CHALMERS

Influence on driving style and fuel consumption with powertrain calibration

Bachelor of Science thesis in the Mechanical engineering programme

AID MUJANOVIC

Department of Applied Mechanics
Division of Combustion
CHALMERS UNIVERSITY OF TECHNOLOGY
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SAAB 9-3, 2.0l T AT XWD, Saab Automobile AB.

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Preface

As a final moment in the mechanical engineering education at Chalmers University of Technology, a thesis work is done on behalf of a company or university. The thesis work covers 15 credits, of the total 180 credits which the education consists of, and includes various areas of work such as planning, literature studies, practicalities and presentations of results. This thesis work is carried out in the spring term 2011 for Saab Automobile AB and has been executed at Saab in Trollhättan as well at the university's department of applied mechanics.

I would like to express my gratitude to everyone at Saab who helped me in some way or another. You have always had the desire and time to discuss problems and your commitment has been an important source of inspiration to work hard.

Thank you Sven B Andersson, associate professor in the department of applied mechanics, for sharing your knowledge within this area and your support throughout the working process. Birger Schlaich, I am very grateful to you for giving me the opportunity to work with this thesis at Saab. You always gave me tips, advice and invited to discussions that made work to go forward.

Sammanfattning

Det utförda arbetet på SAAB Automobile AB i Trollhättan handlar om att studera ifall det är möjligt att införa ett nytt körläge med fokus på en ekonomisk bilkörning. Det här läget, som kom att kallas för ECO-mode (ECO = Economy), är tänkt att underlätta och råda föraren under körningen. Detta genom att exempelvis i bil med manuell växellåda, tipsa om vilken körväxel man skall köra på, i den tänkta, assisterande displayen i instrumentpanelen, och i bil med automatisk växellåda ge föraren maximala möjligheter att köra ekonomiskt. Själva ECO läget initierades utav att CO_2 credit utlovats ifall biltillverkarna kunde påvisa en positiv real life förbrukning. I praktiken skulle detta innebära att man exempelvis kunde dra av ett par gram (CO_2-utsläpp) vid certifiering och därmed finns all anledning att studera detta område.

I denna undersökning är man intresserad av vilka effekter ECO läget skulle bidra med i en bil med automatisk växellåda. Ett eventuellt införande av läget kommer sannolikt att lämna såväl positiva som negativa intryck inom ett antal områden där ljudkomfort och upplevd körglädje hör till vad som kan påverkas negativt, medan bränsleförbrukning, och därmed CO_2 utsläpp, är aspekter som förväntas bli positivt påverkade. För att kunna ge svar på frågorna, samlades data in från de standardiserade cyklerna, EU & US samt ifrån Saabs egendefinierade tätorts cykel, THN-VBG cykeln. Körningarna utfördes med två olika kalibreringar för att kunna jämföras: ECO kalibreringen och STD kalibreringen. Nedan följer en sammanfattning av resultaten:

EU-cykeln

- Förbättrad bränsleförbrukning med 5 % med ECO läget
- Minimal skillnad i körbeteende vad gäller gaspedalsreglering mellan ECO & STD. Större variation i pedalpositionerna med ECO läget.
- Minimal skillnad i förmåga att följa målhastigheter vid körning mellan ECO & STD

US-cykeln

- Förbättrad bränsleförbrukning med 5 % med ECO läget
- Minimal skillnad i körbeteende vad gäller gaspedalsreglering mellan ECO & STD. Större variation i pedalpositionerna med ECO läget.
- Minimal skillnad i förmåga att följa målhastigheter vid körning mellan ECO & STD

THN-VBG cykeln

- Bränsleförbrukning förbättrades med 1,7 % med ECO läget.
- Viss skillnad i körbeteende vad gäller gaspedalsreglering, 7 % mer reglering med STD läget
- I denna cykel noterades ökad användning av högre växlar.
- Accelerationsnivåer – Med STD kalibreringen uppnår förarna i allmänhet ”häftigare” accelerationer, upp till $4 m/s^2$ medan man i ECO kalibreringen uppnår accelerationer upp till $2,8 m/s^2$, vilket antyder att ECO kalibreringen till en lugnare körstil än STD, eftersom all data samlats in ifrån verklig trafikmiljö.

Summary

The work done at SAAB Automobile AB in Trollhättan is about to study if it is possible to introduce a new mode with focus on facilitating a more economic way of driving. This mode came to be known as the ECO mode, where ECO stands for Economy, which is supposed to ease and advise the driver during the driving itself, for example by tipping which gear should be chosen with a manual transmission, which is thought to be presented at the assistance display, or with an automatic transmission to increase the drivers means to drive more fuel-efficient. The driver is able to chose whether to follow those advices or not, which basically means that the ECO mode is not governing in any way. The ECO mode itself was initiated due to that CO_2 credit was promised, in order if car companies could prove positive real life fuel consumption. Practically this would mean, for example, to cut a couple of grams (CO_2-emission) when certifying the emission values. Therefore, there is a need to study this scope of work.

In this analysis, there is an interest in what effects the ECO mode would contribute with in a vehicle with automatic transmission. A possible introduction of the mode would probably bring both positive and negative signs within a couple of areas, where vehicle control and comfort belongs to the negatives, while fuel consumption, and therefore CO_2 emissions, is expected to improve. To answer these questions, data was collected from the standardized driving patterns; US, EU and Saab's own defined cycle, the THN-VBG cycle. The tests were performed with two different calibrations, ECO and STD. A summary of the main results follow:

EU-cycle

- Fuel consumption improved by 5 % with ECO mode.
- Minimal difference regarding the accelerator regulations between ECO & STD. Wider variation in the accelerator positions with ECO mode.
- Minimal difference in the ability to follow targeted speed between ECO & STD.

US-cycle

- Fuel consumption improved by 5 % with ECO mode.
- Minimal difference regarding the accelerator regulations between ECO & STD. Wider variation in the accelerator positions with ECO mode.
- Minimal difference in the ability to follow targeted speed between ECO & STD.

THN-VBG cycle

- Fuel consumption improved by 1,7 % with the ECO mode.
- Moderate difference regarding the ability to follow instructions, 7 % more regulation with the STD mode.
- All cycles including real-life driving show an increased use of higher gears.
- Accelerations levels – The STD calibration reaches a wider interval of acceleration: ranging from 0 m/s^2 – 4 m/s^2 whilst the ECO calibrated car rarely passes 2,8 m/s^2. This would indicate that the ECO calibration promotes a more restrained driving style as data is captured in real-life traffic.

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Abbreviations

AT – Automatic Transmission

CAN-bus – Controller Area Network bus

CO_2 – Carbon dioxide

Dyno – Dynamometer chassis

ECM – Engine Control Module

ECO – Economy

EPA – Environmental Protection Agency

EUDC – Extra Urban Driving Cycle

FTP – Federal Test Protocol

GPS – Global Positioning System

GPRS – General Packet Radio Service

KPH – Kilometers per Hour

MVEG – Motor Vehicle Emissions Group

NEDC – New European Driving Cycle

NVH – Noise, Vibration Harshness

REF – Reference

STD – Standard

STFP – Supplemental Test Federal Protocol

TCM – Transmission Control Module

THN – Trollhättan

UDC – Urban Driving Cycle

US – United States

VBG – Vänersborg

Disposition of report

The report consists of seven main chapters. The first chapter is an introduction chapter where you will find out *why* and *when* this thesis was done. The second chapter will bring much of the theory needed to understand *what* this thesis is about. In the third chapter, the procedure throughout the whole work is presented and very important to understand, since it gives an answer on *how* the thesis was carried out. The fourth, fifth and sixth chapters are the result chapters and present the *outcome* of the whole work, probably the most interesting chapters overall. Finally, there is a conclusion chapter, the seventh one, where the most important *conclusions* are presented.

1. Introduction

The introduction presents a deeper explanation of the background, purpose, clarification of the purpose and limitations.

1.1 Background

With increasing attention on CO_2 emissions, which is directly proportional to fuel consumption, a project with focus on Powertrain calibration to facilitate efficient and fuel saving driving style has been initiated at Saab Automobile in Trollhättan, Sweden. The definition of this type of driving style and calibration is called ECO-mode.

A possible introduction of ECO-mode would contribute with several impacts in other areas. Handling, comfort and NVH are examples of these areas and large deviations here are likely to be perceived as annoying by many drivers. Therefore, there is a need to study this scope of work. The results will hopefully give an answer on whether this is an area to pursue or not.

ECO-mode, expressed in few words, implies a modification in the calibration of the ECM (accelerator pedal map) and the TCM (shift map).

1.2 Purpose

The main purpose with this project is to investigate if it is possible to introduce the system described in the background (chapter 1.1), the ECO-mode. The final decision will be based on investigation and analysis of previously collected (spring 2010) and recently collected data (spring 2011).

1.3 Limitation

Since the study makes a basis for a decision concerning ECO-mode (ECM/TCM calibration), focus is directed to the analysis which will affect the software in the car, if the mode is introduced. Thus, no mechanical work will be done in terms of powertrain parameters (engine, transmission, gearbox etc). Furthermore, the work will not concern the calibration itself, only the analysis that, hopefully, will facilitate a future decision regarding the calibration. Finally, the US, European and THN-VBG driving cycles will be discussed and dealt with. The project is expected to be finished in late spring, 2011.

1.4 Clarification of Purpose

The analysis will try to give answer on this sort of issues:

- How are other areas affected, such as NVH, comfort and handling, by ECO-mode?
- Will the fuel consumption improve? If it does, by how much?
- Does ECO-mode have any influence on driving behavior? (Accelerator pedal positions, how well are the drivers able to follow instructions, will the calibration affect acceleration levels in real-life traffic, choice of gear, accelerator regulation etc.)

2. Theoretical framework

To understand what the work is about, it is important to understand the basis. This chapter brings much of the important theory needed for comprehension.

2.1 ECO-mode – Background

One of the main factors why ECO-mode was introduced was to give ECO minded drivers an "ECO feeling"[1]. Practically this means to calibrate the engine- and transmission control module, so that a feeling of sluggishness is acquired[1]. The idea of this is to influence drivers in such way that they may drive more relaxed (less aggressive), which definitely leads to less fuel consumed and thus to an economic way of driving. As a result of this, the levels of CO_2 emissions are cut, since the fuel consumption is directly related to CO_2 emissions[2]. The last-mentioned, was also one of the reasons behind the ECO-mode, that a so called CO_2 credit could be awarded, if car companies could prove positive real life consumption.[1 3]

Certified consumption differs from real life consumption to the extent that certified values are derived from dyno tests, while real life values are taken from real driving patterns[1 3 [1]]. In reality, the certified values are most likely to be lower than those from real life driving [1 [2] [19]]. Though, their common characteristic is that they, probably, will both gain lower values when ECO-mode is activated[1].

ECO-mode itself is a function, a mode, in the car which the driver can chose to activate and inactivate with a simple button-rotation. When ECO-mode is active, the ECO-maps, in this case the engine-map and transmission-map, are activated which in turn are calibrated in such way that the feeling of sluggish emerges[1]. However, activation of ECO-mode will probably confine some comfort related functions; examples of those are air conditioning, electrically operated windows and sound system.[1 3]

The engine map is associated with the accelerator pedal map, which in this case decides how much power (or torque) is demanded from the engine. The transmission map is associated with the shift map. Depending on pedal position and vehicle speed, the shift map decides what gear to use.

2.2 Driving cycles – General theory

A driving cycle could be described as a standardized driving pattern and is usually shown in a velocity- time diagram [3] [4] which represent different types of driving styles [4]. Since the majority of all car manufacturers are required to provide information regarding fuel consumption and emissions, the driving cycles are utilized for this purpose [5] [6] [19]. As a result, customers are able to compare and get a notion of the fuel economy.

Fuel economy tests differ from region to region [2]. This is appropriate to the extent that typical driving conditions such as geographically, topographically and weather-wise aspects vary [2]. Nevertheless, they all have one common property; they always show lower fuel consumption than the real life consumption. [1 [1] [2]]

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[1] Birger Schlaich (Senior Engineer DriveQuality, SAAB Automobile AB)
[2] Sven B Andersson (Associate professor, applied mechanics, Chalmers University of Technology)
[3] Internal Information SAAB Automobile AB

The main reason is that car manufacturers calibrate and prepare their cars before testing which means that the car will be in the shape it takes to perform the test in best possible manner [1][5]. More often than not, the cars are tested by putting the drive wheels on a dyno, a machine that allows it to simulate driving conditions while remaining stationary. [1][7]

The dyno itself is tied to an electric motor. The motor, which is linked to a computer, senses the speed and power from the wheels and is calibrated by inputting the weight of the vehicle so that load can be applied to the wheels in purpose to simulate actual driving. [7]

Next, a digital flow meter is installed into the engine's fuel line and linked to a computer. This device samples fuel flow twice a second during the test and the data collected is used to compare and determine the fuel consumption and emissions. [7]

Figure 2.1 Dynamometer chassis testing
Source: http://www.gtspirit.com/2010/04/04/panamera-turbo-dyno-test-at-hennessey-performance/ (Acc 2011-01-25)

2.3 Different types of driving cycles

All driving cycles have one common property: They are used in the purpose to define fuel consumptions and emissions levels [3]. Section 2.3.1 presents a review of the most common cycles in EU and US.

2.3.1 EU cycles

NEDC

The NEDC is the regulated European cycle for defining the specific fuel consumption (in liters per 100 km) and emissions of passenger cars [3] [8]. This driving pattern consists of two phases; UDC and EUDC. The first mentioned phase, UDC, is the urban driving and is built up by four identical cycles where each one of them takes 195 seconds to complete in a distance of 1,013 km each. Since one cycle is repeated four times, the total UDC time is 13 minutes in a distance of 4,052 km. Characteristics of this phase is a top speed of 50 kph and low load (torque). [9]

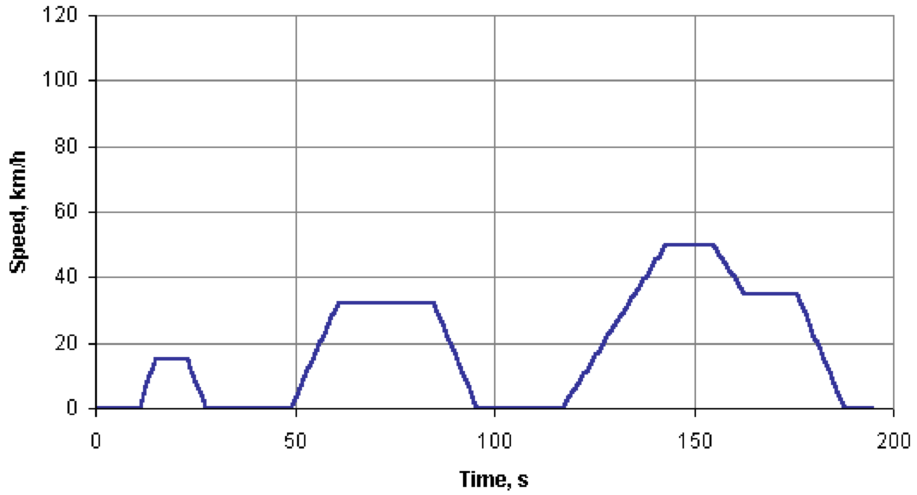

Figure 1.2 One out of four repetitions in the urban driving pattern (EU-cycle)

EUDC is the phase which is to be driven right after the UDC. This phase is called the "highway driving" phase and consist of one cycle, which in turn is driven only once (figure 2.3). This phase simulates what a highway driving appears to be like and takes 400 seconds to complete in a distance of 6, 96 km. Characterizing for EUDC is higher loads and speeds, up to 120 kph.
[9] [10]

A complete NEDC is shown in figure 2.4.

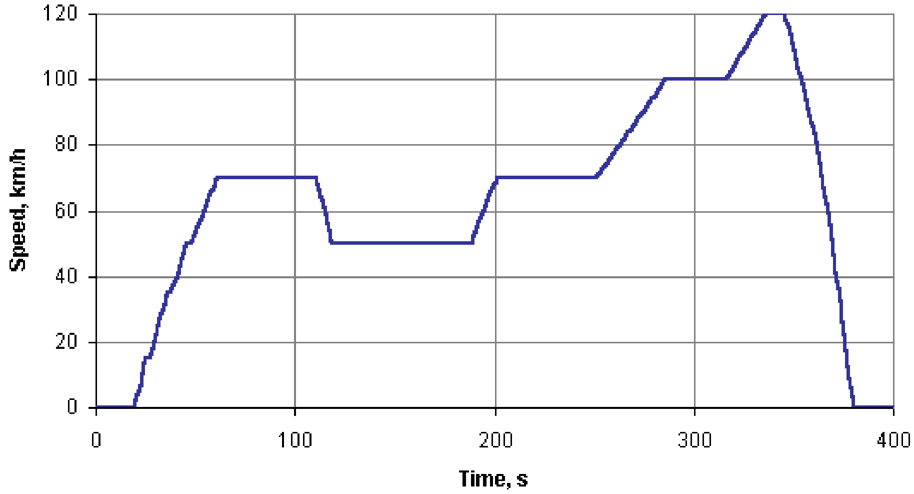

Figure 2.3 The second and last phase of the NEDC

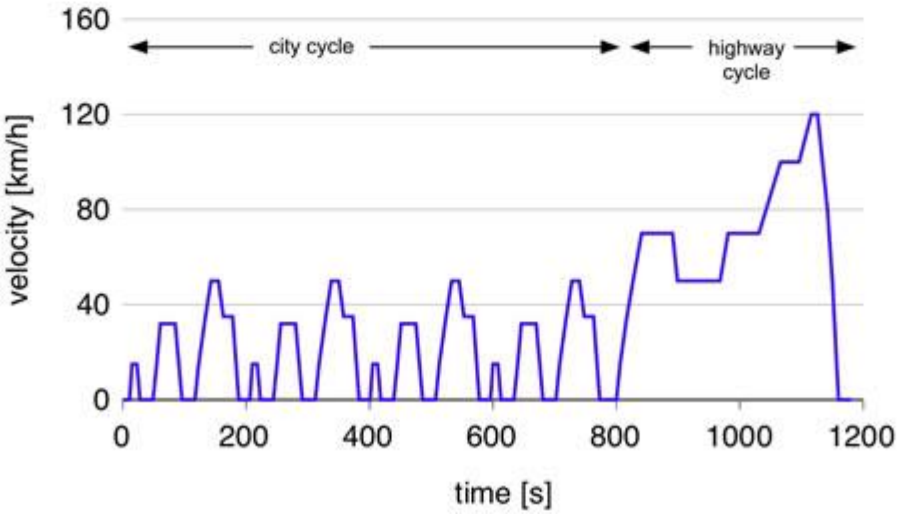

Figure 2.4 Full NEDC

The New European Driving Cycle is also referred as the MVEG cycle. [10]

2.3.2 US cycles

FTP-72

The FTP-72 cycle, developed in 1972 and the oldest EPA driving cycle, has come to be known as the Urban Dynamometer Driving Schedule (UDDS) [12]. The test represents city driving and follows a 12 km long route which takes 1372 seconds (22.87 minutes) to complete with a maximum velocity of 90 kph[11][14]. In 1975, the EPA set a maximum threshold for cold start CO emissions that led to the creation of the FTP 75 driving cycle [12] described in figure 2.5.

