Monitoring driving behaviour in fuel consumption in light duty diesel vehicles

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Abstract

This work monitors and records the effects of a selected group of drivers and their driving behaviour in the consumption of diesel fuel cars.

The challenge was based on the comparison of different driving behaviours and the individual analysis of the drivers’ progress after they have adopted new techniques of driving.

The monitoring was accomplished by using the datalogger CarChip technology, manufactured by Davis Instruments, and linked to the OBDII port of the vehicles concerned. This monitoring was carried out by five drivers for a period of twenty days.

The initial phase comprises ten days which monitored the usual driving habits of the participants; the following phase corresponds to the monitoring of the drivers’ behaviour after they have been fully instructed about the eco-driving rules which aim for less fuel consumption and a reduction of the car emission gases.

The evaluation criteria of driving behaviours, based on the eco-driving rules, encompass the driving dynamics (acceleration, speed), idling time, correct use of the transmission and the analysis of fuel consumption. Each car was checked to ensure that drivers would not be restricted by their cars performance since these showed different engine power/weight ratio.

Two driving dynamic qualification and experience validation methodologies were developed using the VSP (Vehicle Specific Power) and statistic methods, ANOVA1. The developed methods proved to be efficient for it and it was possible to distinguish the driving behaviour of the different participants in these two different phases.

The limitations of the vehicles demonstrated that the most aggressive driver seemed to be the only one conditioned by the vehicle acceleration capacity. This one demanded more than 90% of the maximum engine power in certain situations. Therefore one concludes that if he possessed a car with more engine power/weight ratio, he would be even more aggressive.

It was also proved that the gentlest driver is gentle by choice, reaching the maximum of 60% of the engine power of the vehicle. All participants showed alterations in their driving behaviour, becoming gentler in accelerations and decelerations.

The unnecessary idling time was ignored by many drivers. In what concerns the use of fuel cut mechanism situations it was verified that all drivers but one, benefited from this measure even before the training lessons. The driver who didn’t benefit from this technology corrected himself in the second phase of monitoring.

It was verified that all participants that showed significant alterations in their driving behaviour, becoming gentler showed significantly consumption reduction to 29%.

Keywords: Monitoring, CarChip, Driving Behaviour, VSP, OBD
Objectives
This all project aims to monitor the driving behaviour effect on the consumption of diesel vehicles. This work tries also to highlight the benefits, in consumption ratios, of the adoption of driving behaviour practice, fairly simple to apply, and without involving costs in modifications either in technology or fuels. This work intends to highlight the capacity of monitoring using small devices easily put to use in vehicles – the CarChip technology. These devices enable the monitoring on the road and in real time, allowing us to take into consideration all variables of the driving act. This work intends to contribute to the fields of driving behaviour evaluation. Methodologies are presented to make possible the distinction of different driving behaviours.

Monitoring
The monitoring applied in this project used the technology CarChip of Davis Instruments presented in Figure 1. The equipment is connected to OBI port of the vehicles. All vehicles manufactured from year 2000 are equipped with this port. The available data from the OBI port vary from vehicle to vehicle. The device can be programmed to register a maximum of five variables. Within the available parameters one can find the car speed, the engine speed, the air flow rate, the air inlet temperature, the manifold air pressure, the throttle position among other parameters. It also allows the choice of time break to register variables. By default the speed variable is always monitored second by second. The minimum time break to register the other variables is five seconds.

![Figure 1. Monitoring device, CarChip (Davis Instruments)](image)

Data Processing
Due to the complexity and huge amounts of vamples obtained it was necessary to use a software programme that handled all the different observations and made a detailed data analysis. The chosen software was MatLab.

Firstly it was necessary to extract the data from the CarChip software, grouping all drivers’ journeys and putting them into separated files. Having the data processed and correctly read by MatLab it was necessary to separate them into two types of files: one separating all journeys to enable analysis journey by journey; and another grouping all the journeys together in order to accelerate the reading by the software when processing them all together.

