle, there was a 9.5% reduction in particulate matter (PM) emissions and 3.3% in total hydrocarbon emissions (THC). There were a small increase in the order of 2.5% in carbon monoxide (CO) emissions due to two peaks when the diesel engine restarts. To compensate for this peak emission, the engine must remain off for a longer time during the cycle. This increase is not seen in the other cycles precisely because they remain for a longer period in idle speeds and thus compensate for what was emitted in the emission peaks of carbon monoxide (CO) at the restart of the diesel engine. The small increase perceived in this cycle does not influence the total carbon monoxide (CO)

emissions, as its emission limit is much higher than that measured in the dynamometer.

Table 4. ETC Emission Results

| Gas | Unit | On [avg] | Off [avg] | Dif. [%] |
|-----------------|---------|----------|-----------|----------|
| CO | [g/kWh] | 1.1414 | 1.1132 | 2.5 |
| CO ₂ | [g/kWh] | 695.0372 | 696.3192 | - 0.2 |
| THC | [g/kWh] | 0.1712 | 0.1770 | - 3.3 |
| NO _x | [g/kWh] | 8.6890 | 8.7884 | - 9.5 |
| PM | [g/kWh] | 0.0135 | 0.0149 | - 9.5 |
| Fuel cons. | [kg] | 5.6080 | 5.6360 | - 0.5 |

- Curitiba Urban Cycle Result** - Table 4 detailed the results obtained in the Curitiba Urban Cycle tests. For these results, 111 hours of test on the bus, with 1948 km covered and 4441 engine combustion starters. The “On” column represents the average of the five tests performed with the Start-Stop in operation. The “Off” column represents the average of the results with Start-Stop off. The last column corresponds to the difference between the results, as shown in the table below. In this cycle, which represents the closest proximity to the actual condition of use of the vehicle, there was a significant reduction of 57.1% in emissions of particulate matter (PM), 3.1% in emissions of carbon dioxide (CO₂), of 9.2% in nitrogen oxide (NO_x) emissions and 29.6% in total hydrocarbon (THC) emissions.

Table 5. Bus Cycle Emissions Results

| Gas Component | Unit | On [avg] | Off [avg] | Dif. [%] |
|-----------------|---------|----------|-----------|----------|
| CO | [g/kWh] | 0.6570 | 0.8388 | -21.7 |
| CO ₂ | [g/kWh] | 669.8236 | 690.9522 | - 3.1 |
| THC | [g/kWh] | 0.2396 | 0.3402 | - 29.6 |
| NO _x | [g/kWh] | 6.9924 | 7.7014 | - 9.2 |
| PM | [g/kWh] | 0.0154 | 0.0360 | - 57.1 |
| Fuel cons. | [kg] | 2.3910 | 2.5100 | - 4.7 |

In terms of emissions, the results achieved show that, in addition to being extremely economically viable, the Start-Stop proves to be a great tool to reduce emissions of polluting gases in large urban centers. These results provide an opportunity for owners of large fleets concerning the carbon credits that can be obtained with this significant reduction in polluting gases.

6 Conclusions

This work presented promising results for a better understanding of the Start-Stop technology implemented in the fleet of commercial vehicles of the urban cycle. The hypothesis validation carried out with hundreds of interviews with fleet owners located in several cities in Brazil, helped in the scope of this research. In the first stage of the

work, the installation of the components in the vehicle was carried out simply and the operating logic proved to be very effective. It was possible to show the potential of the system in a real cycle of urban drivability since the route defined in the city of Curitiba reflects this condition very well. The procedures used to perform the tests on the vehicle, allowed us to evaluate some different modes of operation and thus compare the results with the vehicle empty, loaded, and in a severe cycle of use, simulated in a controlled environment.

The expressive 5.9% reduction in diesel consumption in tests with the empty vehicle was a great example to compare with vehicles that run on urban lines with low occupancy rates. On the other hand, when we covered the same route with the loaded vehicle, we could see a 4.5% reduction in consumption. This condition can be compared to vehicles that use more than 70% load capacity in their operation. The purpose of carrying out the tests on the test track was to evaluate a cycle that resembled the operation of a mining company, and in this way, we noticed a 3.9% reduction in consumption. When calculating the average consumption reduction, which was 4.8%, we make sure that the technology can reduce total costs of ownership (TCO). It was possible to verify that the Start-Stop technology imposes a lower severity on the starter motor since the diesel engine starts with the engine at the working temperature, that is, above 60°C and this fact contributed positively. The starter used in this research was designed for approximately 24,000 starts and in the evaluation carried out there was a projection of linear wear that would withstand over 38,000 starts, thus extending the brush life by 60%. On other hand, a point that needs to be taken considering is the high number of starts that the vehicle starts to perform in a shorter period. This condition brings the need to reduce the periodicity from 24 months to 8 months after the maintenance of the starter. The cost involved in this reduction in maintenance periodicity is very low concerning the financial gain obtained by reducing diesel consumption.

The second stage of the research carried out with the diesel engine on the dynamometer, was very enriching because it was possible to measure with extreme precision the reduction in emissions of polluting gases and confirm the reduction in the consumption of diesel in the chosen cycles. For example, in the ETC cycle, the reduction was in the order of 9.5% in emissions of particulate matter (PM) and 3.3% in emissions of total hydrocarbons (THC). Even the small increase of 2.5% in carbon monoxide (CO) emissions measured in this cycle, did not present itself as a demerit because the average of 1.1414 g/kWh is 71.7% far from the PROCONVE P7 emission limit which is 4 g/kWh. In the WHTC cycle, there was a significant reduction of 12.1% in emissions of particulate matter (PM), 1.3% in emissions of carbon dioxide (CO₂), and 8.2% in total hydrocarbon emissions (THC).

In the urban cycle of Curitiba, which is the closest to the actual condition of use of the vehicle, there was a surprising reduction of 57.1% in emissions of particulate matter (PM), of 3.1% in emissions of carbon dioxide (CO₂), 9.2% in nitrogen oxide (NO_x) emissions and 29.6% in total hydrocarbon (THC) emissions. It was also possible to confirm the reduction in diesel consumption, which was around 4.7%.

Given the results exposed in this work, the Start-Stop system presents itself as a promising solution to reduce diesel consumption in urban fleets, positively affecting

total property costs (TCO), as well as significantly reducing emissions of polluting gases emitted by the engine. The same starting number that is imposed on the starter is also imposed on the battery, so an in-depth study of the impact on this commercial vehicle component is suggested.

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