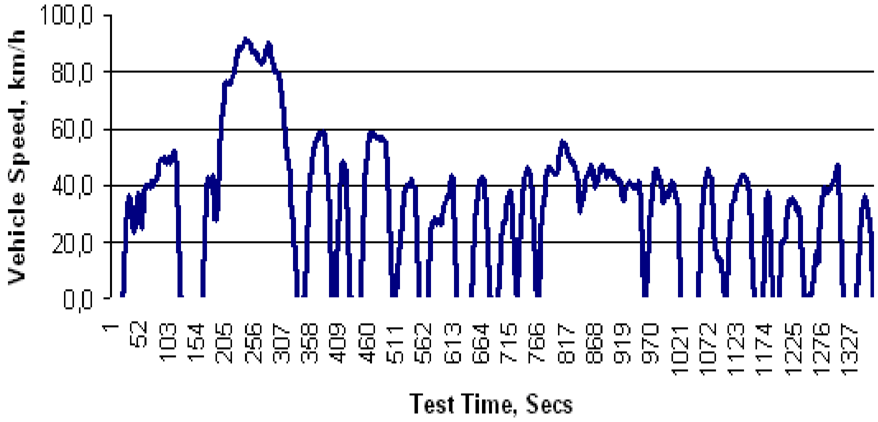

Figure 2.5 Full FTP-72 driving schedule

FTP-75

The FTP-75 driving pattern is the same as FTP-72 with one exception – the first 505 s are repeated at the end under hot start conditions. The cold start phase is defined as the first 505 seconds of FTP-75. Since there is an additional third phase at the end, it takes 505 seconds more than FTP-72 to complete, thus the total time is 1875 seconds and total distance of 17, 8 km. [12] [13][14] In US, the FTP-75 is very common [3] and as of year 2000, vehicles have to be additionally tested on two supplemental federal test procedures (SFTP) designed to address the shortcomings with the FTP-75 in the manner of aggressive, high speed driving (US06) and the use of air conditioning (SC03). [13]

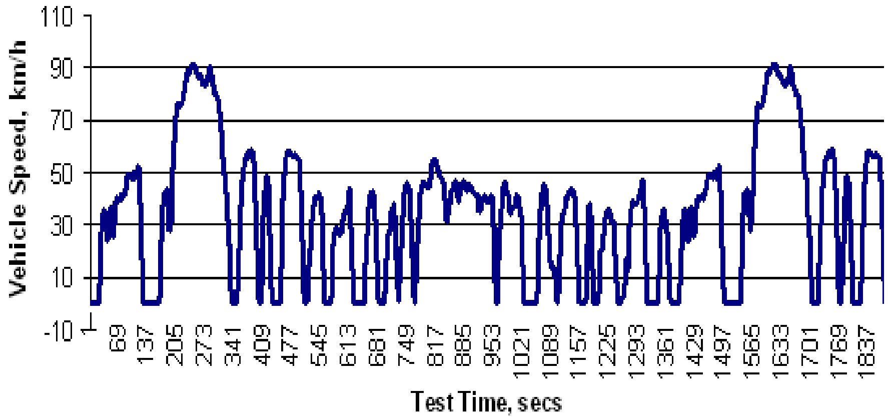

Figure 2.6 A complete FTP-75 driving schedule

US06

The US06 represents aggressive, high speed, and high acceleration driving behavior, rapid speed fluctuations, and typical driving behavior following startup [15]. The cycle follows a 12.8 km route with a maximum speed of 129.2 kph, and duration of 9.93 minutes [14] [16]. The US06 is a complement to FTP-75, since the last mentioned lacks this sort of driving type. [16]

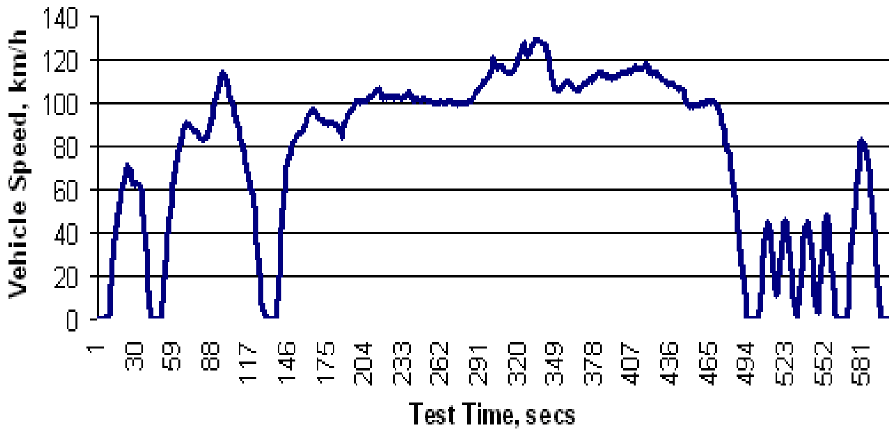

Figure 2.7 SFTP US06 cycle in full

SC03

The SC03 is like the US06 a complement to the FTP-75[17]. Like mentioned before, it is associated with the use of air conditioning since the FTP-75 is not including it. This cycle follows a route of 5,8 km and takes about 10 minutes to complete[14] whereas the highest velocity reaches about 90 kph, which clearly indicates that the cycle is not as aggressive as the US06.[15][17][18]

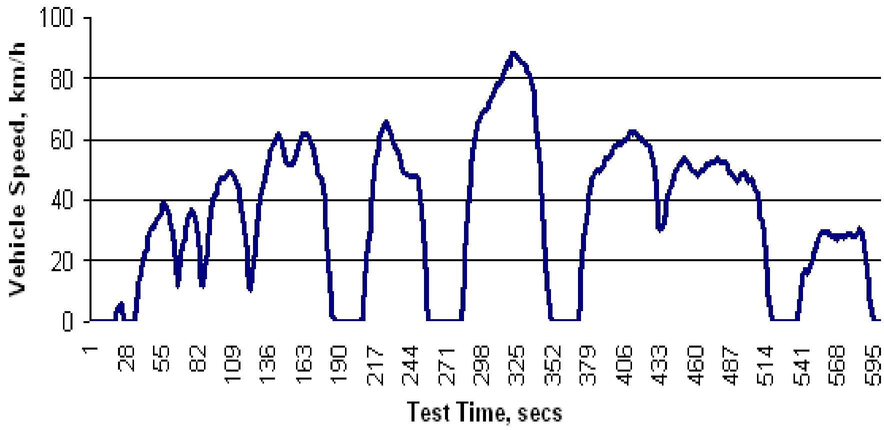

Figure 2.8 SC03 – With air conditioning in use

HWFET

The United States Highway Fuel Economy Test route was developed by the Environmental Protection Agency to determine the highway fuel economy for light-duty vehicles. The cycle takes 765 seconds to complete with a distance of 16.5 km whereas the top speed is 96,5 kph [14] [20]. The cycle simulates highway driving and is along with the FTP75 (of the US-cycles) tested and used for analysis in this paper.

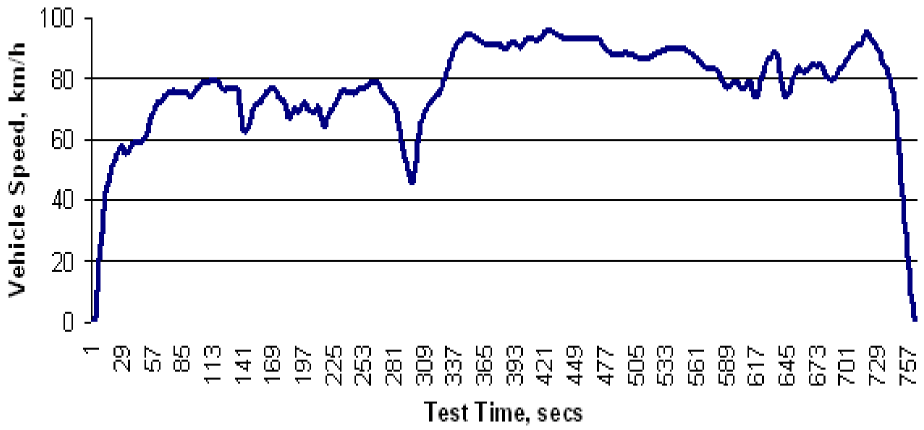

Figure 2.9 Full highway driving cycle

2.3.3 THN-VBG

The THN-VBG, Trollhättan – Vänersborg circuit, is a Saab-defined driving pattern which is used in same purpose as the driving cycles described earlier. However, it differs from the ordinary cycles due to real driving with many different drivers. This means that there are wider variations in important aspects, such as fuel consumption, behavior and NVH which means that these types of driving tests are harder to analyze. Another aspect making this circuit hard to analyze is the unpredictability. For example, it is impossible to know how many red lights will be encountered during the test or how the traffic conditions look like at any point during the circuit.

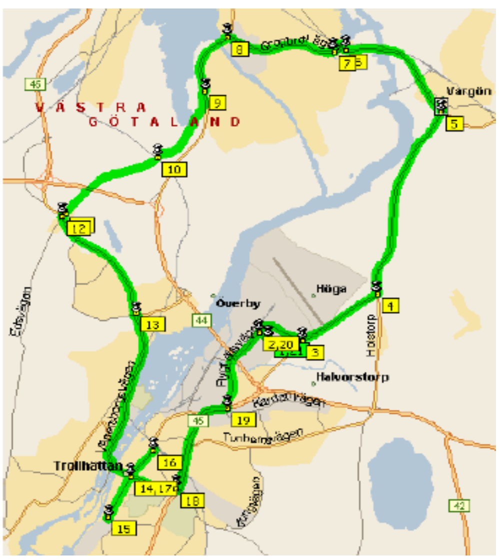

Figure 2.10 THN-VBG cycle

The driving pattern follows a 35 km long route and takes about 45 minutes to complete. The average speed is 40-50 kph whereas all drivers are encouraged to fill out forms that include points like; Hot/cold engine at startup, average fuel consumption [l/100km] and distance travelled [km]. Also, the drivers have an opportunity to leave other thoughts and comments about the car and the test.

3. Procedure

The procedure throughout the work is presented here. Every moment is explained in detail to ease the understanding of how the thesis was carried out.

3.1 Material

The car which is tested is a SAAB 9-3 with a 2,0l turbocharged engine. The gearbox is of automatic type with a hydraulic torque converter, six gears and possibility to use torque converter lock-up on gears 2-6 and the car has a mechanical four-wheel-drive drivetrain.

Figure 3.1 SAAB 9-3, 2.0l T AT XWD

3.2 Collection of data

The data, which is to be analyzed, was collected from the car's CAN-bus system with a Flight Recorder of type IPETRONIC M-LOG. The data was transferred and uploaded through a GPRS-system on a storage server, from where it was downloaded and prepared for analysis. All channels with temperature data were sampled with 0,5 Hz while the rest were sampled with a frequency of 10 Hz. The reason why all temperature channels were sampled with 0,5 Hz depends on three aspects, the first one is because temperature is a factor which does not change quickly which means that parameters that has anything to do with temperature, such as engine intake air temperature, outside air temperature etc, would not change quickly and therefore there was no need to have a high frequency in terms of this (the higher frequency, the higher rate of data collection per second). The second aspect is to save place on the storage server and the final and third aspect is to process the data itself. The more data available, the more space it takes and time to process. The data collection method presented here above is common for all driving cycles.

There were three different driving-cycles, EU, US and the THN-VBG cycle, which was defined by Saab (see figure 2.10). EU and US cycles, which are discussed in chapter 2, are driven on dynos, while the Saab defined cycle is driven in real traffic.

The EU-cycle was driven six times, three with ECO calibration and three with STD calibrations. The US-cycles are divided in two parts, the first one is FTP-75 (urban) and the second part is HWFET (highway). FTP-75 is driven four times, two with ECO and two with STD mode where as it is exactly with HWFET, so a total of eight tests were performed.

One thing to be noted when speaking of US-cycles is that SAAB's simulation model regarding the US-cycles is based on warm conditions. This means that the first phase (the cold one) in FTP-75 is not simulated at all; this cold phase is calculated instead.

The THN-VBG cycle was driven 22 times, 13 times with ECO calibration where 10 of them had useful data and three were expurgated due to huge deviations in the data. 9 runs were done with STD calibration, where six had useful data and three of them were expurgated due to same reason as the ECO-calibration. The deviations depend on huge variations, due to real traffic driving, with different drivers, different weather- and traffic conditions.

3.3 Analysis

The analysis was mainly done in the technical software for managing, analyzing and reporting technical data, called DIAdem. Since DIAdem is not very complicated, it took about a week to learn the basics which were enough to carry out an analysis. Equivalent software for managing and analyzing data is MATLAB, which was thought to be used from the very beginning, though it was put to side due to better usability with DIAdem when looking and analyzing data is in focus. Instead, MATLAB was used to another purpose; Retrieve values, from the collected data, which were needed to make diagrams in Microsoft Excel. Also, MATLAB was used when programming the algorithm that calculates number of fluctuations in different curves.

There was also some sort of flexibility considering the data, since it could be opened and worked with in both MATLAB and DIAdem, which saved a lot of time because there was no need to convert the data in different forms.

When speaking of analyses and data, diagrams and graphs become very useful. DIAdem which is an excellent tool to make graphs and diagrams was put to side this time. The reason is Microsoft Office Excel, since the acquaintance with Excel is huge, the choice was definite. A huge majority of the diagrams and graphs were made in Office Excel, though there are some that derive from DIAdem, nevertheless, they are only "print screen"- versions. Above all, they are both used in purpose to clarify causes in their specific context and as foundation to what the final decision will be based on regarding the ECO-mode.

In addition to the gathered data and the programs used, evaluation reports are very important. These are necessary when speaking of parameters like noise, vibration and harshness. The data collected which was analyzed in DIAdem, could not give a definite answer on how these are affected, so can the evaluation reports. These were filled in by the drivers themselves when testing the cars (THN-VBG circuit) and are intended to be used in the analysis regarding NVH.

What should be taken in consideration is that the result chapter often shows analyses made on a few samples of the whole analyzed data. This is done because it often appears that specific analyses show exactly the same characteristics. Otherwise, they would take a lot of space in the describing text and also present almost the same thing as the samples do. In other cases, where the characteristics of a result may differ, a full analysis is presented.

Another relevant aspect to pay attention to is the analysis procedure done on the THN-VBG runs. Since there are a lot more tests done, and therefore a lot more data to process, this analysis is more of "characteristics-type-showing", which means that focus is directed to show common characteristics for these tests. The time to study these data in deep is not enough but again, if the results differ a lot and something has a strong impact on the results, a full analysis is declared.

3.3.1 Drivers' behavior

Parameters that were of interesting view when the drivers' behavior was to be analyzed were: the position of the accelerator during the different routes and how well the drivers could follow the targeted speed (EU-cycle and US-cycle). The THN-VBG cycle had a different question formulation. In this case, it is not appropriate to look at how well speed limits were followed because speed is highly likely to vary in a real life driving, than in a cert-cycle, due to huge individual difference in driving. Therefore, aspects such as acceleration levels and accelerator pedal motion are central when analyzing the driver behavior.

Accelerator position – (EU- cycle and US - cycle)

The accelerator position diagrams clarify how the accelerator was depressed during the cycle over a period of time. With aid of DIAdem, it was possible to plot the pedal profiles and see what differences there were between the standard calibration and the ECO calibration. The charts were made with an interval of 0% - 50% (accelerator position, x-axis), even though the standard calibration never surpasses 30 %, it was appropriate to have this range of interval to make a fair and wieldy analysis, since the ECO calibration surpasses 40 % limit. Also, these intervals were divided into 10 classes; 0-5[%], 5-10[%], 10-15[%] and so on, making it possible in an easy way to compare which accelerator positions were used the most part of time. Reason why there were 10 classes, and not fewer or more, is because; few classes would give a less accurate analysis, while a big number of classes would take a lot of time to process, though it would be more accurate.

The x-axis, which represented accelerator position, was plotted against a y-axis that stood for time, in seconds. With this type of histograms, it is possible to see connections, such as dominating accelerator positions, between the accelerator and the different calibrations.

Accelerator position – THN-VBG cycle

There is a slight difference in procedure when coming to the analysis of the accelerator position in the THN-VBG cycle. In this case, the classes are increased by 10, which means that there are 20 classes instead of 10 and the accelerator position range is increased by 50 %, which means 0-100 % instead of 0-50% as it was with the EU and US.

The increase depends on one main aspect: THN-VBG cycle is a real life cycle and driven by many different drivers in real traffic. Therefore, wider variations are common and thus the scales were doubled. Any less, the charts are of same type; made in Excel with the same X and Y axis units.

Target speed (EU-cycle and US-cycle)

The second interesting factor regarding the influence on behavior (EU-cycle and US-cycle) was how well the drivers could follow instructions (target the demanded speed) while running the tests.

These conclusions could first be made when the gathered data was plotted against the reference data. The reference data in this case is the original data which is used to describe the different driving cycles. By comparing (looking at the correlation factors of) the collected data with the reference data, it gave an opportunity to see how close to target the cycles were driven, how well the actual vehicle speed followed the original speed target and where the most deviations were present.

The original data was available in Excel format while the collected data had to be analyzed in DIAdem before it was put in Excel for comparison. Example of the analysis procedure could be summarized in the grid (table 3.1).

Table 3.1 Targeted speed vs. actual speed

Reference Time [s]	Reference Speed [kph]	Reference Time [s]	Drivers' Speed [kph]
X_1	Y_1	X_1	Z_1
X_2	Y_2	X_2	Z_2
X_3	Y_3	X_3	Z_3
X_4	Y_4	X_4	Z_4

The reference time consists of a varying amount of points, (X_x – depending on which cycles is tested) which are all represented by a value, in this case an "Y_x" value for the reference speed, and a "Z_x" value for the drivers' speed during the test. If the Z – values are close, or identical, to the Y – values, it means that the route was followed quite accurately. If Z – values differ a lot from the Y – values, it means that the route was not followed with precision. The comparison is made in DIAdem.

The correlation (used in this part of analysis) is in statistic, the relationship between two or more observed data values whereas the correlation coefficient is its measuring value. If the correlation coefficient is 1 or close to 1, it means maximal positive correlation, if the value is 0 it means that there is no relationship, and if the value is negative 1, it means maximal negative relationship, see figure 3.2. The correlation is calculated with Excel.

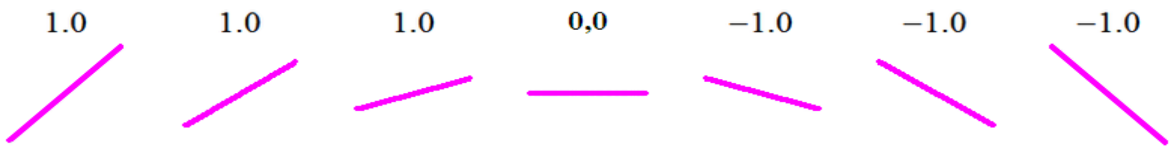

Figure 3.2 Correlation

By calculating the correlation of the observed data values, the Y-values and the Z-values, a coefficient is received, as explained earlier, that shows how well the Z values followed the Y values, and therefore it is possible to answer the question: How well did the drivers follow the targeted speed during the EU-cycle?

Accelerations levels – THN-VBG

Acceleration levels show the difference between the calibrations in manner of vehicle acceleration. By looking at them, it becomes known how the drivers accelerated the vehicle during the tests. To calculate these, a study of all the tests in DIAdem is made, where it is possible to retrieve precise numerical values, in this case, the acceleration values. These values were copied and pasted in Excel, where graphs and diagrams were made out of them.

Choice of gear – THN-VHG cycle

This area is only present in the THN-VBG cycle and is a way to study the differences in the TCM calibration (shift points). The selection of gear hints about what gear the drivers usually used when they drove the THN-VBG cycle. By studying this, information is provided to know if the idea agrees to the fact that drivers drive easier and less aggressive, when the car feels sluggish. With more aggressive driving style, lower gears will be selected. But at the lower engine speed limit for any given gear, the gear selection will be determined by the TCM (shift map) calibration rather than the driver or the driving style.

The process regarding choice of gear is uses the same steps as earlier: Values were retrieved from MATLAB and pasted in Excel. Excel was powerful to use here since many different calculations had to be done: Firstly, how many times each gear was used, secondly how much of the total cycle time each gear was used, and thirdly, make histograms and graphs that compares and strengthens the result of the analysis.

Step 1: To calculate the total number of when a gear was chosen, the command “search” was used in Excel to find the specific gear’s number of hits. This was done for all the six gears, of course.

Step 2: Every gear was divided (number of hits) with total hits which gives a percentage that shows how often a gear was driven with.

Step 3: Graphs and diagrams could be made in many different programs in many different ways. Like mentioned earlier, Excel was used.

Next thing here is about to find out if the gears were driven with locked or open converter. This gives information about differences in the AT calibration. A locked converter gives a better efficiency at the cost of NVH comfort, and is a crucial parameter in the balancing of fuel consumption vs. drive quality vs. NVH. Since the driver is not able to affect the calibration itself, it does not tell much about the driver behavior directly, though what is interesting is how the accelerator regulations look like when driving in locked vs. open converter.

So, to analyze this, the first interesting question is: When is the converter open and when is it locked? A locked converter is present if a constant close to zero is present when differentiating the quotient between engine speed (rpm) and vehicle speed (kph), see figure 3.3. By “close to zero” means that it appears often in an interval around zero, usually in -3 and +3 (amplitude). This could be seen in figure 3.4.