In short all the work processed in this project was through MatLab software. Several programmes were elaborated to produce all the results.
Description of monitored vehicles

Five drivers were analyzed and their vehicles are shown in table 1.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Driver 1</th>
<th>Driver 2</th>
<th>Driver 3</th>
<th>Driver 4</th>
<th>Driver 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make</td>
<td>Fiat</td>
<td>Citroën</td>
<td>Renault</td>
<td>Peugeot</td>
<td>Volvo</td>
</tr>
<tr>
<td>Model</td>
<td>Croma</td>
<td>C4 Picasso</td>
<td>Clio</td>
<td>207</td>
<td>V50</td>
</tr>
<tr>
<td>Engine</td>
<td>Diesel</td>
<td>Diesel</td>
<td>Diesel</td>
<td>Diesel</td>
<td>Diesel</td>
</tr>
<tr>
<td>Maximum Power [kW]</td>
<td>110(150 CV)</td>
<td>100(138 CV)</td>
<td>63 (85 CV)</td>
<td>50 (70 CV)</td>
<td>80 (109 CV)</td>
</tr>
<tr>
<td>Capacity [cm³]</td>
<td>1910</td>
<td>1997</td>
<td>1461</td>
<td>1398</td>
<td>1560</td>
</tr>
<tr>
<td>Driving Wheels</td>
<td>Front</td>
<td>Front</td>
<td>Front</td>
<td>Front</td>
<td>Front</td>
</tr>
<tr>
<td>Acceleration (0 to 100 km/h) (s)</td>
<td>9,6</td>
<td>12,4</td>
<td>12,7</td>
<td>15,1</td>
<td>12,1</td>
</tr>
<tr>
<td>Maximum Speed [km/h]</td>
<td>210</td>
<td>195</td>
<td>174</td>
<td>166</td>
<td>190</td>
</tr>
<tr>
<td>Combined Consumption [l/100km]</td>
<td>6,1</td>
<td>6,1</td>
<td>4,4</td>
<td>4,5</td>
<td>5,0</td>
</tr>
<tr>
<td>Urban Consumption [l/100km]</td>
<td>8,2</td>
<td>7,9</td>
<td>5,2</td>
<td>5,8</td>
<td>6,3</td>
</tr>
<tr>
<td>Extra Urban Consumption [l/100km]</td>
<td>4,9</td>
<td>5,1</td>
<td>4,0</td>
<td>3,8</td>
<td>4,3</td>
</tr>
<tr>
<td>Length [mm]</td>
<td>4783</td>
<td>4470</td>
<td>3986</td>
<td>4030</td>
<td>4522</td>
</tr>
<tr>
<td>Height [mm]</td>
<td>1603</td>
<td>1660</td>
<td>1496</td>
<td>1472</td>
<td>1457</td>
</tr>
<tr>
<td>Width [mm]</td>
<td>1775</td>
<td>1830</td>
<td>1707</td>
<td>1748</td>
<td>1770</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>1530</td>
<td>1656</td>
<td>1165</td>
<td>1160</td>
<td>1341</td>
</tr>
<tr>
<td>Engine Power / Weight [kW/kg]</td>
<td>0,072</td>
<td>0,060</td>
<td>0,054</td>
<td>0,043</td>
<td>0,060</td>
</tr>
</tbody>
</table>

Table 1 Description of monitored vehicles

Driving Evaluation Criteria

<table>
<thead>
<tr>
<th>Tips on Eco-Driver</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Driving in anticipation</td>
<td>Reducing global acceleration</td>
</tr>
<tr>
<td>2- Accelerating and decelerating gently</td>
<td>Reducing positive and negative acceleration</td>
</tr>
<tr>
<td>3- Avoiding idling situations</td>
<td>Reducing situations in which vel=0 km/h</td>
</tr>
<tr>
<td>4- When descending and braking keep the car in gear</td>
<td>Reducing situations in which RPM=Idling∧ vel&gt;vel_min km/h during Δt &gt; t_min seg</td>
</tr>
<tr>
<td>5- Driving in lower revolutions</td>
<td>Reduction of high revolutions</td>
</tr>
<tr>
<td>6- Knowing how to analyze consumption</td>
<td>Reducing high consumption</td>
</tr>
</tbody>
</table>

Table 2. Eco-driving criteria and respective numerical indicators

Table 2 includes the tips of a good eco-driver

The first two tips concern the driving dynamics, i.e. the gentleness/aggressiveness in accelerations and decelerations. The third rule calls the attention to avoid unnecessary idling situations. The rules corresponding to numbers 4 and 5 concern the correct use of the transmission. The reductions of consumption (and the implied emissions) are the result of good driving practices – gentle dynamics and the efficient use of the transmission.