Figure 3.3 The quotient of engine speed (rpm) and vehicle speed (kph) is differentiated

If figure 3.3, is zoomed somewhere on the constant line (in this case around 800 s), a close-up on what the "constant line" looks like emerges. It is obvious that the line rarely is gliding on the zero to 100 %, though it still is regarded as a locked converter.

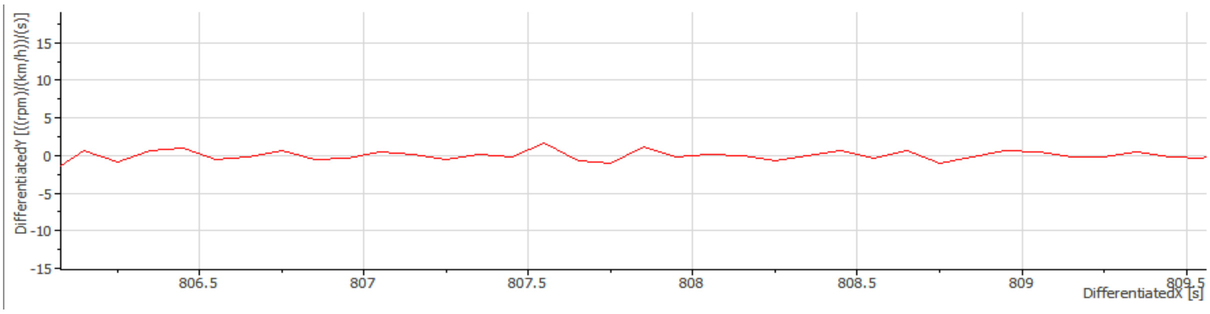

Figure 3.4 If the constant line in figure 3.3 is zoomed, another more "fluctuating" curve is received, though it is still regarded as "constant"

Finally, to calculate the portion of when the converter is locked during a test, DIAdem was used to add all samples that are in the interval of -3 to +3 and divide them by the total samples. This gives a percentage of how much of a specific test was driven on a locked converter.

3.3.2 Fluctuation Value

The most central aspect when speaking of drivers' behavior is probably to study how the accelerator was regulated during the cycles (EU, US & THN-VBG). This is of importance because if it is possible to put a value on how a curve fluctuates, it is possible to decide how the drivers have worked with the accelerator in the different calibrations. By studying the number of fluctuations, it is possible to get familiar with how the different calibrations stand in relation to each other.

How is the fluctuation value compiled then? There were different methods discussed; Rain flow method and unimodal regression were present from the very beginning when the problem was encountered, though they were put to side since they were not applicable manually on the curves because some curves are made up of over 30000 values.

So the only way to get a precise analyze is to, somehow, include all these 30000 values in a smooth way. The key to this smooth way of analysis is programming where MATLAB is used in order to form the algorithm which summarizes the fluctuations of a curve. The code and description are presented here.

```
A = [];
B = diff(A);
B = sign(B);
n = 0;
m = 0;
TotalF=0;
for i =1:length(B)-1
    if B(i) > B(i+1)
        n = n+1;
    elseif B(i) < B(i+1)
        m = m+1;
    end
end
TotalF=n+m
```

The code works simply by putting the curve's values in the vector A = [ ], whereas the code uses a for-loop to step through the vector while the" if" and "elseif" statements checks for positive and negative derivates. One fluctuation is the result of when the curve goes from a positive to a negative derivate and vice verse. The total numbers of fluctuations are put in a variable called "TotalF", which is presented when the code is finished with the calculation.

The procedure is done for all the curves since this algorithm is applicable for all the curves in all cycles with all calibrations.

The small rings in figure 3.5 show where fluctuations appear and these are those to be summarized in the algorithm.

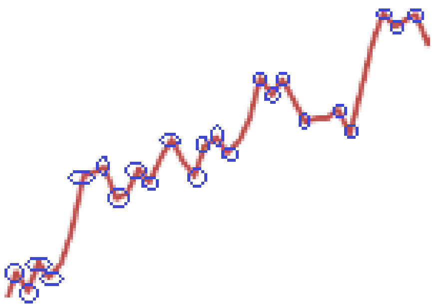

Figure 3.5 The small rings indicates where fluctuations appear

3.3.3 Modified Algorithm

The modified algorithm described here in chapter 3.3.3, counts fluctuations that have a, at least, 5 percent difference in accelerator position, which means that any kind of noise is neglected. This is useful, since the total fluctuations are reduced and results that probably represent more realistic change in accelerator positions are received.

```
A = [];
B = diff(A);
C = sign(B);
n = 0;
m = 0;
p = 0;
TotalF=0;
Fluctuations_over_five=0;

for i =1:length(B)-1
      if C(i) > C(i+1)
      n = n+1;
      elseif C(i) < C(i+1)
      m = m+1;
end
end

for i =1:length(B)
      if abs(B(i)) >= 5
      p = p + 1;
end
end
TotalF=n+m
Fluctuations_over_five = p/2
```

The difference between this program above and the program in page 22 is that another for-loop and an if-statement are added. The for-loop has the same function as before, step through the vector, while the if-statement checks for differences of at least 5% accelerator movement.

3.3.4 Fluctuations in urban part and highway part (EU-cycle)

An analysis was also made to study how many fluctuations there were per km in the MVEG cycle, so the algorithm in chapter 3.3.3 was applied again. Though, this time the data was split into “urban data” and “highway data”.

The urban data is the data copied from 0s – 7800s (in the original data from an excel file) since the urban part is represented by the first 780 seconds of the cycle. A frequency of 10Hz is used, which means that the 7800 (780 seconds * 10 Hz = 7800) values required to retrieve the number of fluctuations in the urban part are used. After that, a simple division by 4 is done, since the urban part is 4 km long.

Respectively was done with the highway part, with the exception that the values 8000 – 11800 are used this time, since 800s – 1180s represent the highway part. Also, a division by 7 is done, because the highway part is 7 km long (6,96km).

3.3.5 Fuel consumption

The fuel consumption is a very crucial parameter when speaking of ECO-mode, since ECO-mode is basically based on it. The analytical method which was done in order to establish the fuel consumption for both the calibrations, STD and ECO, follows three steps, described in detail:

Step 1: The logged data was put in MATLAB so that all values could be retrieved in order to make it possible to calculate, values like “min”, “max” and “mean”. These are all of interest, though the average consumption is the main focus because it gives the best reflection of the fuel consumption.

Step 2: The data was copied and pasted into Microsoft Office Excel whereas the values (max, min and mean) were calculated with the smart functions integrated into the software. Here is an example of the calculations done with one ECO calibration. Similar calculations were done with the rest of the ECO calibration and also with all STD calibrations which can be found under the “result” chapter.

Table 3.2 Calculation of max, min and mean values

ECO 1	Function in Excel	Value [l/100km]
Max	=MAX(A1:A12193)	117,5882
Min	=MIN(A1:A12193)	0
Mean	=AVERAGE(A1:A12193)	8,297636

The “A1:A12193” indicates that calculations (min, max and mean) include all values in the range from A1 to A12193 in the Excel sheet. (The A_x number may vary, from 10k to 30k)

Step 3: When the method presented in chapter 3.3.5 was made on all of the tests (six EU test and eight US tests), it was easy to calculate the total average fuel consumption for both calibrations, simply by adding all average values for the ECO calibrations, and all average values for the STD calibration and divide by the number of tests available in the specific cycle.

Table 3.3 Example of comparison of average fuel consumption EU cycle

ECO calibration	STD calibration
(ECO1Average + ECO2Average + ECO3Average)/3	(STD1Average + STD2Average+STD3Average)/3
= Average ECO calibration	= Average STD calibration

The procedure explained above is also done on the THN-VBG cycle with one difference; the fuel consumption calculations are made in two levels. The first level calculates the fuel consumption from start with a cold engine whereas the second level calculates the fuel consumption with a warm engine; this means that the cold engine part of the circuit is neglected in the second level.

4. Results – EU cycle

The following section will present results obtained from the analysis in the EU data.

4.1 Driver Behavior (accelerator position) – EU cycle

One of the main eye-openers was about to find out if ECO-mode had an influence on the driver's behavior. A comparison between STD- and ECO-modes accelerator profiles and the driving pattern profile clearly indicates that there is a difference between the drivers' behaviors. To form an opinion on how the behavior has been changed, it is recommended to take a look at the driving cycle profile (figure 4.1).

The lines without a "*" represent the complete European driving cycle. An assessment of figure 4.1 indicates that there are not any differences, if any at all, which is completely natural because the driving cycle pattern is identical. Though, what could be seen is that the ECO-mode profile (the upper line of the two in figure 4.1) and the STD-mode profile (the lower line in figure 4.1) are far from being identical. In turn, this means that the drivers had to work differently with the accelerator, which means that the driver's behavior in this manner is different.

Above all, it is interesting to see how big difference there is and as well to quantify the difference in some sort of number. This is important because these values could be used as references when doing corresponding tests in the future. Nowadays, there is no such reference. Chapter 4.1.1 reveals these numbers and gives a more clear view of how big difference there was.

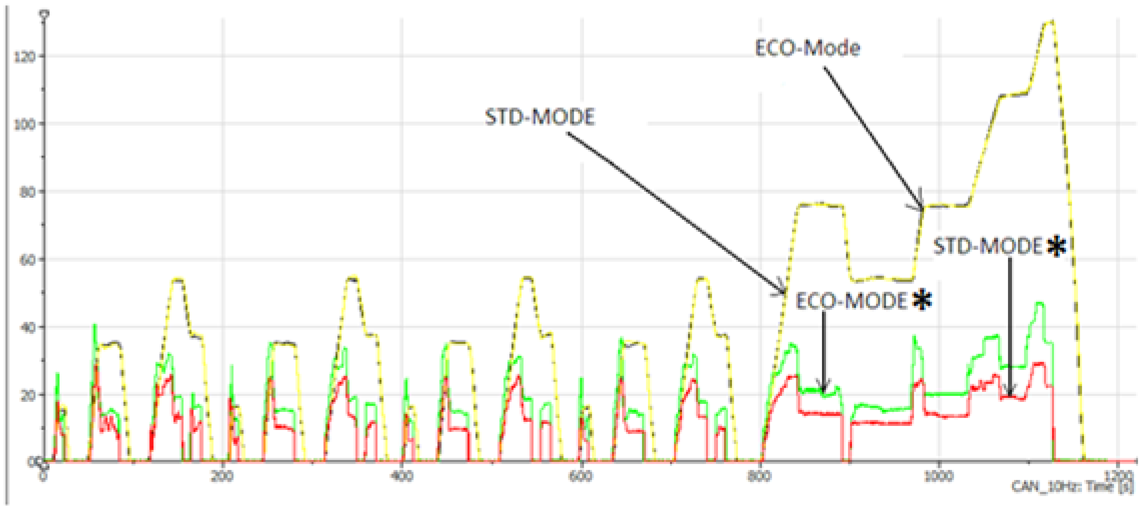

Figure 4.1 Difference between the calibrations in accelerator regulation – identical cycle.

In addition, histograms (see figure 4.2 and figure 4.3) were made from the pedal-profiles in figure 4.1, from one ECO test (DO020660) and one STD test (DO020646), which clarify the range of both modes [%], which acceleration positions dominate and which are submissive. Similar analyses were made on the rest of the EU-tests and all of them show the same results.

The histograms in figure 4.2 and 4.3 are samples used to compare the ranges of the accelerators' positions. It is directly noticeable that the total accelerator position range for STD is quite smaller than ECO, which depends on the pressure applied to the accelerator. The reason why there is a bigger power demand, with respect to how the accelerator was worked with, in ECO-mode is because the ECM and TCM are calibrated differently.

The STD mode is calibrated in a way that it feels more aggressive, which basically means that the accelerator will generate more power when depressed in a specific position, than the ECO-mode when depressed with same accelerator position. That is also the reason why the range of the accelerator positions is smaller than in ECO-mode and also why the STD calibration does not exceed 30 % limit during the cycle at any point, compared to ECO calibration which has a maximum of about 40%. (Sometimes it reached even 40-45 and 45-50% which is similar to all the ECO histograms in this manner, but should not be taken in conclusion since this appears to be only for a few seconds of a total ~1200 seconds)

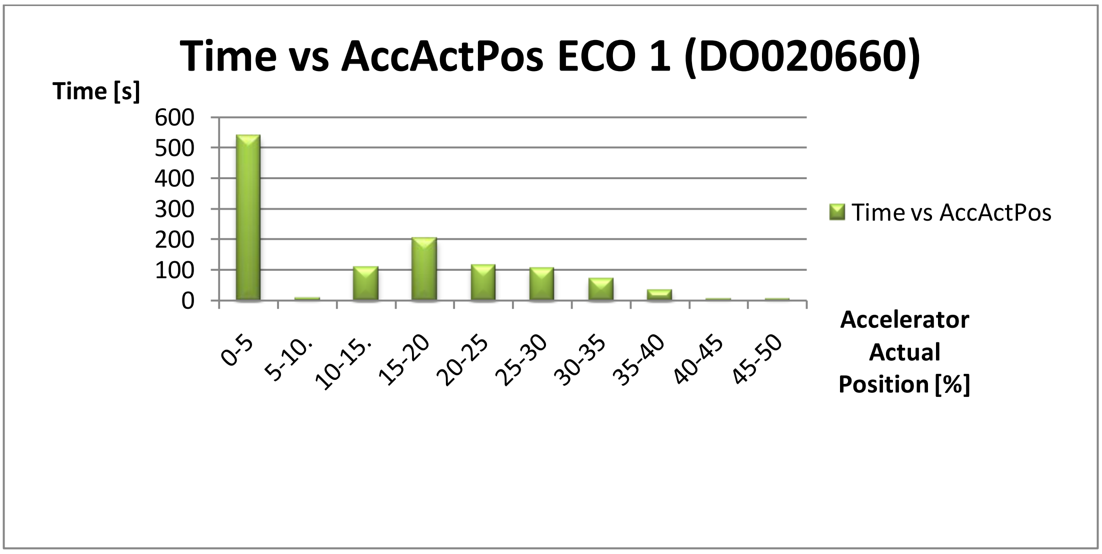

Figure 4.2 Accelerator position range – ECO calibration

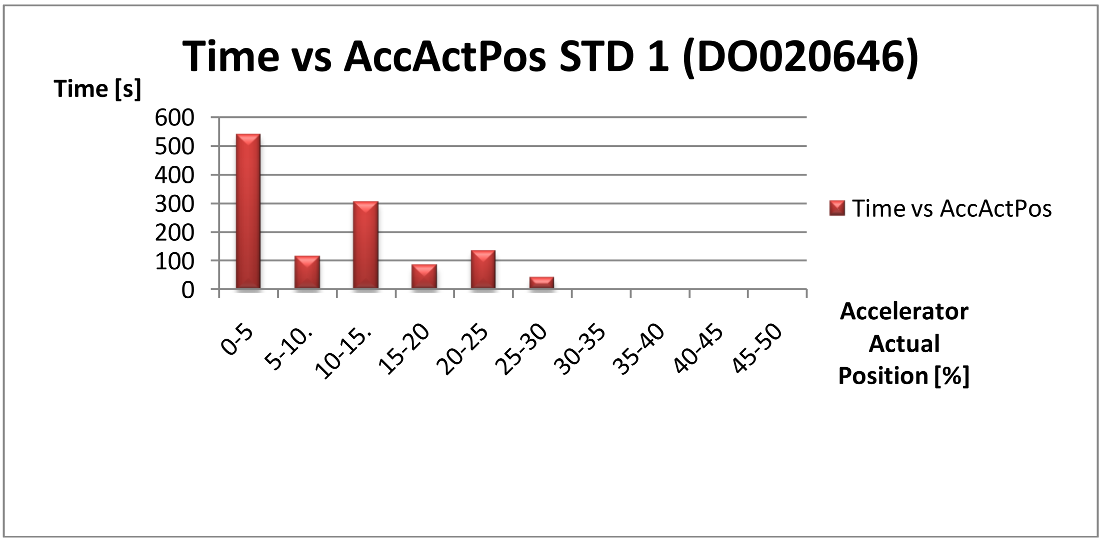

Figure 4.3 Accelerator position range – STD calibration

4.2 Driver Behavior (follow targeted speed) – EU cycle

Like mentioned earlier, it is interesting to see how well the drivers could follow the speed limits during the EU-cycle. The highlight is to study if different calibrations affect the ability to follow the instructions (speed) during the tests, and therefore analyses were done on all of the six EU-cycle tests.

A comparison between the speed profiles, ECO 1 vs. EU and STD 1 vs. EU indicates that the EU speed pattern is impossible to copy since it has huge variations in speed, but similar characteristics can be discerned for both calibrations. Firstly, a study about how well the ECO calibration passed the test is performed.

As seen in figures 4.4 and 4.5 it is noticeable that the biggest variations appear in the highway driving of the EU-cycle, while the first four urban phases are almost identical. For some reason, the drivers encounter problems while running the highway part during every EU-cycle test. The STD calibration (figure 4.5) has similar problems. The urban driving cycles are well executed, but again, the highway driving contributes with wide variations. Probably this is because the vehicle is harder to control when higher speeds are reached.

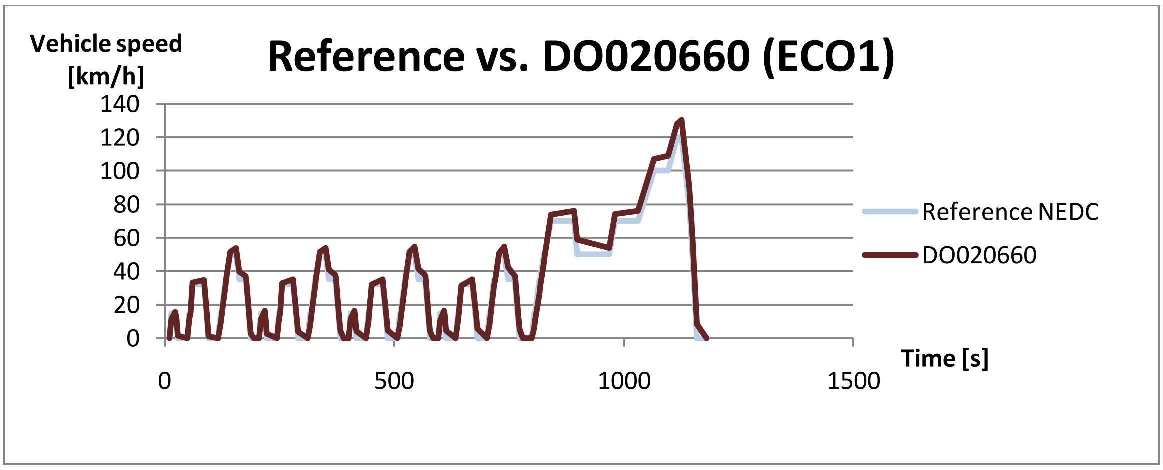

Figure 4.4 The light line is the reference where as the dark line represents driver's ability to follow the reference

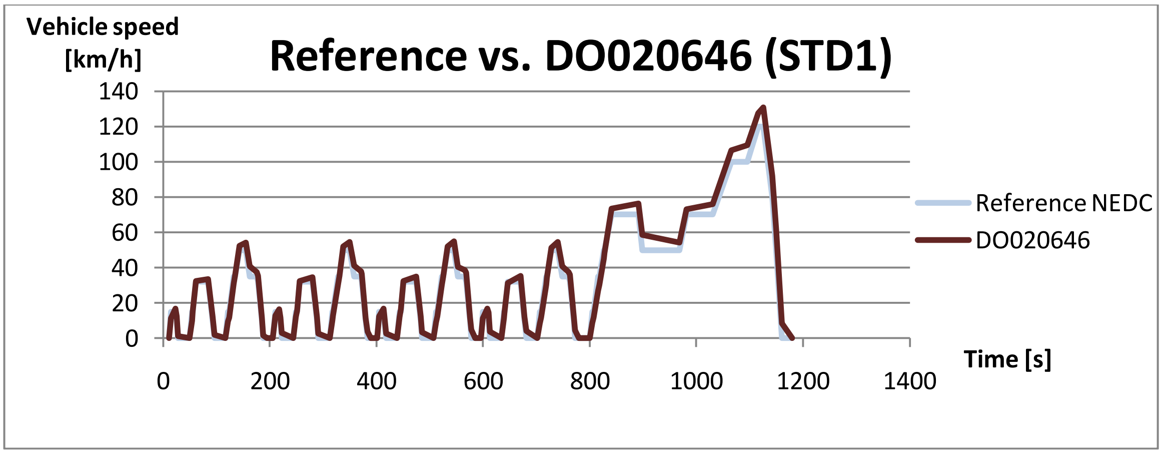

Figure 4.5 Shows the difference between the reference data (light line) and driver's ability to follow targeted speed (dark line)

As far as the charts in previously page can tell, it is hard to conclude which one has the biggest deviations overall. Therefore, a corresponding analysis has been made on the other four diagrams whereas a correlation coefficient has been calculated for all of them.

Table 4.1 Correlation factors for all tests driven in EU - cycle

ECO 1 vs. Ref	ECO 2 vs. Ref	ECO 3 vs. Ref	STD 1 vs. Ref	STD 2 vs. Ref	STD 3 vs. Ref
Correlation	Correlation	Correlation	Correlation	Correlation	Correlation
0,990905	0,972059	0,963285	0,991728	0,643569*	0,995935
Mean Correlation ECO tests			Mean Correlation STD tests		
0,975416			0,877077		

* As the table 4.1 shows, one might think that with the ECO calibration, it is easier to follow the EU route, but this should be taken with a pinch of salt. The reason why mean correlation coefficient factor is lower in STD is because of the second (STD 2) test, where the drivers' values (dark line) seem to be delayed during the whole cycle, see figure 4.6.

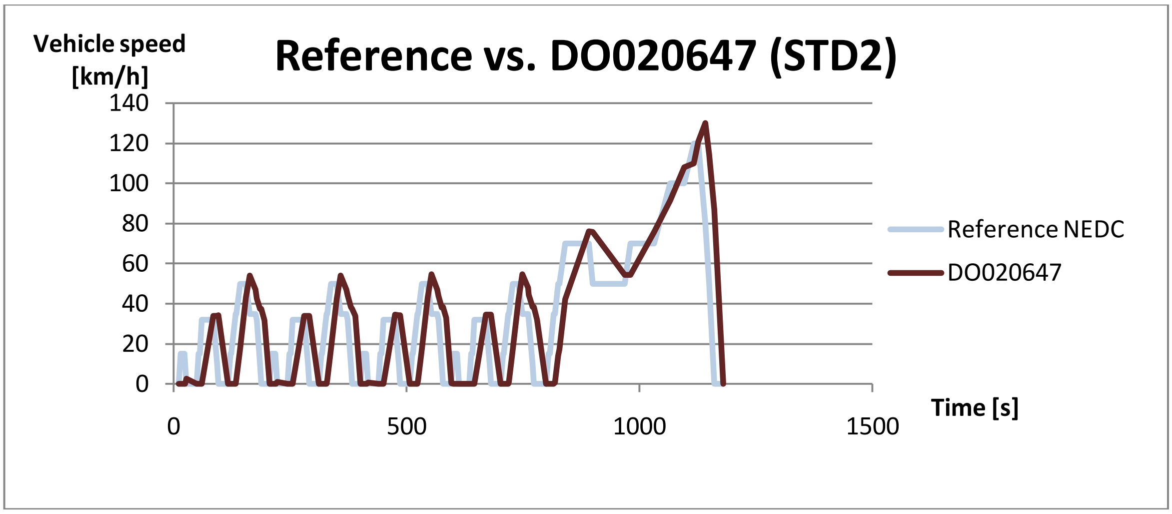

Figure 4.6 This test should not be approved, since it deviates from the requirements and tolerances by far

If only the "normal" tests are compared, which in this case are ECO 1, ECO 2, ECO 3 with STD 1 and STD 3, it is clear that the STD calibration passes the test slightly better, since its correlation factors are closer to 1 than the ECO correlation factors. This leads to the conclusion that it is easier to follow the route when driving with the STD calibration, but only with margin!

Above all, it could be seen that the correlation factor, in most cases, is close to 1, which meant that the tests performed by the drivers were pretty close to the reference values. Next level in future analysis would be to analyze how the correlation factor could be improved.

Important thing to note is that the standardized cert cycles have tolerances and requirements that must be followed. If not so, the authorities will not approve the tests, leading to that the tests have to be driven again. Examples of the tolerances and requirements are that the drivers have to maintain a speed within a tolerance of +/- 2 kph (in the EU cycle) and they are only allowed to drive outside the tolerances for 2.5 seconds (EU cycle). Figure 4.6 shows a test that should not be approved, due to large deviations from the requirements.

4.3 Fuel Consumption – EU cycle

The fuel consumption is a parameter which is expected to show lower values with the ECO calibration. Table 4.2 presents the outcome of all EU tests, regarding the fuel consumption.

A brief analysis of table 4.2 appears to show that the average ECO consumptions are quite smaller, but only with margin. Therefore, a mean value of all mean consumption in STD and ECO would give the fairest and best comparison, see table 4.3.

Table 4.2 Mean fuel consumption for all the tests driven in EU cycle

ECO 1	ECO 2	ECO 3	STD 1	STD 2	STD 3
Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]
8,297636	6,934274	7,035379	8,707509	7,343018	7,447000

Table 4.3 Comparison of mean fuel consumption between the calibrations

ECO tests [l/100km]	STD tests [l/100km]
8,297636	8,707509
6,934274	7,343018
7,035379	7,447000
Average: 7,422429424	Average: 7,832561485

Difference: 7,422429424/7,832561485 = 0,94763755614489 (~5,23 % better with ECO)

As expected, the ECO mode shows a lower fuel consumption by 5,23 % over three EU-tests each. One important thing to notice is that the first test in both calibrations (ECO 1 and STD 1) are run with a cold engine, why these two tests show higher fuel consumption than their corresponding tests (ECO 2, ECO 3, STD 2 and STD3).

This opens up for a discussion about if ECO mode really is worth the 5 % at the cost of drivability and NVH? To decide this, one should take other parameters in consideration; one example is the CO_2 emissions. In this case, lower fuel consumption with the ECO-mode is present, which gives less CO_2. Another example is the drive quality. How are the drivers experiencing these changes? Etc…

A study on whether it is possible to reduce the fuel consumption during the EU-cycle has already been made at Saab and below is a summary of what could improve the fuel consumption.

- Minimize idle
- Maximize acceleration time
- Reduce cruise speed and time
- Increase brake time and distance

Maybe the most important thing, which should not be forgotten, is that fuel consumption and thus CO_2 are very dependent on what type of driver you are. A very aggressive driver will always have high fuel consumption, no matter in what mode she or he drives. Also, the choice of gear is the most affecting aspect regarding the fuel consumption, the higher gear selected by the TCM calibration, the better fuel consumption.

4.4 Fluctuation Value – EU cycle

Since it was interesting to quantify the difference in the accelerator position during the driving cycles in some sort of number, the algorithm described in chapter 3.3.2 was applied on all six accelerator position diagrams, the results are presented in table 4.4.

Table 4.4 Summary of fluctuations in the EU-cycle

Tests:	ECO 1	ECO 2	ECO 3	STD 1	STD 2	STD 3
Number of fluctuations	15388	14974	14989	14815	14958	15127
Average ECO	15117					
Average STD	14967					

The results show similar values which indicates that the change of calibration, does not change the driver behavior. If it did, a bigger difference in the accelerator regulation would emerge and that is not the case at this moment.

What also is of interest is to compare these fluctuations, with the correlation factors, to see connections between accelerator regulation and how the drivers followed the targeted speed.

As could be seen in chapter 4.2, the very best STD correlation factor is the STD 3, (factor of 0,995935), whereas the best ECO correlation factor is 0,990905 (ECO 1). What could be concluded is that the highest correlation factors seem to be related to the highest number of fluctuations; the more the driver worked with the accelerator, the better he drove the cycle (followed targeted speed).

Another comparable aspect is to study which of the regulations in table 4.4 had the best fuel consumption. In previous chapter, it could be seen that ECO 2 and STD 2 have the lowest fuel consumption, but since the STD 2 was terrible (delayed and not correctly performed), a comparison with STD 3 is more appropriate.

It seems that there is no relationship between regulation and fuel consumption, due to the fact that ECO 2 had best fuel consumption (of the ECO tests) and lowest number of fluctuations while the STD 3 calibration, had the best fuel consumption (of the STD tests) but also the highest number of fluctuations, meaning there are no connections between these two parameters; regulation of accelerator and fuel consumption.

Table 4.5 shows the outcome from when the modified algorithm was used in order to calculate the number of fluctuations. Due to the “5 % filter” integrated in the program, all type of noise is neglected, which means that fewer fluctuations are expected.

Table 4.5 Summary of fluctuations in the EU-cycle with filtration

Tests:	ECO 1	ECO 2	ECO 3	STD 1	STD 2	STD 3
Number of fluctuations	7530	7359	7385	7292	7288	7371
Average ECO	7425					
Average STD	7317					

When comparing these results with the ones in previous page, it is clear that the total number of fluctuations is reduced to about half of what they were from beginning. This gives a relative difference which is a bit clearer since there is no noise included here. Again, the ECO calibrated car has a slight more regulation but only with margin.

By judging from the results in previous section and the results presented here, it seems that ECO-mode does not have any impact on the drivers’ behavior since the regulation is near the same in both calibrations.

It is of interest to study how the fluctuations appear to look like in the urban part and the highway part of the MVEG cycle. (Values in parenthesis are those calculated with the original code = no filtration.)

STD1	Urban: 4038 (8302)	Highway: 3254 (6513)
STD2	Urban: 4036 (8369)	Highway: 3252 (6589)
STD3	Urban: 4107 (8528)	Highway: 3264 (6599)
ECO1	Urban: 4223 (8867)	Highway: 3307 (6521)
ECO2	Urban: 4091 (8518)	Highway: 3269 (6457)
ECO3	Urban: 4136 (8595)	Highway: 3249 (6395)

A quick look indicates that there is a slight more regulation in the ECO mode, in both urban and highway part. Next, it is interesting how much regulation is present per km in the MVEG.

There are about 4000 fluctuations in the urban part, resulting in ~ 4000/4 (division by 4 because the urban part is 4 km long). About 1000 fluctuations per km in the urban part is the result.

Corresponding analysis was made for the highway driving and results in ~ 3200/7 (division by 7 because the highway part is ~ 7 km long). About 450 fluctuations per km are received in the highway part, which is about half the regulation compared to the urban part. This is all logical, since the urban part is representing city driving, where frequent stops and accelerations are very common.

5. Results – US cycle

The following chapter presents the outcome regarding the US cycle.

5.1 Driver Behavior (accelerator position HWFET) – US cycle

In the US cycle, again it becomes interesting in whether there is a difference in the two calibrations regarding the driver behavior or not. As with the EU cycle, a look at the accelerator position during the cycle is recommended (figure 5.1).

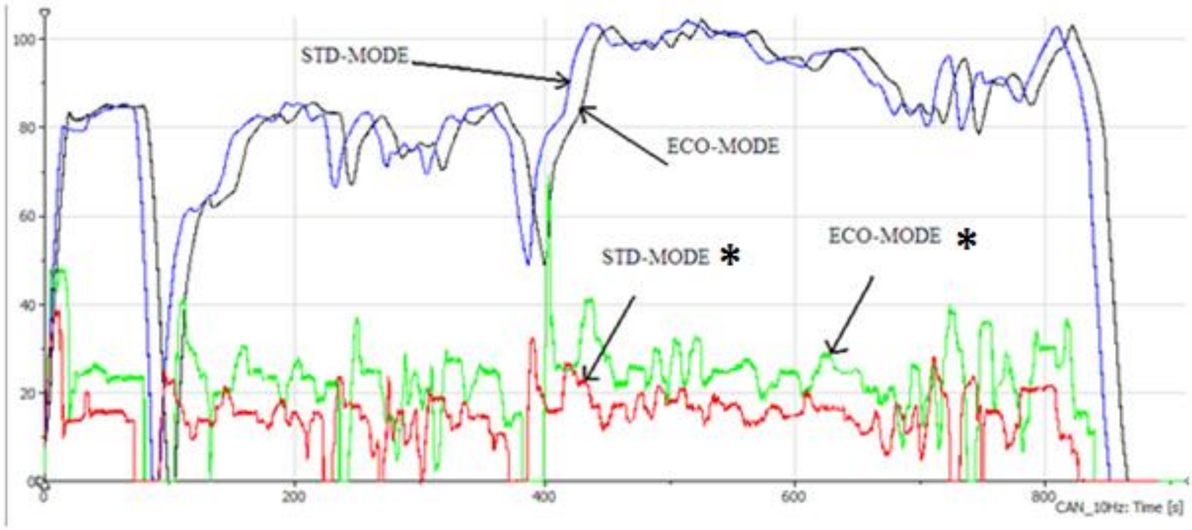

Figure 5.1 Same driving profiles, HWFET, but different accelerator positions (profiles marked with "")*

The driving cycles are near identical (it appears to be some sort of delay), but it is obvious that there is a major difference in the accelerator position levels which in turn indicates that there is some change in the driver behavior in this manner (compare the pedal profiles). Like the EU cycle, the ECO mode needs to be depressed harder to complete the cycle, in this case the HWEFET cycle (highway driving). The "STD-MODE and "ECO-MODE" lines represent the driving cycle profile, while the "STD-MODE*" and "ECO-MODE*" lines represent the accelerator position profiles (DO020668 vs. DO020654).

It is also of interest of how big the difference really is, why histograms were made in addition to the figure (5.1).

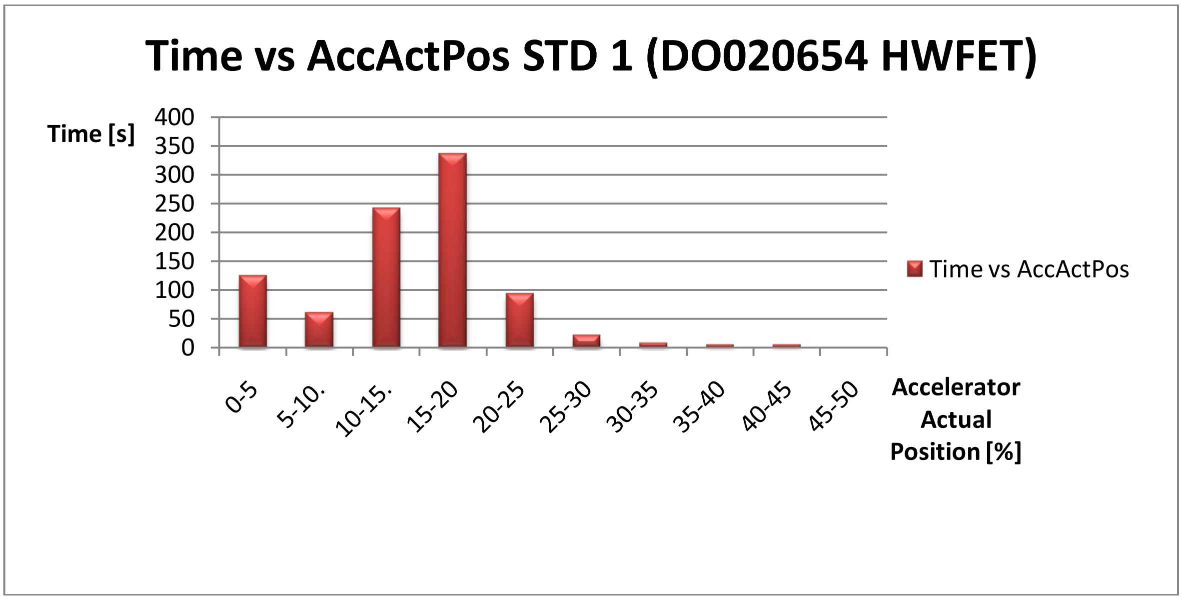

Figure 5.2 Accelerator position range – STD calibration

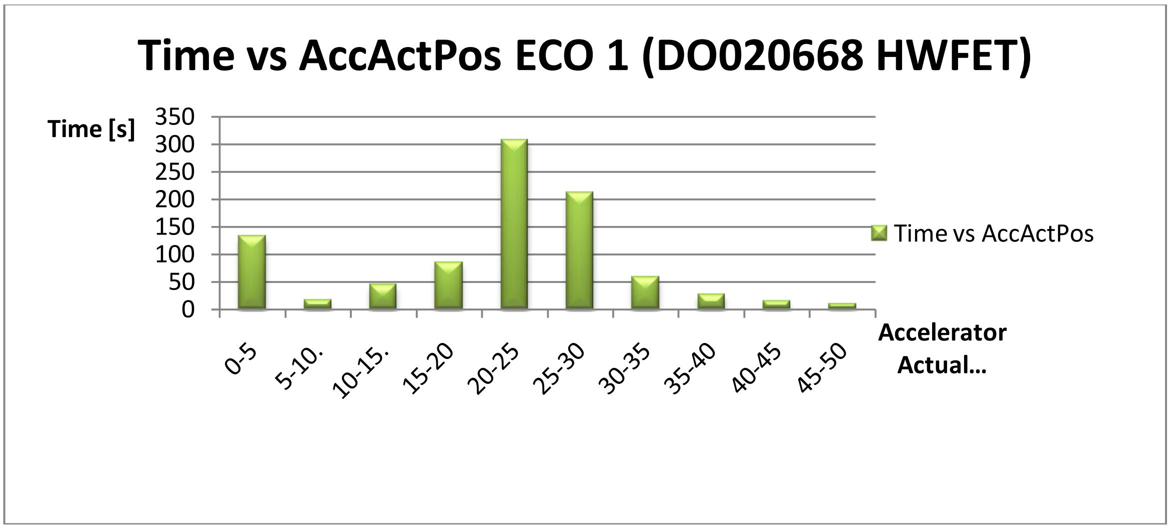

Figure 5.3 Accelerator position range – ECO calibration

It seems that the most appearing accelerator position is 15-20% (figure 5.2, STD mode). Compared to the STD calibration in the EU cycle, there are bigger accelerator positions with ECO mode as well, though it was expected due to the aggressive highway driving where a moderate pressure on the accelerator is required.

The ECO calibrated car, figure 5.3, shows what was thought earlier; more force applied on the accelerator position. Up to 50 % pedal depression overall and in some cases even more.

A comparison between the calibrations themselves in the US cycle, the ECO calibration demands bigger accelerator levels which also was expected and now it is known that there is about 15-20% more depression in ECO mode than the STD (when looking at the most dominant positions). Also, it is obvious that a wider range regarding the accelerator positions in the ECO calibrations is present. This in turn can be compared with the ECO tests in the EU cycle, where a wider range in the accelerator positions compared to the STD calibration also was present.

5.2 Driver Behavior (accelerator position FTP-75) – US cycle

Figure 5.4 is the equivalent figure as for the HWFET cycle in previous chapter. The exactly same results could be seen; almost identical driving cycle profile, but different accelerator profiles (the lines with “*”) (DO020666 vs. DO020655).

The histogram in figure 5.5 and figure 5.6 show the same characteristics as the ECO calibration did in the EU and the THN-VBG cycles; dominating position from 0-5% depression.