The first eco-driving rule “driving in anticipation” does not differ much from the second rule “accelerating and decelerating gently”. Basically both imply the same effect in driving – it is possible to state that by carrying out the second rule you are in fact carrying out the first one. Gently accelerating and decelerating one practices driving in anticipation, and therefore evaluated by the same mathematical indicator.
Therefore one is consequence of the other. However one must highlight that driving in anticipation makes a driver more attentive to traffic conditions, avoiding more easily unpredictable situations and unnecessary accelerations.

Firstly it was necessary to check if any of the drivers would be conditioned by the acceleration capacity of the vehicle, jeopardizing the gentle qualifications and experience for the vehicle capacities. Bearing in mind that the dynamics is obtained through the speed and accelerating variables and that the engine power is obtained through the acceleration result for the speed and weight of the vehicle, it is possible to check which engine power is demanded in each dynamic point of measurement (see equation 1). So a methodology has been developed to evaluate how far the different capacities of acceleration of vehicles would limit the drivers’ aggressiveness.

\[ P_i = a_i v_i M \quad \text{being } i = 1, ..., n \text{ measurements made } (1) \]

Each value of \( P_i \) was divided by \( P_{\text{max}} \) which achieved the demanded percentage to the engine in each analyzed dynamic point.

Consequently there was a necessity of developing methodologies which evaluated the drivers’ dynamic behaviour. Two methodologies of analyses: the VSP analysis and the one based on statistical methods, ANOVA1.

**VSP METHODOLOGY**

When we deal with real measurements on the road and taking into account the great variability of driving conditions, it gets complicated (contrary to the roll banks or in numerical simulation in which the variables are more easily manipulated) to correlate specific events with emissions and consumptions and have statistically sufficient data to validate and compare different performances of the vehicle and different driving behaviours.

In each driving situation is concerned, be the vehicle going up a steep slope, doing a sudden acceleration or far exceeding the speed limit, the power output of the engine can be the same in the different situations as previously mentioned. The same will happen if it is in gentle mode, i.e. decelerating, or in a descending situation without using the accelerator and in gear, i.e. in a fuel injection switch off situation. The idea is to use a methodology that gathers demanding situations to the engines of equal power, i.e. the same conditions of functioning, and to associate those to the qualifications and experience of the driving dynamics. The VSP equation appears in the following form:

\[ VSP = v \left[ a + g (\sin \varphi) + \text{Coeff.\-resistência} \right] + \text{Coeff.\-aerodinâmico} \ v^3 \quad (2) \]

Being:

- **VSP**: Vehicle Specific Power [W/kg]
- **v**: Vehicle Speed [m/s]
- **a**: Vehicle acceleration [m/s²]
- **\( \varphi \)**: Inclination of the road [radians]
- Coefficient of resistance
- Aerodynamic coefficient

Since the present study is only for light vehicles the following values have been considered for the coefficients of resistance to rolling and aerodynamics, 0.132 and 0.000302 respectively. It was not possible to estimate the influence the slope had in this analysis for reasons of the limitations of monitoring variables. One assumes flat topography or in other words that ascents were as many as descents.

The challenge in this moment is in using this VSP methodology to analyze the qualifications and experience of the participants’ driving.

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1 \( P_{\text{max}} \) means the maximum engine power of each vehicle indicated by the manufacturers shown in table 1
When the VSP method was being analyzed, two influences divided into two components have been identified: $va$ (speed*acceleration) component and $v$ (speed) component.

The $va$ component has got a major influence for lower speed since the aerodynamic coefficient reduces the speed weight greatly when this shows lower values. However the $s$ component has got a higher expression in high speed. Bearing in mind that the power of acceleration of the vehicles diminished at high speed, the acceleration tends to be reduced in situations of excess speed.