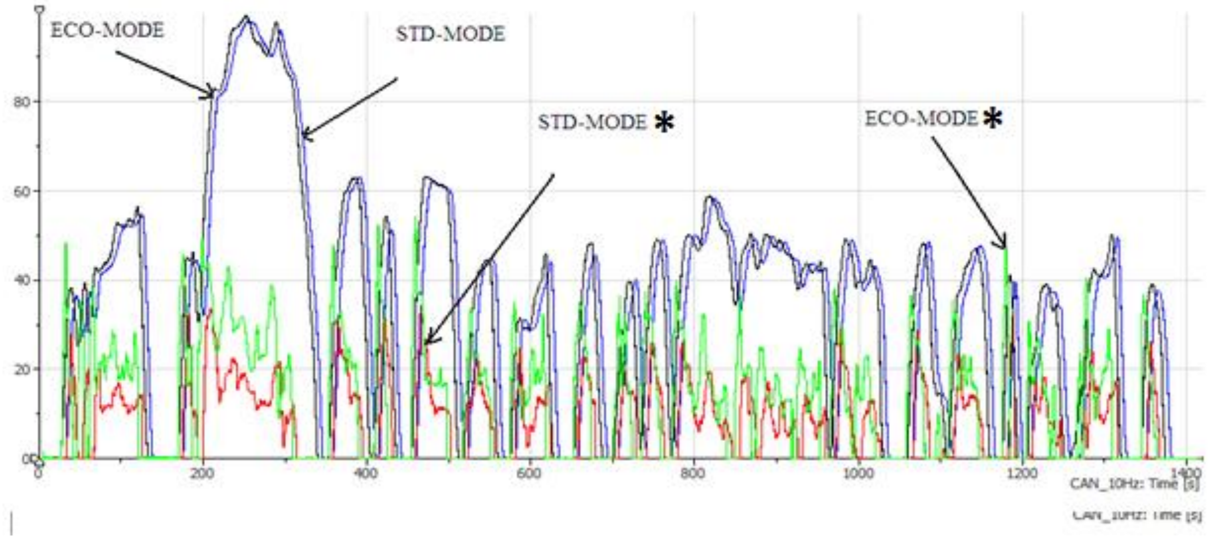

Figure 5.4 Same driving profile, FTP-75, different accelerator positions (profiles marked with “”)*

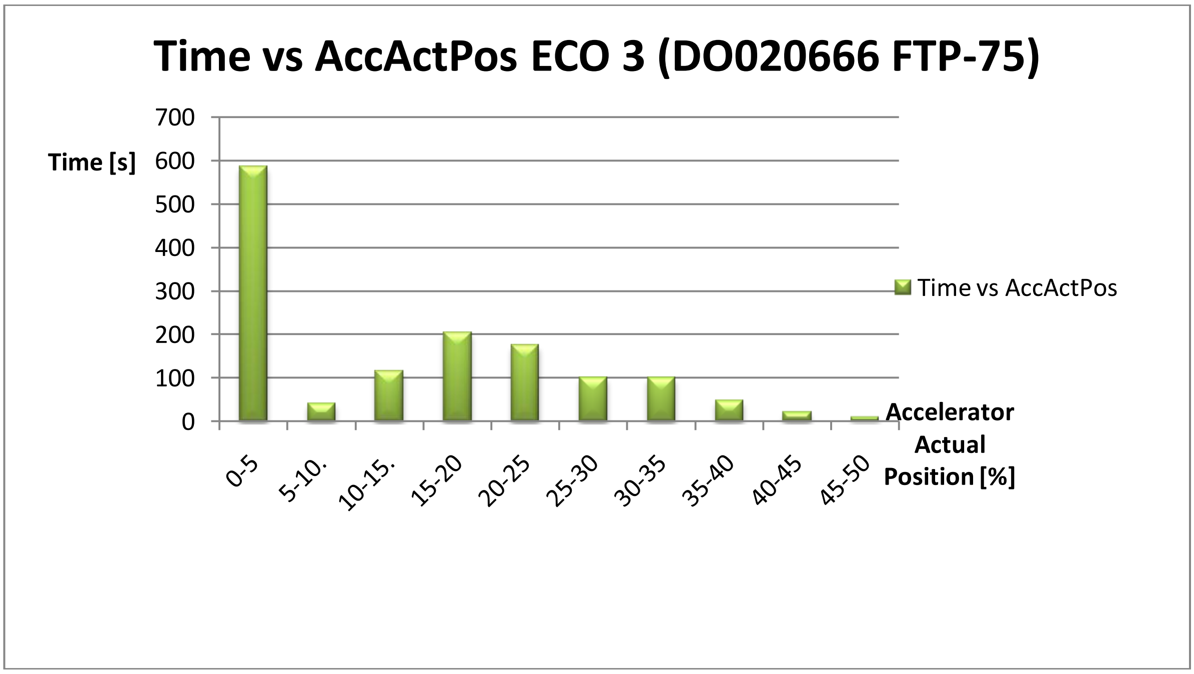

Figure 5.5 Accelerator position range – ECO calibration

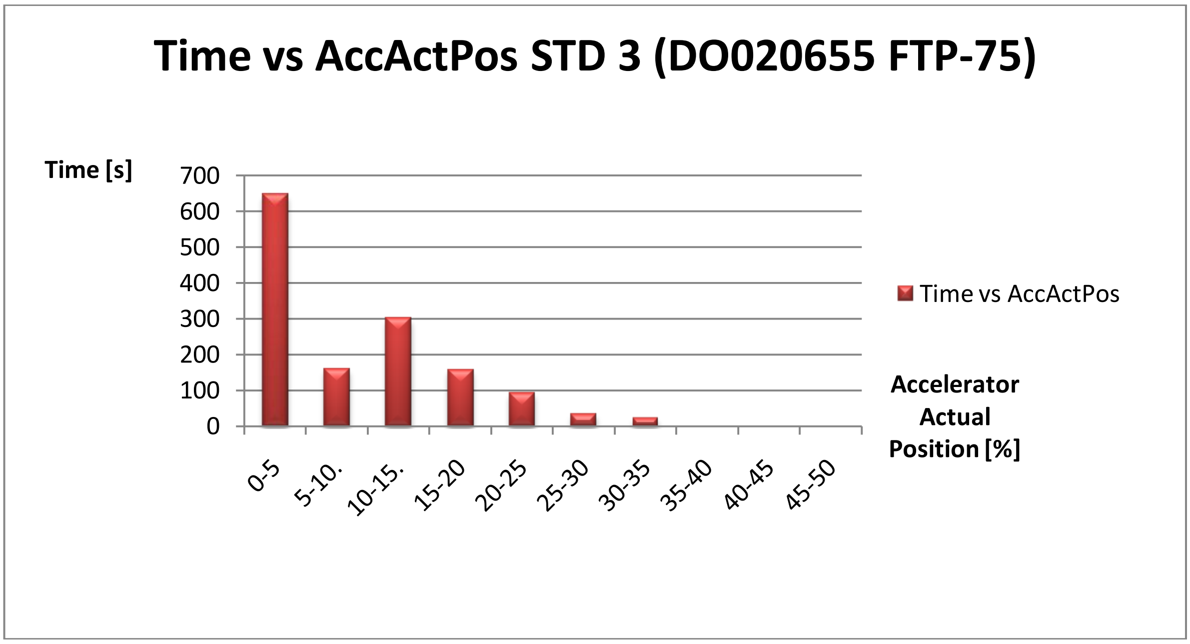

Figure 5.6 Accelerator position range – STD calibration

The acceleration positions could be summarized as:

The HWFET cycle showed a new "characteristic" since it was not present in any other cycle. It should be taken in consideration that this cycle, HWFET, is known for its aggressiveness, which is one reason why there is a "new" results regarding the accelerator positions. The FTP-75 showed the same characteristics regarding the accelerator positions in both ECO and STD mode, as was the case earlier in the study (compare with EU cycle and THN-VBG cycle).

5.3 Driver Behavior (follow targeted speed) – US cycle

A total of eight tests were driven, four were driven in the FTP-75, two tests per calibration and four tests were driven in the HWFET, also two tests per calibration. The correlation factor is used in purpose to compare drivers' ability to follow instructions, in this case the speed.

FTP-75

This standard calibration test (DO020652) passed the cycle without any kind of difficulties. A correlation factor of ~0,97 indicates that the driver almost copied the reference cycle. A slight vehicle speed exceedance could be distinguished through the whole cycle, though it is only by some km/h. It should be remembered that it is impossible to follow the route with 100 % precision, which means that a correlation factor of 1 will not be able to achieve.

The eco test did pass the cycle very good as well (figure 5.8), with a slight decrease of the correlation factor. Another thing to note is that the US-cycles are more aggressive overall, making them harder to drive.

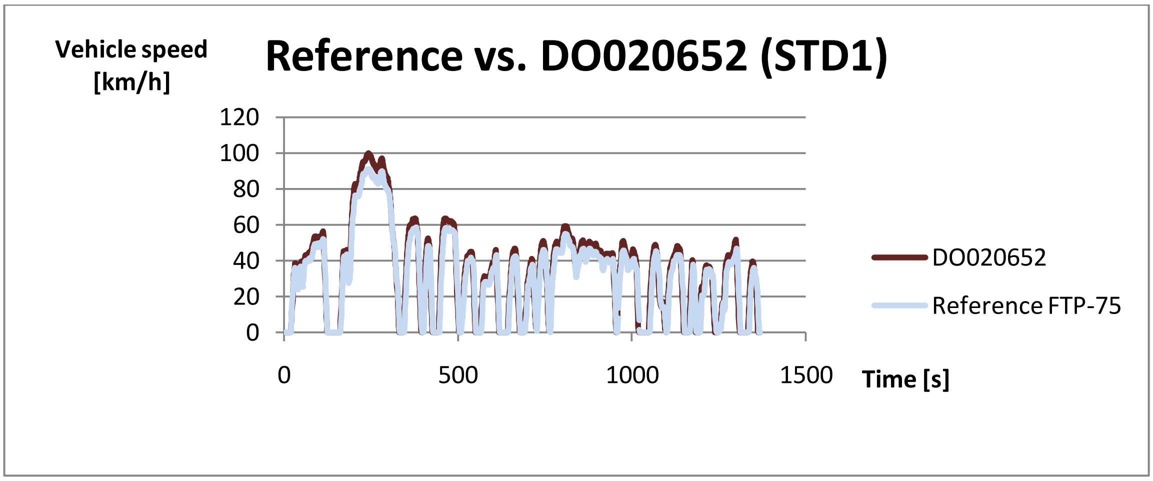

Figure 5.7 The light line is the reference, dark line shows driver's ability to copy the reference

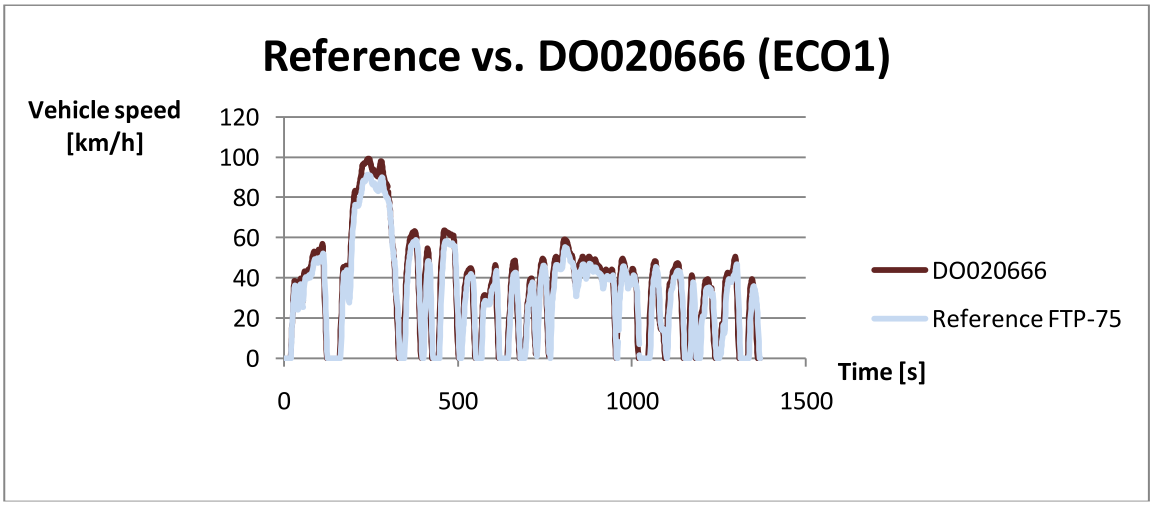

Figure 5.8 Reference data vs. driver's ability to follow targeted speed

HWFET

The highway test is probably easier to copy than the FTP-75 route, firstly because of its simplified pattern and secondly because of less accelerations and retardations. It also takes about 600 seconds less to complete than the FTP-75.

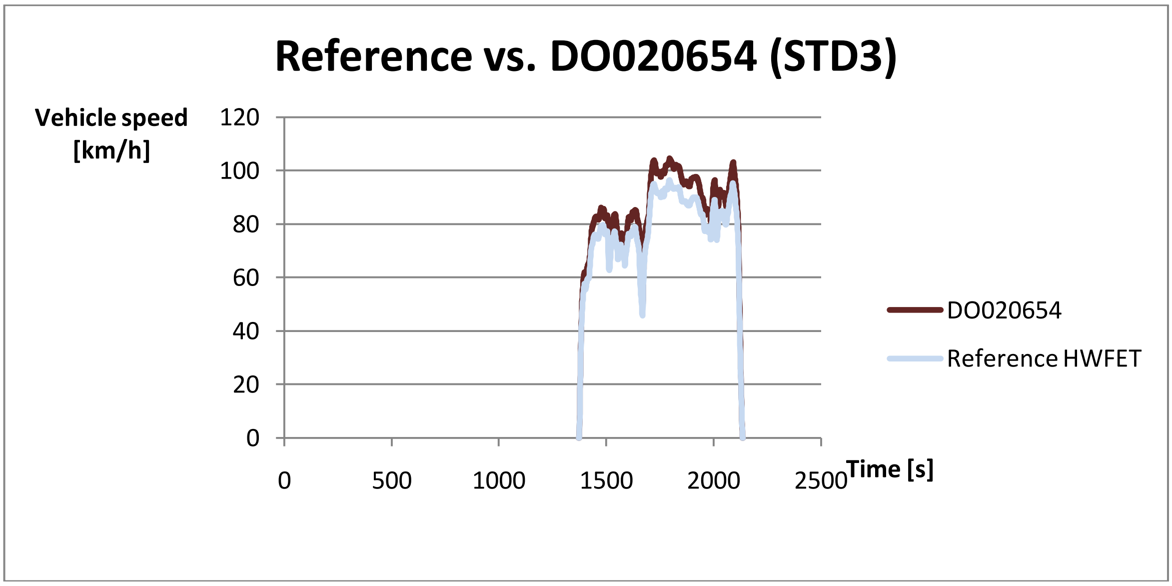

Figure 5.9 The light line is the reference, the dark line shows drivers' ability to follow the reference – highway driving

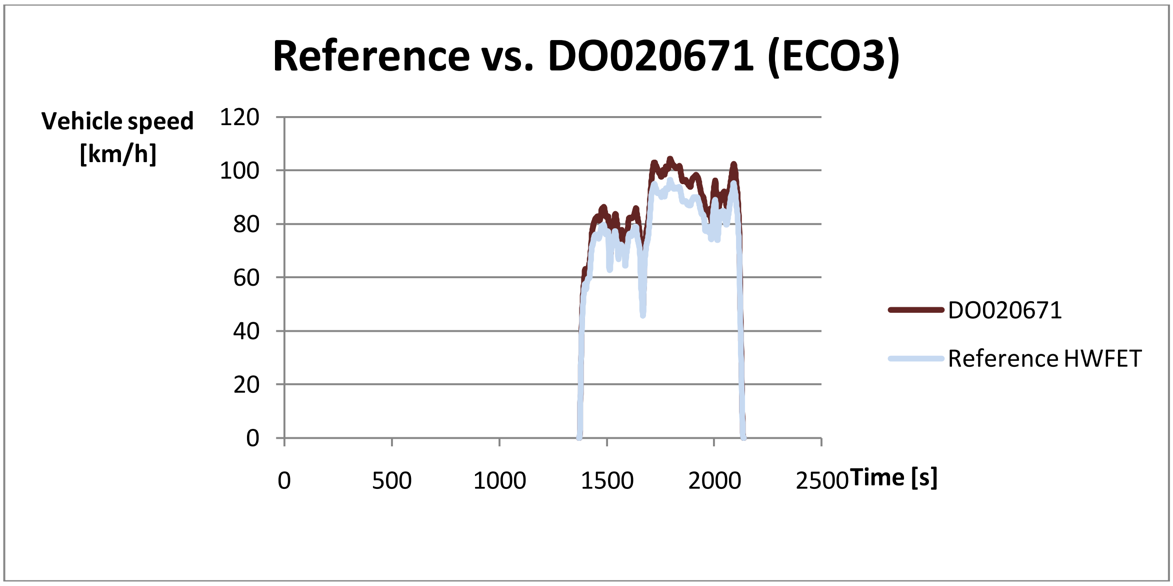

Figure 5.10 Reference data vs. driver's ability to follow targeted speed

Correlation factors FTP-75

According to the results in table 5.2 it is evident that the HWFET cycle is easier to complete in the manner of following the targeted speed, mainly due to less stops and accelerations compared to FTP-75.

An analysis, similar to the one in the EU-cycle, was done to compare the correlation factors of each test with its corresponding regulation to see if there is any relationship between correlation factor and regulation.

The results signifies that there is no relationship between them, since in first case, HWFET, have the highest correlation factor (ECO 4) which is associated with least regulation and in the other case, FTP-75, have the best correlation factor (STD1) which is associated with the test with most regulation.

Table 5.1 Summary of the correlation factors in the FTP-75

Ref. (FTP-75) vs. STD 1	Ref. (FTP-75) vs. STD 2	Ref. (FTP-75) vs. ECO 1	Ref. (FTP-75) vs. ECO 2
Correlation	Correlation	Correlation	Correlation
0,976517	0,973056	0,95338	0,971654

Correlation factors HWFET

Table 5.2 Summary of the correlation factors in the HWFET

Ref. (HWFET) vs. STD 3	Ref. (HWFET) vs. STD 4	Ref. (HWFET) vs. ECO 3	Ref. (HWFET) vs. ECO 4
Correlation	Correlation	Correlation	Correlation
0,998165	0,997225	0,997301	0,998318

5.4 Fuel Consumption – US cycle

The fuel consumption in US cycle is, like with the EU cycle, expected to be lower with the ECO calibrated car. In this analysis, the fuel consumption calculations are divided into a "highway" part, named HWFET, and an "urban" part called FTP-75.

HWFET

Table 5.3 Summary of fuel consumptions in the HWFET cycle

ECO 1	ECO 2	STD 1	STD 2
Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]
6,448827	6,413106	6,783338	6,743444

ECO tests [l/100km]	STD tests [l/100km]
Average: 6,4309666	Average: 6,763391

Difference: 6,4309666/6,763391 = 0,950849 (~5% better with ECO)

FTP-75

Table 5.4 Summary of fuel consumptions in the FTP-75 cycle

ECO 3	ECO 4	STD 3	STD 4
Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]
9,714058	8,526675	10,02183	9,014211

ECO tests [l/100km]	STD tests [l/100km]
Average: 9,1203665	Average: 9,5180205

Difference: 9,1203665/9,5180205 = 0,9582 (~5 % better with ECO)

As expected, a positive consumption with the ECO calibration compared to the STD calibration is achieved. As much as 5 % better fuel consumption with ECO in both highway and city driving, identical to the results in the EU-cycle, where an improvement of also 5 % was achieved with the ECO calibrated car.

A wrap up regarding the fuel consumption in all the driving cycles indicates that the ECO calibration really improves the fuel consumption, especially in the standardized driving patterns (EU and US). The THN-VBG cycle has not the same positive effect but it is still regarded as better with ECO.

5.5 Fluctuation Value – US cycle

The accelerator regulation is central when studying the driver behavior. The values in parenthesis are those compiled with the original code, meaning no filtration.

HWFET

Table 5.5 Shows the fluctuations during the HWFET with both calibrations

Tests:	STD 3	STD 4	ECO 3	ECO 4
Number of fluctuations	7736 (15290)	8157 (16704)	7852 (15529)	7319 (14505)
Average ECO	7586 (15017)			
Average STD	7947 (15997)			

FTP-75

Table 5.6 Shows the fluctuations during the FTP-75 with both calibrations

Tests:	STD 1	STD 2	ECO 1	ECO2
Number of fluctuations	9118 (18777)	8782 (17954)	8542 (17037)	8559 (16881)
Average ECO	8551 (16959)			
Average STD	8950 (18366)			

It appears to be a negligible difference in the fluctuations, which is in common with what the EU cycle showed. There is sufficient data to support the fact that the driving behavior (when speaking of accelerator regulation) does not change between ECO and STD calibration when driving the standardized driving cycles.

6. Results – THN-VBG cycle

The sixth chapter is the final result chapter. It will present the results regarding the THN-VBG cycle.

6.1 Driver Behavior (accelerator position) – THN-VBG cycle

Figure 6.1, is the equivalent figure for the one in chapter 4.1 and 5.1. It shows how the pedal profiles (lines marked with "*") looks like when driving identical cycle, in this case the THN-VBG cycle, with different calibrations. Since it is driven in real traffic, the driving pattern can never be the same, which also can be seen in the figure 6.1. Even though it is hard to see the graphs themselves, it is still discernable which of the calibration had to be depressed more than the other. Again, the same results as earlier emerge; the modification in the calibration does change the drivers' behavior in the manner that drivers have to press the accelerator harder to complete the THN-VBG pattern with the ECO-calibration.

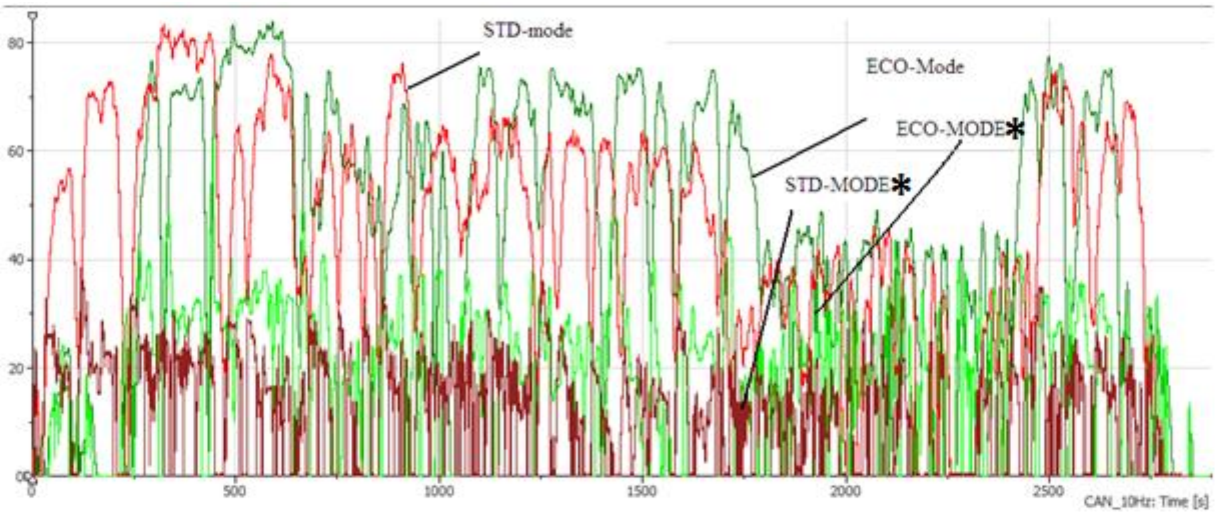

Figure 6.1 Same cycle driven – different accelerator pedal regulation (lines marked with "")*

In addition to the describing image (figure 6.1), histograms were made on all the tests with this driving pattern, whereas they describe what accelerator positions dominate during the cycle tests. By studying the histograms it is quite easy to see how the pedal was depressed during the cycles and with aid of it, it is possible to see further connections between the two calibrations. Some of the histograms are presented on next page.

ECO calibration – Accelerator positions

As mentioned before, the histograms were made out of 20 classes and an accelerator range of 0-100% due to bigger variations. From the previous analysis, the EU cycle, it was noted that in the ECO calibration, there was a bit more depression of the accelerator than the STD, which is also what THN-VBG cycle show. This was expected to be since the fact that one has to depress the accelerator harder in the ECO-calibrated car. Samples of few diagrams are presented in figures 6.2, 6.3 and 6.4.

The ECO histogram in figure 6.2 shows a range from 0%-65%, though it has to be taken in consideration that the big ranges (50% - 65%) are only present for a few seconds and should therefore not be taken in conclusion since these few seconds cannot represent the whole cycle's characteristic, which in this case is 2700 seconds (THN-VBG- cycle).

A fair conclusion from the histogram in figure 6.2 (and also 6.3 – 6.4) would be that the dominant accelerator positions, apart from the 0%-5%, is the range between ~15% and ~35%. This conclusion is common for ~80 % of all the ECO mode runs.

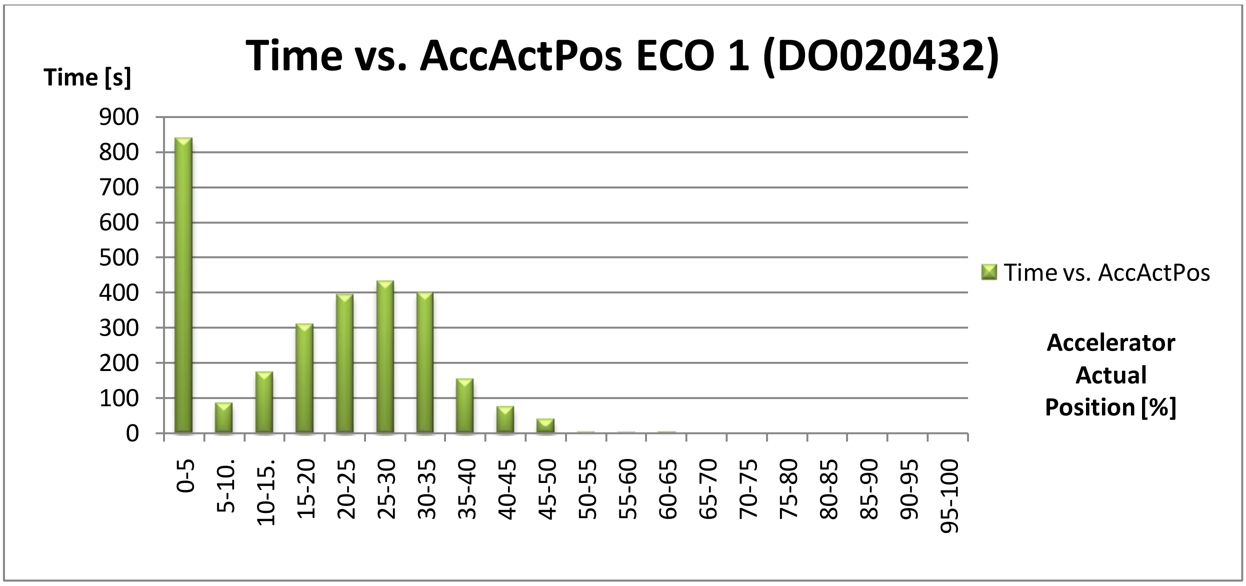

Figure 6.2 Accelerator position range – ECO calibration

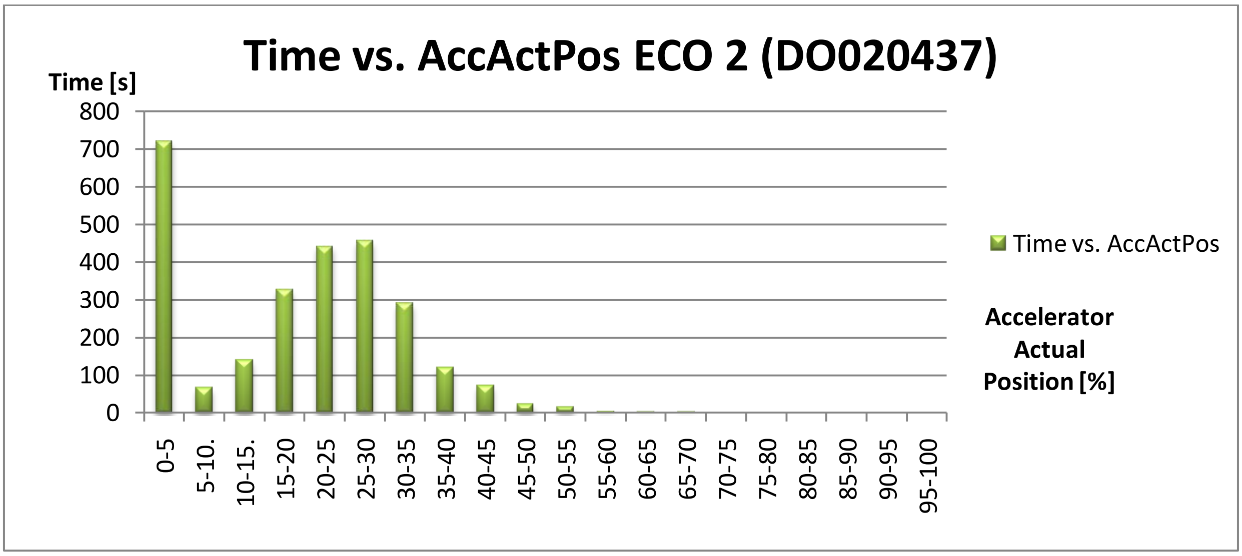

Figure 6.3 Accelerator position range – ECO calibration

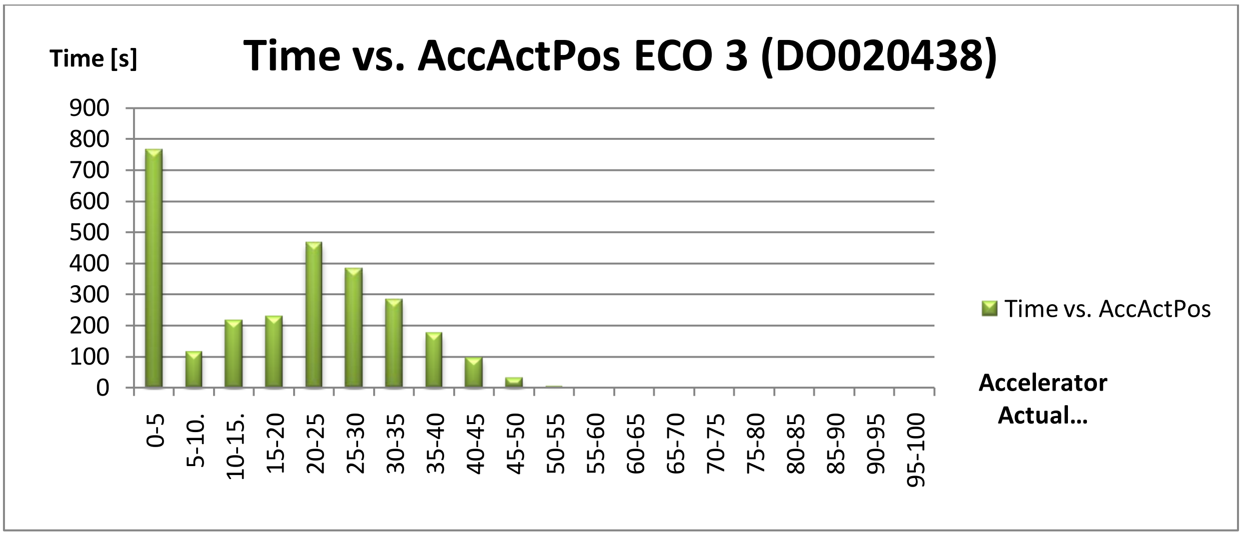

Figure 6.4 Accelerator position range – ECO calibration

Figures 6.3 and 6.4 are other examples presenting the same fact. There is a big range yes, but during the most time, the accelerator is depressed somewhere around 15%-35% (apart from the 0-5% range).

The final conclusion regarding the ECO mode and accelerator positions (THN-VBG cycle) is summarized next:

The tests where ECO mode is activated, there are many different ranges, some of them up to 85%, but since these big ranges only appear for a few seconds, they cannot be concluded here. Apart from the 0%-5% interval, the most common accelerator positions are ranging from ~15 to ~40 % of total pedal capacity. Also, what could be discerned in these cycles is a secondary peak (the first is found in the 0%-5% interval), which appears somewhere in the range ~20% to ~30%. See figures 6.2, 6.3 and 6.4.

STD calibration – Accelerator positions

The STD-calibration tests in the EU-cycle did not require as much pressure on the accelerator as the ECO-calibration. Let's now have a look at some samples (figures 6.5, 6.6 and 6.7) done for the STD calibrated car during the THN-VBG cycle.

A brief analysis of figure 6.5, 6.6 and 6.7 makes it noticeable that the overall range is quite smaller than the ECO calibrated car, which basically is expected since it's more aggressive. As with the ECO car, there is a secondary peak, but this time it appears in the range ~10% - ~20%, which is about 10 % less compared to ECO.

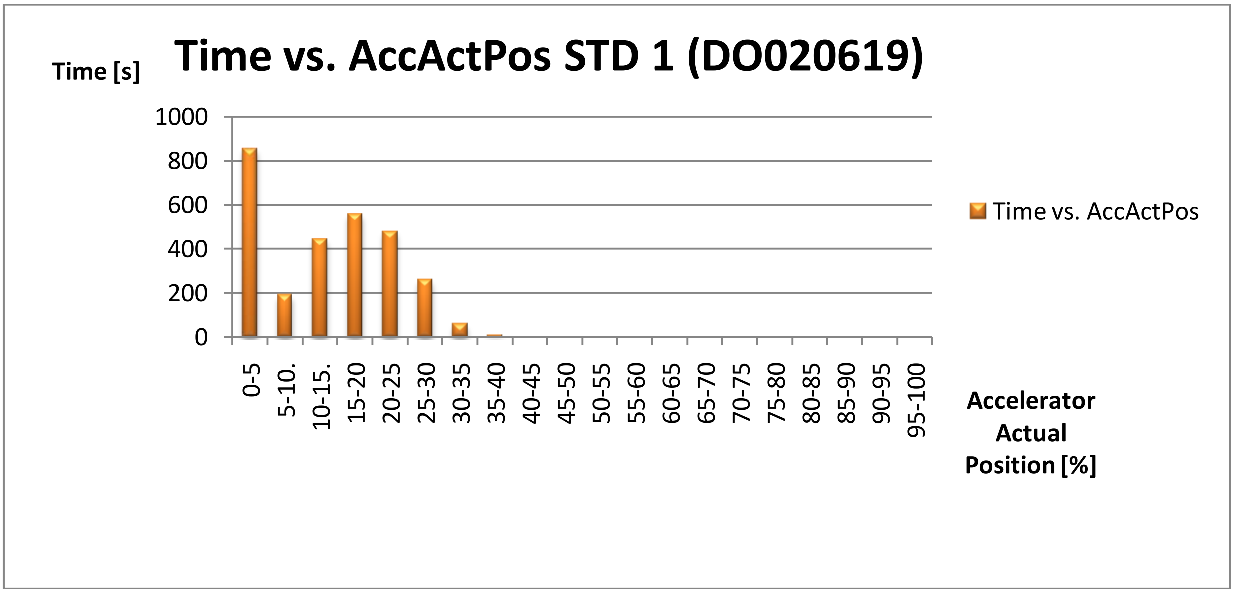

Figure 6.5 Accelerator position range – STD calibration

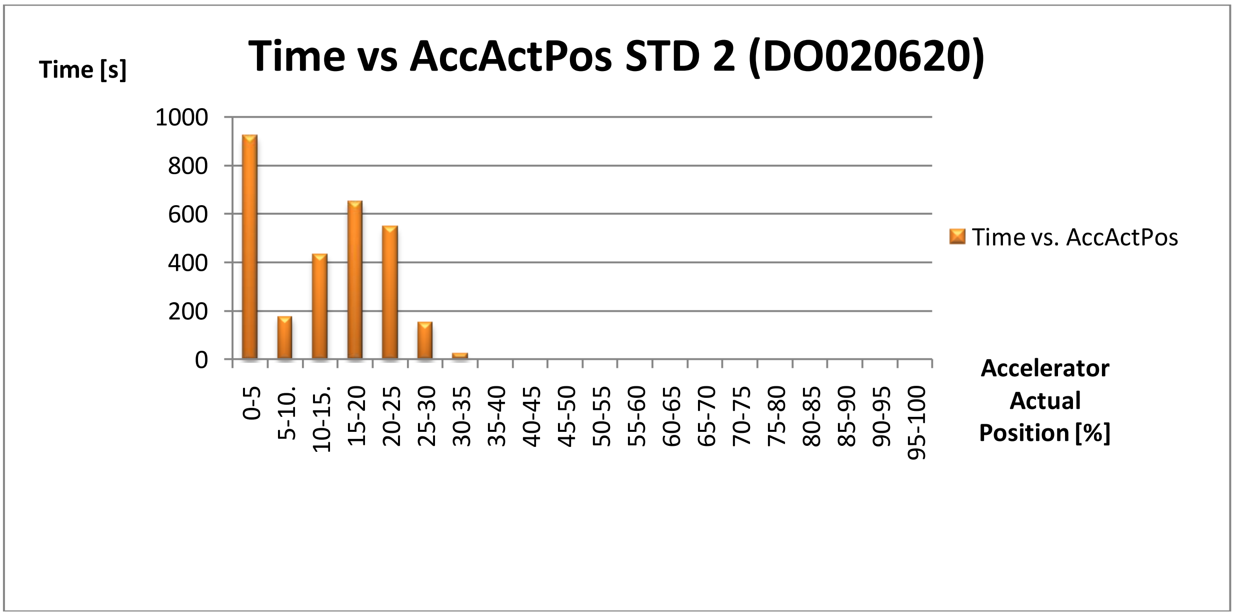

Figure 6.6 Accelerator position range – STD calibration

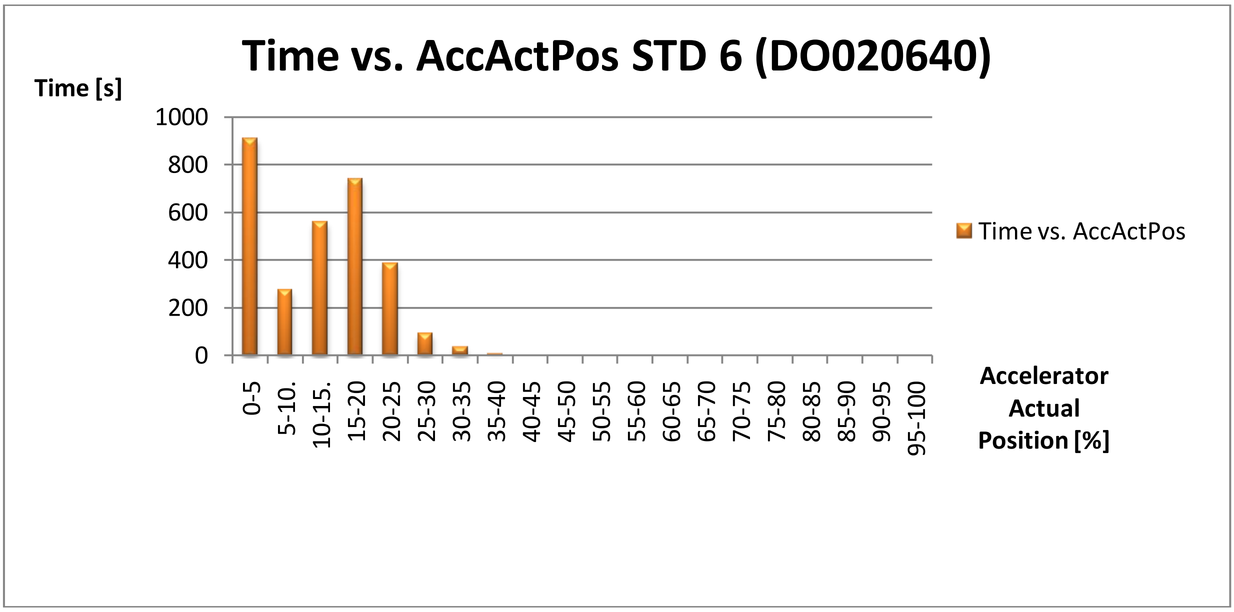

Figure 6.7 Accelerator position range – STD calibration

An overall summary between these two calibrations regarding the accelerator position in the THN-VBG cycle follows:

- ECO calibration has a wider overall range
- The secondary peak in the ECO car appears in the range of ~20% - ~30%
- The secondary peak in the STD car appears in the range of ~10% - ~20%

6.2 Driver Behavior (acceleration levels) – THN-VBG cycle

The main aspects looked at in the THN-VBG cycle regarding the driving behavior are the accelerations levels and choice of gear.

Acceleration levels ECO

Most appearing vehicle acceleration lies in between 0 m/s^2 and 0,4 m/s^2, as shown in figure 6.8 and 6.9. (All of the ECO tests showed the same results).