One can make an analogy between the type of routes already achieved and expressed in the previous paragraph: for typically urban routes the influence of the acceleration is more meaningful; for extra-urban routes the speed component acquires a predominant importance.

Bearing in mind the objective of this project which was to monitor the influence of driving behaviour on consumption, we used the VSP method to separate the influences of components $va$ and $s$ and attribute a punctuation system to each form so that we could evaluate the different dynamic qualifications and experience of the drivers.

**Component $va$**

It was initially necessary to visualize which was the influence of $va$ in the expression (2) to evaluate the influence of the component $va$ in the driving dynamics. Therefore we sketched the isolines $va$. (see figures 2, 3, 4, 5 and 6)

$Va$ isolines have been sketched corresponding to the values -32, -16, -8, -4, -2, 2, 4, 8, 16 and 32 so that to separate the areas in the dynamic qualifications and experience, giving each area a correspondent punctuation shown in table 3.

<table>
<thead>
<tr>
<th>$va$</th>
<th>[0  2]</th>
<th>[2  4]</th>
<th>[4  8]</th>
<th>[8 16]</th>
<th>[16 32]</th>
<th>[0  -2]</th>
<th>[-2 -4]</th>
<th>[-4 -8]</th>
<th>[-8 -16]</th>
<th>[-16 -32]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>100</td>
<td>50</td>
<td>0</td>
<td>-50</td>
<td>-100</td>
<td>100</td>
<td>70</td>
<td>40</td>
<td>10</td>
<td>-20</td>
</tr>
</tbody>
</table>

Table 3 Score table for the $va$ intervals

Figure 2 $va$ isolines combined with the qualification and experience dynamic for Driver 1

Figure 3 $va$ isolines combined with the qualification and experience dynamic for Driver 2
As one can see in table 3, the positive $\nu_a$ scale is different from the negative $\nu_a$ scale. This fact can be justified for an aggressive acceleration can be more serious than a sudden deceleration in terms of consumption effects. The braking in itself does not consume fuel although it causes rapid wear of the brakes. The decelerations do not have a direct effect upon the consumption of fuel. However the decelerations are serious because braking needs an acceleration to compensate the deceleration and accelerations have a direct effect upon the consumption of fuel.

Component $v$

The component $s$ corresponds to the influence of speed. The same procedure that has been done to the component $\nu_a$, has also been attributed to a punctuation scale which benefits the vehicular traffic at low speeds. The punctuation system works to guarantee the maximum punctuation of 100 points, penalizing linearly from 90km/h, and once it reaches 120km/h the punctuation will attribute negative values.
ANOVA1 METHODOLOGY
This work utilizes a statistical technique, the analysis of the variation (ANOVA) followed by a complementary method known as Tukey-Kramer test. Through the statistical method of ANOVA1 one can verify if, in fact, the drivers show significant behaviours different from one another which statistically can be distinguished. The Tukey test appears as a complementary method to the ANOVA1, evaluating all differences among the drivers with an interval of confidence of 95%. The ANOVA1 method was used to analyze acceleration rate and negative acceleration rate and consumption rate separately.

The third rule “Avoiding idling situations” concerns those in which the engine is running but the vehicle is stationary. So the idling time is an unnecessary waste of fuel. However all drivers that participated in this project travel most of their time in urban areas where situations of traffic that imply using the idling occur, such as obligatory stops at traffic lights. Obviously there are drivers who do not encounter traffic lights so frequently.

It would not be a fair indicator since the idea is to evaluate the unnecessary time at the idling and not penalize in time the obligatory tick over. With this type of monitoring it is not possible to investigate if we deal with obligatory or unnecessary idling situations. If we had opted for estimating all moments in which the engine is running and the vehicle speed is zero, it would have been an extremely subjective analysis leading to fallacious results.

So we opted to evaluate the idling time at the beginning and end of each journey, situations in which none of eco-driver wastes fuel.