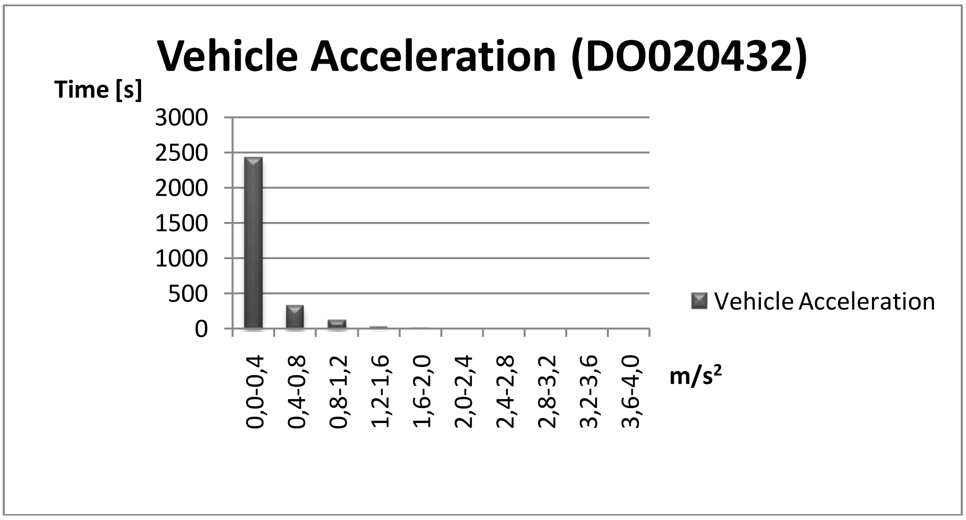

Figure 6.8 Acceleration levels – ECO calibration

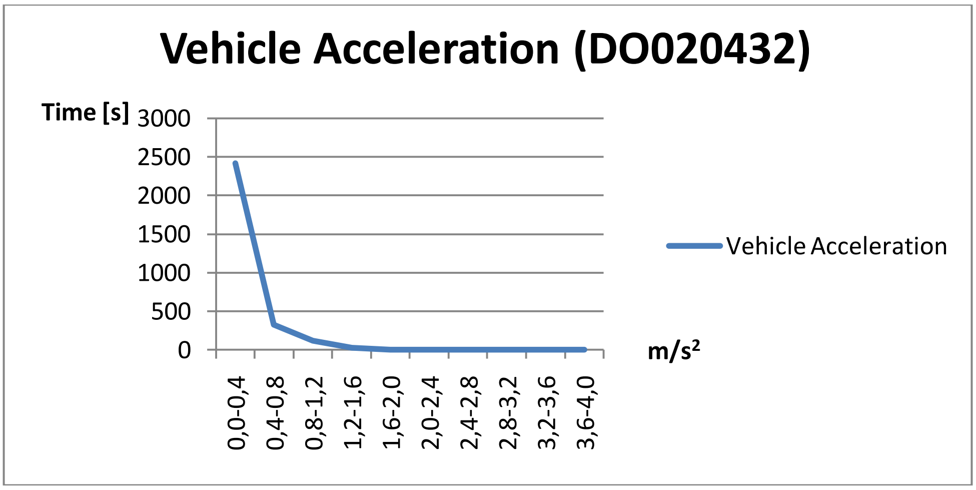

Figure 6.9 Acceleration levels – ECO calibration

Acceleration levels (ECO tests) could be summarized as:

- Most common acceleration (0 m/s^2 and 0,4 m/s^2) – for about 2500 seconds of total time.
- Rarely reaching accelerations of 2,8 m/s^2 and above (according to all tests)

Acceleration levels STD

The acceleration levels for the STD calibration appear to be near the same as with the ECO calibration. Though, the difference lies in the range acceleration range; The STD calibrated car, reaches acceleration levels of over 2,8 m/s^2 often, even though it might be for only a second, whilst the ECO never does.

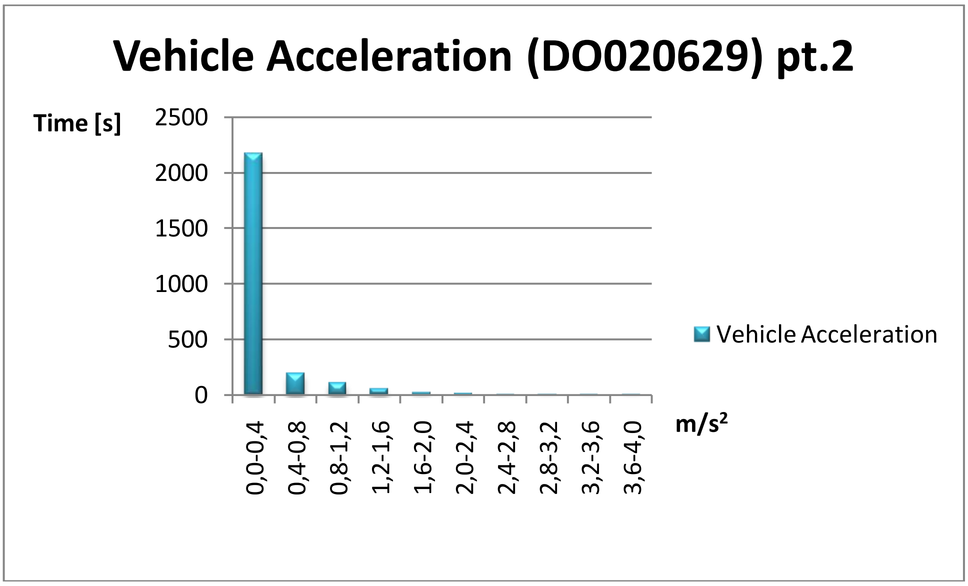

Figure 6.10 Acceleration levels – STD calibration

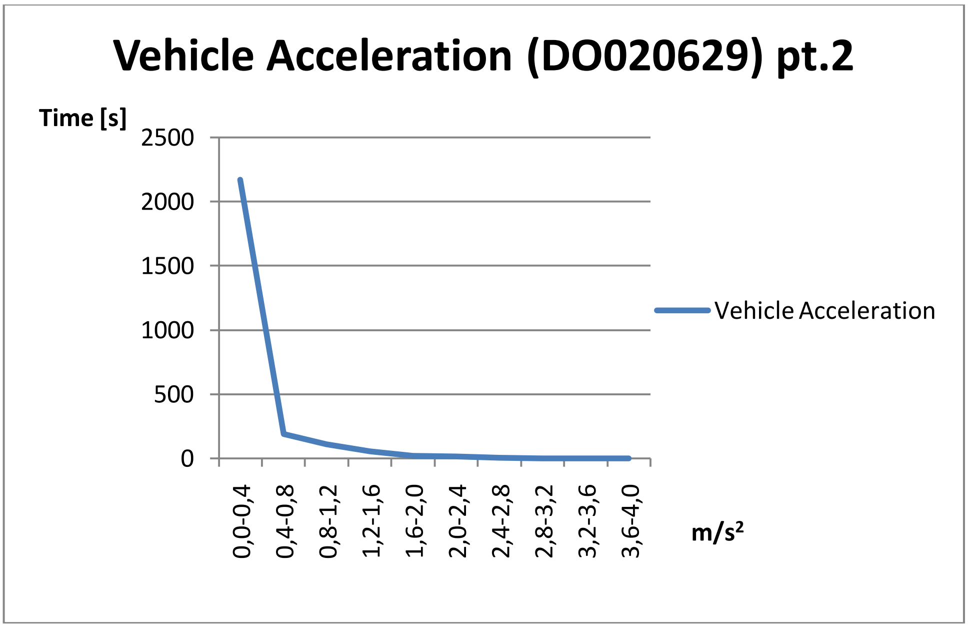

Figure 6.11 Acceleration levels – STD calibration

The conclusion regarding the acceleration levels would be that they are pretty much the same, in a characterizing way, though they are reached in different ways. An example of the last mentioned is that the drivers had to work differently with the accelerator.

6.3 Driver Behavior (choice of gear) – THN-VBG cycle

The choice of gear is one of the primary factors that control how the fuel consumption is affected. The higher gear chosen the less fuel consumed, therefore it is supposable that the ECO mode uses higher gear overall when the THN-VBG tests are run.

Figure 6.12 is a summary of six STD tests. Characterizing for the calibration is that all of the tests are running on the fourth gear during the most part of time in the THN-VBG cycle. Another notice is that only one STD test, STD 4, runs on sixth gear once (for about 10 % of total cycle time).

Figure 6.13 is the equivalent figure for the ECO calibration. Here, it could be seen that the most common gear is the fifth where as the sixth gear is present in all the ECO tests.

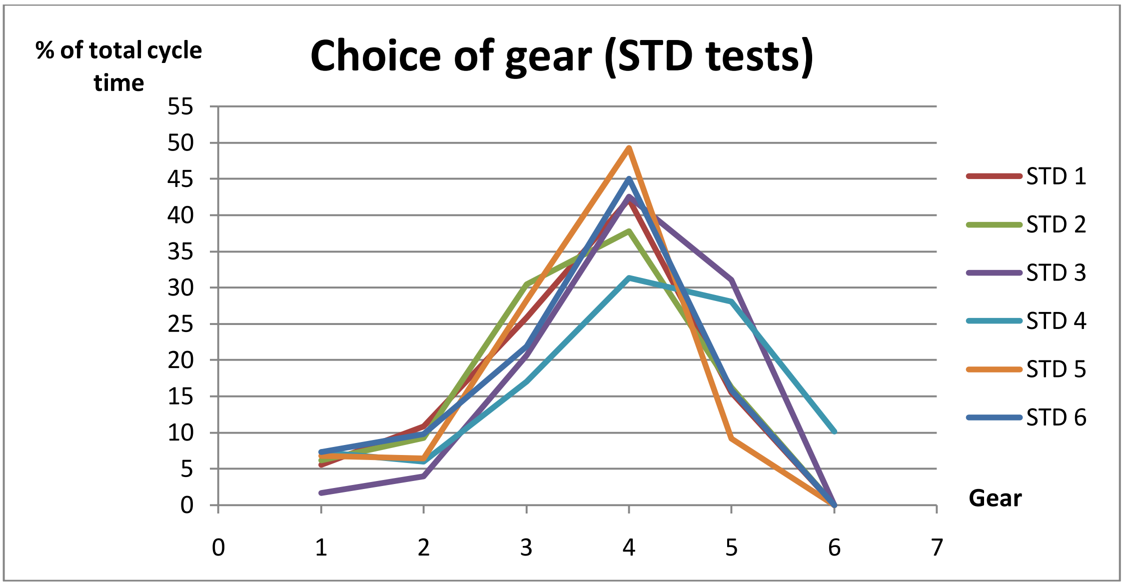

Figure 6.12 The 4th gear appears to be the most common in the STD calibrated car

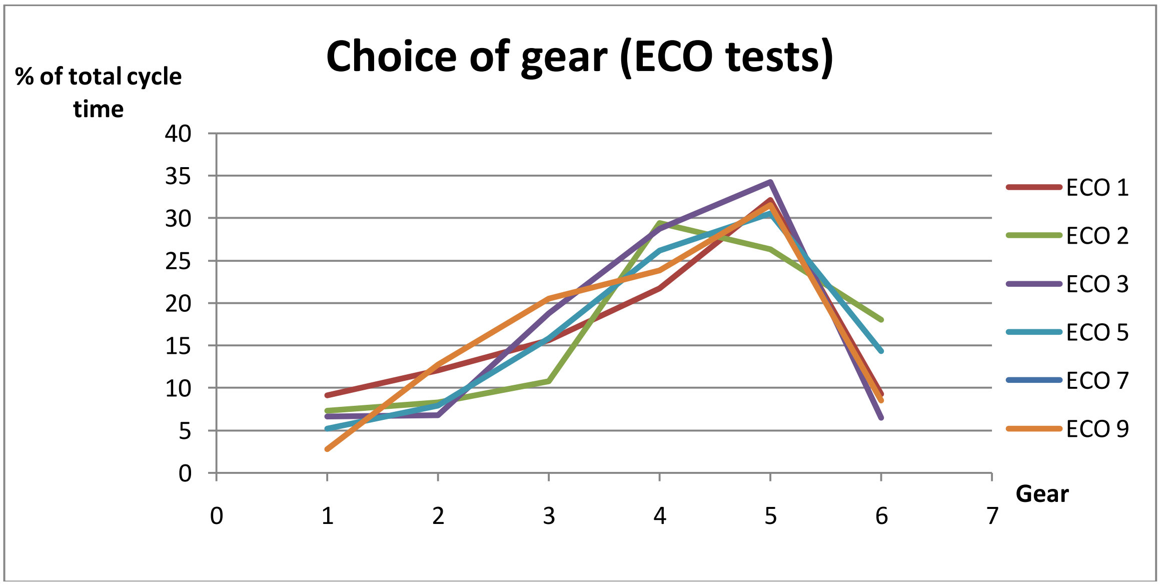

Figure 6.13 In the ECO calibrated car, the tests were mostly driven with 5th gear

Figure 6.14 shows the difference between the calibrations in the manner of chosen gears. The truth is that STD calibration does run on a lower gear, mostly the fourth, while the ECO calibration runs, more often than not, in the fifth gear. This is also why the ECO mode presents lower fuel consumption, which in this case is the purpose. In this figure, it is more obvious that the most common gears in the STD calibration last longer than the most common in the ECO calibration. For example, it could be seen that fourth gear in STD calibration is driven for about 40-50 % of the time (for the most part of the tests), while ECO calibration's most common gear, the fifth is running for about 30-35 % of the total cycle time.

But there were a few ECO tests that were driven with fifth gear for the most part of time also, though; they would not be representative since the majority of the ECO tests show the opposite, see figure 6.14 (dark tones = STD, light tones = ECO)

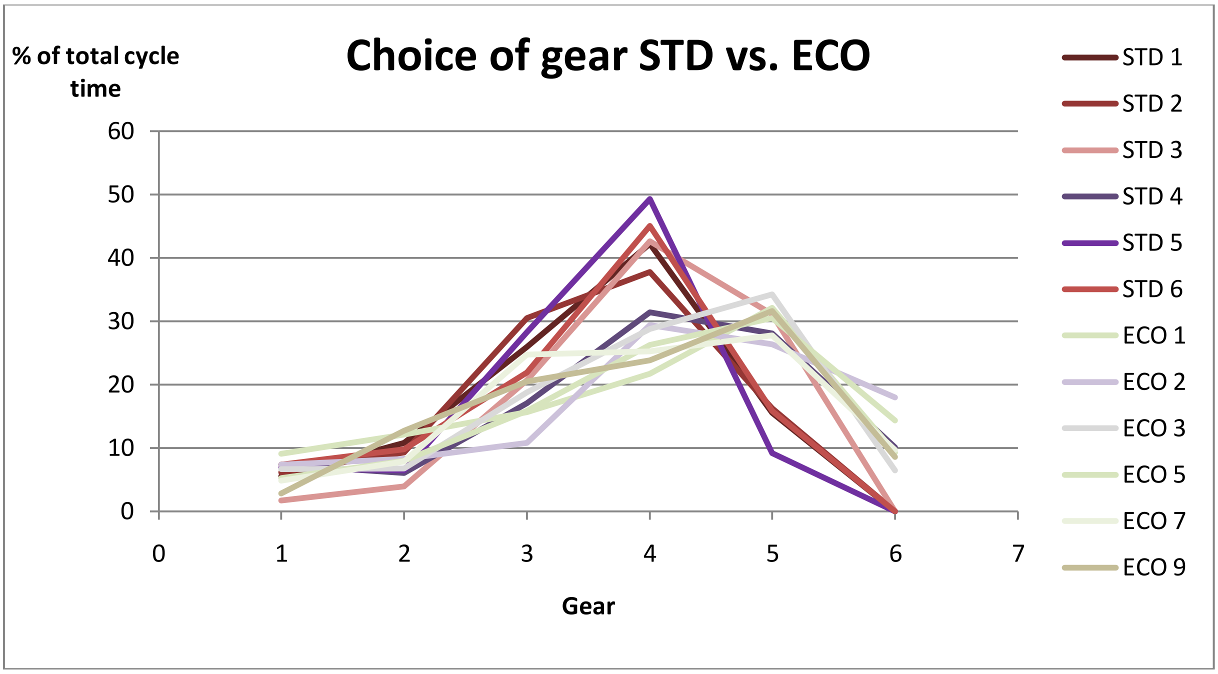

Figure 6.14 Shows the difference between the calibrations in manner of most common gears used during THN-VBG cycle

Next, it is interesting to see how big part of the time the gears were driven with open and locked converter (figure 6.15).

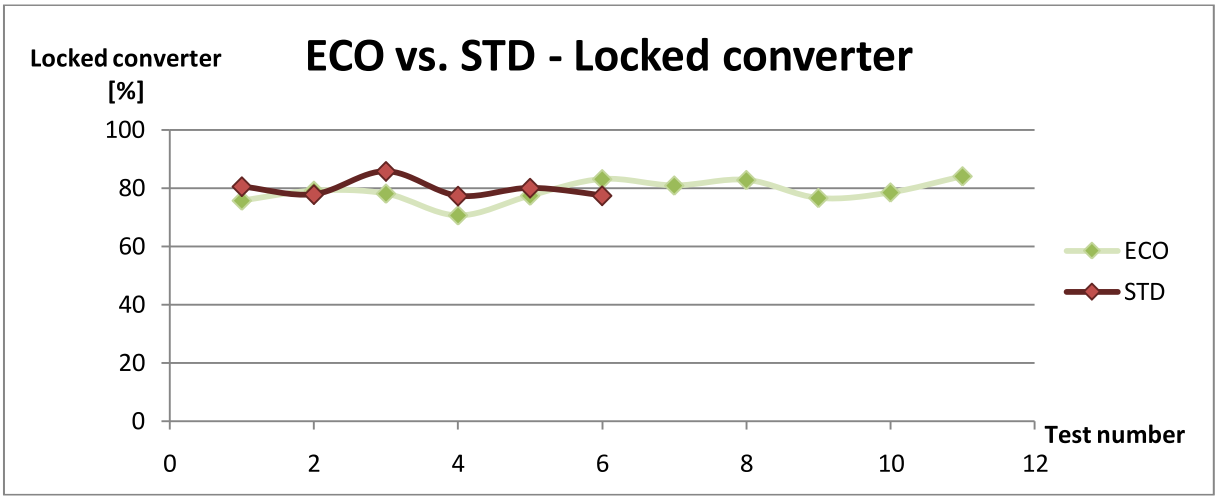

Figure 6.15 Shows how much every test in THN-VBG cycle was driven with a locked converter

This analysis came as a surprise, since it was expected that the ECO mode would be driven more often with locked converter than the STD mode. Like mentioned earlier, the main reason behind better fuel consumption with ECO mode is because of the higher gears used, but since it also allows to go lower in rpm with locked converter, it should give at least a little rash in the "last" gear. Finally, no difference appears if one shifts in STD mode from a locked converter to another locked converter at higher rpms, compared to the ECO mode.

So there is a reason to make further analysis in this area.

6.4 Fuel Consumption – THN-VBG cycle

Since the fuel consumption parameter is a very important parameter to analyze, all the ECO and STD tests in the THN-VBG cycle were taken in consideration when calculating the fuel consumption. Firstly, the fuel consumptions with cold engine are presented (tables 6.1 and 6.2).

Table 6.1 Mean fuel consumption for all the tests driven in THN-VBG cycle (ECO mode)

ECO 1	ECO 2	ECO 3	ECO 4	ECO 5	ECO 6
Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]
12,18958	11,4232	11,71261	10,39191	11,69159	11,92473

ECO 7	ECO 8	ECO 9	ECO 10 pt.1	ECO 10 pt.2
Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]
10,99005	10,81471	10,81873	11,18423	10,42529

ECO tests cold engine [l/100km]
Average: 11,23333

An average fuel consumption of 11,2333 is the result of 11 ECO tests in the THN-VBG cycle. Noticeable is that the fuel consumption never drops below 10l/100km in any test whereas the highest value retrieved is above 12l/100km. It might sound a little huge, but it should be taken in consideration that these tests were driven in cold conditions.

Table 6.2 Mean fuel consumption for all the tests driven in THN-VBG cycle (STD mode)

STD 1	STD 2	STD 3 pt.1	STD 3 pt.2	STD 4 pt.2	STD 5	STD 6
Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]
11,15593	10,73663	10,50519	12,28529	10,08744	10,56136	11,47448

STD tests cold engine [l/100km]
Average: 10,97233
Difference: 10,97233/11,23333 = 0,97676557 (2,32 % better with STD)

Surprisingly, the STD calibrated car appears to pass the THN-VBG cycle slightly better, at least when looking at the overall average fuel consumption. Though, what should be paid attention to is also that there were not as many STD tests as there were ECO tests, which makes it very difficult to tell which of the calibrations would pass the THN-VBG circuit better under same circumstances. Also, it is not known how cold the temperatures were when the tests were performed. It is also not known if the ECO tests were driven in colder temperatures than the STD test since there is no information regarding it.

What should not be forgotten is that there were different drivers and conditions (weather, traffic conditions, red light stops etc), as well that makes it even harder to make a 100% correct statement regarding the real life fuel consumption.

The equivalent results shown in tables 6.3 and 6.4 come from the fact that a filtration was made which filtered out the cold engine part of the test, which in turn is the reason why there are better and fairer fuel consumptions here.

As seen from table 6.3, an average fuel consumption of 9,4l/100 km is present, where also wider variations are visible. For example, the best ECO test had a consumption of 7,7l/100km whereas the worst used about ~3,7l more fuel (11,4)

Table 6.3 Mean fuel consumption for all the tests driven in THN-VBG cycle, with warm engine (ECO mode)

ECO 1	ECO 2	ECO 3	ECO 4	ECO 5	ECO 6
Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]
8,533665	8,11507	8,897736	11,3802	8,824139	8,909147

ECO 7	ECO 8	ECO 9	ECO 10 pt.1	ECO 10 pt.2
Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]
9,504399	10,81065	7,71126	11,17014	9,642126
ECO tests warm engine [l/100km]				
Average: 9,408957				

Table 6.4 Mean fuel consumption for all the tests driven in THN-VBG cycle, with warm engine (STD mode)

STD 1	STD 2	STD 3 pt.1	STD 3 pt.2	STD 4 pt.2	STD 5	STD 6
Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]	Mean fuel consumption [l/100km]
9,21181	10,42399	8,579423	10,17081	9,972904	10,55492	8,09985
STD tests warm engine [l/100km]						
Average: 9,573387						
Difference: 9,408957/9,573387 = 0,98291827 (~1,70% better with ECO)						

By judging from the STD-table (6.4), the fuel consumption is not much worse at all. It is surprising since it was expected to show better improvements with the ECO-calibration.

But like earlier, there are not as many STD-tests as ECO-tests, making it hard to determine how the fuel consumption would look like if there was same amount of available data in both calibrations.

6.5 Fluctuation Value – THN-VBG cycle

The fluctuation value in this cycle is quite more interesting than previous, since different drivers and different traffic conditions are current.

Results shown in table 6.6 are done with the “5%-filter” code, which indicates that some of the data is filtered out (see chapter 3.3.3). As could be seen from table 6.6, there is 7 % more regulation with STD, even though the number of fluctuations are reduced for about half of the origin (since a filter is used now).

The 7 % more regulation could be since the STD accelerator is more responsive, which in turn means; the more movement of the accelerator, the more “happens”. As with the EU-cycle, it seems to be no relationship between regulation of accelerator and fuel consumed.

Table 6.6 Calculation of total number of fluctuation in every test (THN-VBG cycle), with modified algorithm

Tests:	ECO 1	ECO 2	ECO 3	ECO 4	ECO 5
Number of fluctuations	21185	20025	20360	19058	13210

ECO 6	ECO 7	ECO 8	ECO 9	ECO 10 pt.1	ECO 10 pt.2
14988	22191	21367	19044	22871	22490

Average: 19708

Tests:	STD 1	STD 2	STD 3 pt.1	STD 3 pt.2	STD 4 pt.2	STD 5	STD 6
Number of fluctuations	21563	21856	20528	18838	20810	20949	23358

Average: 21129 (difference: 19708/21129 = 0,9327 ~[7%])

Also, most regulation is present in a STD calibration (STD 6) while least regulation is an ECO test (ECO 5). The STD 6 has almost twice the regulation as the ECO 5, see figure 6.16. Marked ellipses in figure 6.16 showing fluctuations that are not even present in this ECO test.

But, there are some ECO tests showing high numbers of fluctuations, like ECO 7 and ECO 10, with over 22k fluctuations each. ECO 7 and ECO 10 show more regulation, than 6 out of 7 STD tests, which indicates that the ECO calibration demands quite much regulation after all. Though, the main reason why STD calibration shows 7 % more regulation overall, is because some of the ECO tests show extremely low fluctuations values, such as ECO 5 and ECO 6. So, huge variation in fluctuation values are noticed in the ECO mode, ranging from 13k to 22k, while the STD is more solid and shows a range from 20k to 23k.

But again, mostly it always depends on what driver drove the cycle and also different traffic conditions have a huge impact on the accelerator regulation.

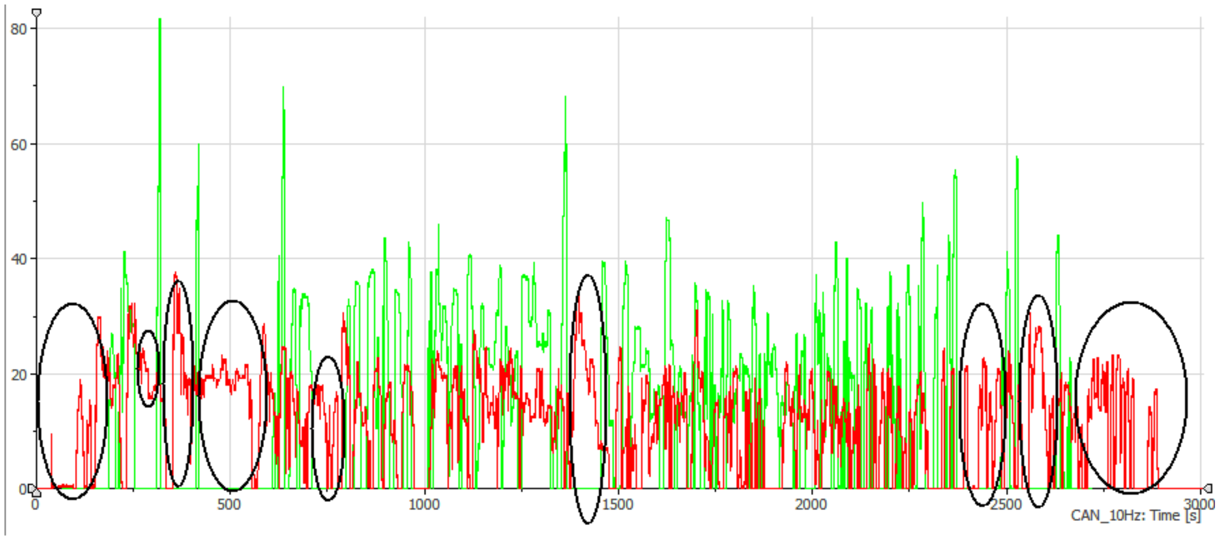

Figure 6.16 ECO vs. STD test

Where are the most fluctuations present?

ECO-mode

It is very hard to analyze every diagram in detail and tell where the most fluctuations appear. Therefore some characteristics will be presented in figures 6.17 and 6.18 which are very common for the THN-VBG circuit.

The ellipse (in figure 6.17 and 6.18) shows an interval ~ (0-500s) where there is least regulation overall. This interval is driven in some kind of highway type of driving. The rectangular is the interval which varies the most; sometimes it has very high levels of fluctuations, while sometimes it has “fewer” fluctuations (compare figure 6.17 and 6.18). The circle represents the part where the most fluctuations always appear. This depends on the city driving, where tight traffic conditions, red lights, frequent stops and accelerations etc are common – demanding more regulation.

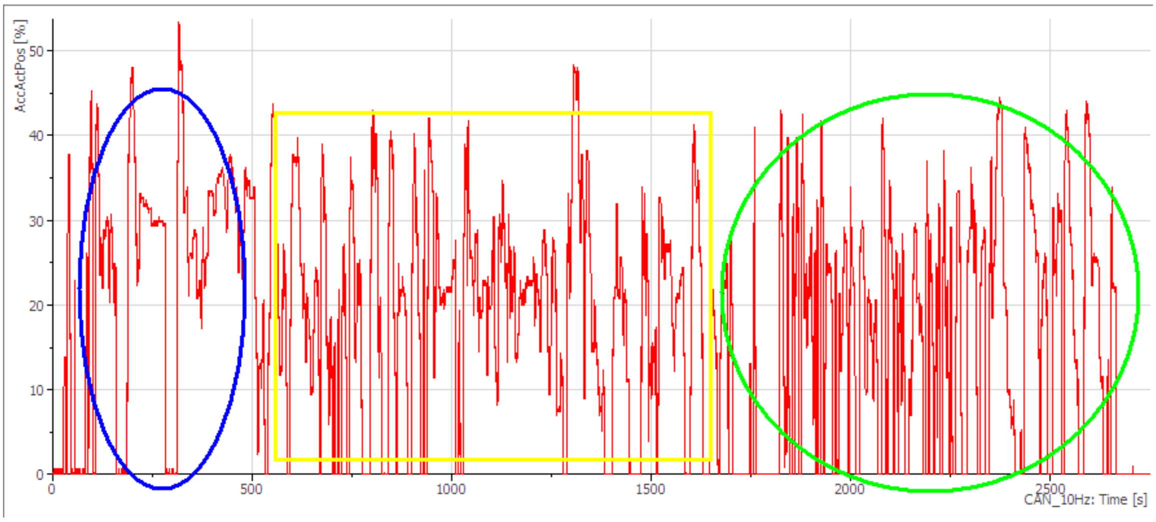

Figure 6.17 Different intervals with different accelerator regulation (ECO mode)

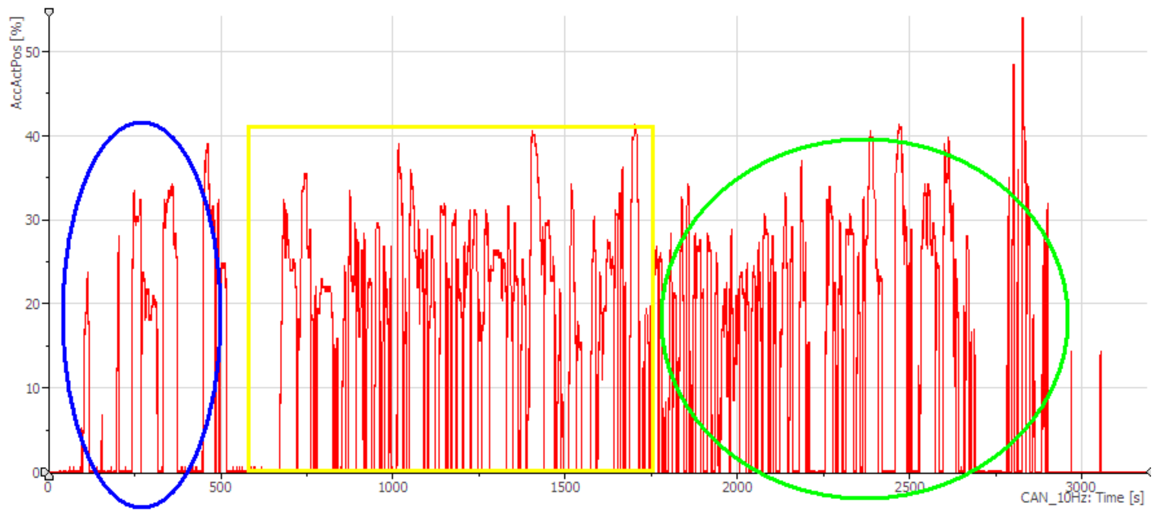

Figure 6.18 The ECO mode often shows the same characteristic (compare with figure 6.17)

STD-mode

The STD-calibrated car does not have the same characteristic as the ECO-mode. In fact, it is not possible at all to discern anything characterizing from these diagrams; compare the two figures 6.19 and 6.20.

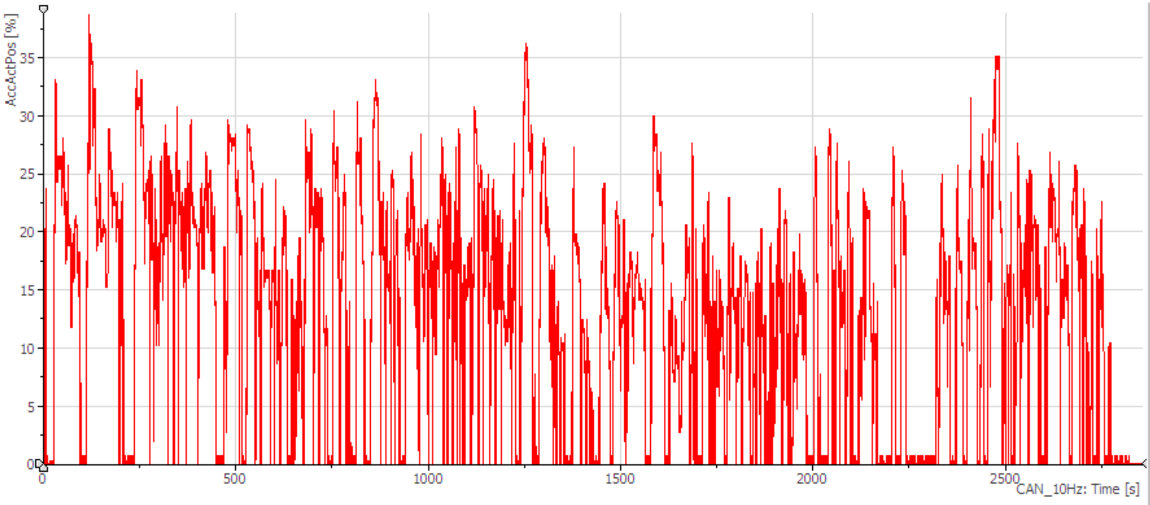

Figure 6.19 The STD calibration often shows inequality in the accelerator regulation, making it impossible to tell where most fluctuations appear

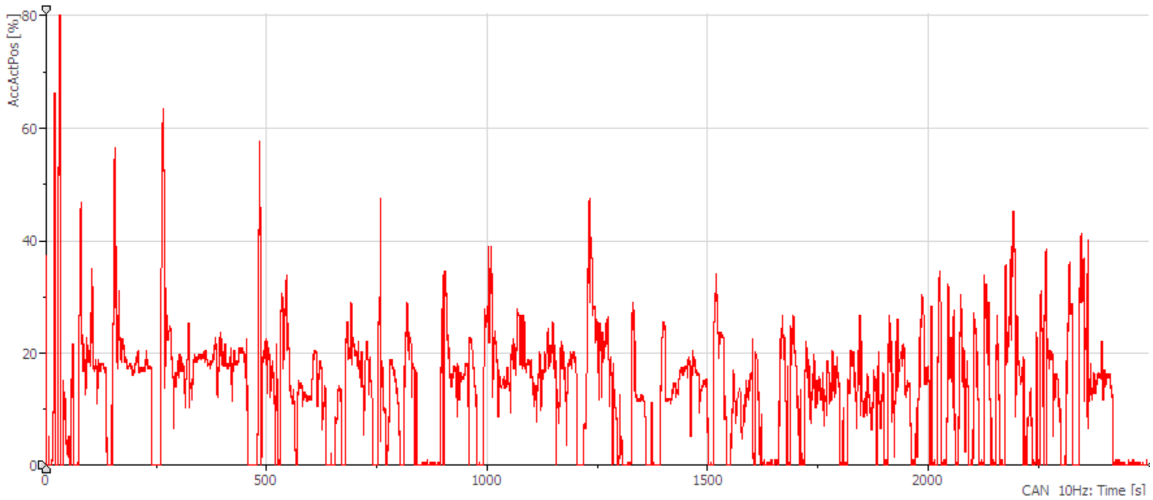

Figure 6.20 Again, it is hard to tell where the most fluctuations appear with STD mode

Figure 6.20 is another example of how the fluctuations might look like in the STD – mode. It is nowhere near figure 6.19, making it difficult to point the finger on what is characterizing for the STD-mode regarding the fluctuations during the THN-VBG cycle.

7. Conclusion

The implementation of this thesis has been very interesting and informative, but it has also brought challenges and difficulties. One of the main difficulties was the time aspect in relation to progression. For example, there were some periods when it was tricky and time consuming to obtain the information needed to complete a specific task which in case led to lost time and less effective work. Despite this, the thesis could be completed within the time line where it brought very useful conclusions regarding the ECO mode.

The working procedure had different approaches depending on which driving cycle was processed. The standardized cycles, US and EU, had the same question formulation while the THN-VBG cycle had a different one, due to the fact that THN-VBG cycle had very wide variations in the data, caused by real traffic driving by different drivers. Therefore, it was appropriate to modify the question formulation so it would fit the THN-VBG cycle and make it possible to give answers on the main aspects: Fuel consumption and driver’s behavior.

The fuel consumption showed positive numbers in all the driving cycles with about 5 % better in the EU and US cycles, while there was an improvement of only 1,7 % in the THN-VBG cycles. Like mentioned earlier, the THN-VBG is driven in real traffic by different drivers, which is a problem since real life consumption becomes very hard to determine, due to huge variations. For example, there were some tests in the THN-VBG that had better fuel consumption improvements than 1,7 % and there were also tests that showed worse fuel consumption, making the 1,7 % improvement an average number of the total fuel consumption improvement. The EU and US cycles are standardized and driven by professionals on dynamometers, where the cars are well prepared for the tests, which in case are the main reasons why the fuel consumption is better in the standardized cycles.

So why does ECO mode present better fuel consumption than the STD mode? Well, mainly because of the modification in the ECO calibration, making the ECO calibrated car drive more often on higher gears.

The driver behavior was split into a couple of minor areas: Follow instructions (demanded speed), accelerator positions and accelerator regulations were present in the EU and US cycles, while acceleration levels, choice of gear, accelerator regulation and accelerator positions were analyzed in the THN-VBG cycle.

As far as the results can tell, it is obvious to conclude that there was a minimal difference regarding the accelerator regulation in the standardized cycles, whilst there was 7 % more regulation in the THN-VBG cycle. Probably it is because of the more aggressive accelerator in the STD mode. The accelerator position ranges are always wider in the ECO mode, no matter what cycle was driven, due to more force required on the ECO accelerator to perform the same work as the STD mode.

The difference in gear choice is also evident, since the ECO mode often runs on a higher gear (5th) than the STD mode (4th). Main reason lies in the fact that ECO mode is calibrated in such way: To shift up earlier and maintain a higher gear overall, compared to the STD calibration.

Comfort and NVH were two areas that were supposed to be analyzed on a high level in both calibrations but since this data (verbal driver feedback) somehow had gone missing, there was no analysis done. Instead, reliance on internal suggestions about how the NVH and comfort should be affected when going from STD to ECO mode is appropriate. The NVH area is of course studied in depth by the Saab NVH team.

How reliable are these values then? Since the final results in every cycle and every area analyzed often show some sort of average value, it is inappropriate to claim that the obtained results are 100 % realistic. This is especially concerning the THN-VBG results due to huge variations and secondly because there is not the same amount of STD data available as ECO data. But at the same time, much of the results lean towards logical conclusions, for example the fuel consumption, it is meant to show lower values in the ECO mode and that is also what the majority of results show. And then of course, it is always possible to say that a specific STD test had better fuel consumption than another specific ECO test, though this would not be a fair conclusion.

The accelerator regulation in the standardized cycles is an exception. It is 100% correct to claim that there is a minimal difference in the driving behavior, since the outcome, almost always, is the same, or near the same, no matter how many tests are analyzed. It is also 100 % correct to claim that the accelerator position ranges always are bigger in the ECO mode, since every test supports this.

Regarding the part “follow targeted speed”, it is acceptable to state that there is a minimal difference in the driver’s ability to follow these instructions. There is enough data to support this fact.

So, should Saab continue with ECO mode or not? At the moment, Saab are not introducing ECO mode because there is no regulatory framework in order to benefit from it as certified consumption. Though, the results obtained from the analysis will be used to optimize the STD mode. A rebalance has to be done where better certified fuel consumption at minimal cost of NVH is to be achieved. Also, the results will be used in the rebalance of drive quality, which will make it easier to achieve a better fuel consumption for the eco minded driver, but doing so will bring negative effects on the performance and the sport feel of the car.

Recommendations on future work would be:

- Study the locked/open converter area – Surprising outcome in this analysis was detected, since the ECO mode did not use locked gears more often than the STD.
- Study the standardized cycles to optimize driving patterns which leads to better cert values (fuel consumption) – In what way is it appropriate to drive (choose shortcuts, earlier brakes, minimized idle etc) to reduce the certified consumption?
- Study in depth how NVH is affected when going from STD to ECO mode Powertrain calibration approaches – This was thought to be done on a high level in this thesis, but no data (drivers’ verbal feedback) were available and therefore no analysis was carried out.

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