The fourth rule “When descending and braking keep the car in gear” concerns the use of the fuel cut mechanism. Nowadays all vehicles are equipped with this technology which makes possible in descending and/or braking situations, keeping it in gear and taking the foot from the accelerator, leaving in motion due to inertia results in zero consumption. So this rule allows the vehicle to save fuel in situations where it is possible to profit from the fuel cut mechanism. The criterion found to evaluate this situation resulted by contrast, i.e. penalizing situations in which the drivers, descending or braking, drive in a non gear mode, i.e. gearstick in neutral. So it was necessary to identify numerical indicators to could this behaviour as follows:

\[
\text{RPM}= \text{idling}, \text{ } \Delta t>2\text{sec} \text{ } e \text{ } v>30\text{km/h};
\]

The first indicator is the one that characterizes the bad use of the transmission. The second one is used not to encompass situations of changing gear. Sometimes when one changes gear the time taken by the clutch is expressed in the engine speed a value equal to the idling time. For safety the time interval that RPM is equal to the idling has to be superior to two seconds. The third indicator that imposes speed has to be superior to 30km/h and is used not to confuse situations of non-use of fuel cut mechanism with situations of pre-braking, since a traffic situation obliges the driver to immobilize the vehicle: this uses the clutch and the engine speed descends to the idling engine speed.

The fifth parameter concerns the rule 5 “Driving in lower revolutions” was not evaluated in this project because that criterion was not only related to the good use of the transmission but also with the speed regime predominantly adopted. The drivers of this project did not travel the same routes as each other, so some came out to be benefited. The drivers who drove with excess speed were doubly penalized, not only by the RPM highest regimes but also by the VPS methodology for excess speed. Another reason, no less important, is the fact that an eco RPM range is not universal. Because there is not a RPM eco interval and because it is subjective to adopt one, since the vehicles, all diesels, are different and could have different and efficient RPM ranges, we opted to abandon this criterion in the drivers’ evaluation.

The sixth advice of eco-driving, “Knowing how to analyze consumption” was embodied in this project to reduce the natural consumption of fuels. This used as an indicator analyses if, actually, a reduction in the consumption of fuels has been established when a more correct style of driving occurred. Basically this indicator is the result of the application of all the other measures mentioned above. We felt the need of
comparing consumption values among the different participants. One should stress that all monitored vehicles are European, manufactured after the year 2000. All participants declared both urban and fast highways journeys. We used, mainly, the urban consumption used in combined journeys published by the respective vehicle manufacturers, available in table 1, with the intention of normalizing the consumption and comparing values.

**Results**

In this chapter the results for all the indicators previously explained are shown.

![Figure 7](image1.png)

**Figure 7** Ranking of the different drivers in both monitoring phases obtained for the positive component $v_a$ through the VSP method

In component $v_a$ positive it was verified that all drivers improved in their driving behaviour. Driver 1 showed the highest improvement, 25.2%, followed by Driver 4 with 19.1%, then Driver 5 with 18.9%, then Driver 3 with 11.0% and at last Driver 2 with 3.6%. Driver 2 improved, but it's improvement was small compared with the other four drivers.

![Figure 8](image2.png)

**Figure 8** Ranking of the different drivers in both monitoring phases obtained for the negative component $v_a$ through the VSP method

In negative component $v_a$ the results showed an improvement for Driver 1, 31.6%, Driver 4, 21.9%. Driver 2 showed only 0.8% change in the second phase of monitoring. And for Driver 3 and Driver 5 the results
manifested a decrease of their driving behaviour concerning negative component \( va \) with 10,8% and 13,8% reduction, respectively.

Analyzing the results for component \( v \), it was verified that all drivers except Driver 1 reduced their speed in the second phase of monitoring.

In the analysis of ANOVA1 results the scale is analyzed in the opposite way from the VSP methodology. A reduction in acceleration rate is considered an evolution. So in this case, once again Driver 1 showed the highest development with 19,5% reduction. Driver 5 and Driver 4 showed an improvement of 15,4% and 11,6% respectively. Driver 3 also showed an improvement with 7,4% reduction. Again it was observed that Driver 2 did not show much change in his/hers driving behaviour concerning acceleration rate with only 2,7% reduction.
The analysis for ANOVA1 results for negative acceleration rate is similar to the ones obtained for positive acceleration rate. Driver 1 showed a reduction of 17,1%, Driver 5 a reduction of 12,4%, Driver 3 9,6% reduction, Driver 4 9,4% and Driver 2 with 4,3% reduction.

For the average idling time (see Fig. 12), unnecessary at the beginning and at the end of each journey one verifies that the drivers did not fulfill this eco-driving rule in the second phase of monitoring. In general practically all with the exception of Driver 4 who reduced and Driver 5 who maintained, all increase the idling time.
The use of fuel cut mechanism (see Fig. 13) one verified that the only driver that did not do it was Driver 4. Nevertheless Driver 4 showed a quite visible progress in the second phase of monitoring. In the first phase he/she showed 21.88% of the distance run in neutral; in the second phase, after being enlightened of the benefits of good use in fuel cut mechanism, he/she reduced to 1.25%.

Concerning the consumptions, through the adopted methodology to proceed to a comparison of the consumptions among the different participants, it is possible to put them in the same graphic display shown in figure 14. The analysis of the consumption reduction has to do with the drivers change in previous results, a better explanation will be given in the next chapter.
Conclusion

Regarding the dynamics the developed models proved to be efficient because through them it was possible a distinction in driving behaviour of the different participants which enabled us to clearly distinguish the more aggressive from the more gentle drivers.

Concerning the hypothesis of gentle driving being conditioned by the capacity of the vehicle acceleration, this idea was rejected. The gentler driver of the group (Driver 4) possesses a vehicle with a less engine power/weight (0.043W/kg) and he/she is the one who seems to less limited by his/her vehicle not overtaking the 60% and the 50% of the vehicle capacity in the first and second phase respectively. Driver 4 demanded from his/her vehicle he owns less than half of its response capacity. Driver 1 (apparently the most aggressive of the group) might be limited, showing situations that demand more than 90% of the maximum power of the vehicle. This may be read as if the most aggressive driver who possesses the vehicle with better performance (engine power/weight equal to 0.072) had a vehicle of even more capacity of acceleration would be even more aggressive. Relatively to others drivers analyzed in situations at the limit, Driver 2 and Driver 5 attained 70% and Driver 3 reached 80% of the response capacity of the vehicle. So one concludes that they were not being limited by the acceleration capacity of their vehicles.

Concerning the analysis about the consumptions, through the adopted methodology to proceed to a comparison of the consumptions among the different participants, it is possible to put them in the same graphic display shown in figure 58. We used the statistic method ANOVA1 to evaluate if the behaviours of the different drivers were statistically different. In the consumption analysis we conclude that all drivers showed a significantly reduction except Driver 2 and Driver 3. Driver 1 showed the highest reduction (29,2%), which was expectable since Driver 1 showed the highest improvement in his driving behaviour in \( v_a \) positive component (25,2%) and \( v_a \) negative component (31,6%) through VSP methodology. In ANOVA1 methodology the improvement of acceleration and negative acceleration was highest as well, 19,5% and 17,1% respectively. Driver 2, on the other hand, showed hardly any improvement, \( v_a \) positive component only 3,6% and \( v_a \) negative component 0,8% (VSP analysis) and acceleration rate 2,7% and negative acceleration rate 4,3%, so in the end result Driver 2 did not show a significantly consumption reduction (\( p>0,05 \)). In ANOVA1 analysis for acceleration and negative acceleration rates Driver 3 improved 7,4% and 9,6% and although Driver 3 did show some improvement in \( v_a \) positive component of 11%, he decreased on \( v_a \) negative component with 10,8% in VSP analysis. In the end result it was not sufficient to reveal a significantly consumption reduction in ANOVA1 method for consumption analysis (\( p>0,05 \)). However, it was noticed that Driver 5 also had a decrease in \( v_a \) negative component of 13,5%, even higher than Driver 3, and Driver 5 showed a significantly consumption reduction of 15,7%. However Driver 5 revealed higher improvement than Driver 3 in \( v_a \) positive component (19%). And it was revealed that in ANOVA1 analysis for acceleration and negative acceleration rated Driver 5 improved 15,4% and 12,4% respectively.