POLITECNICO DI TORINO

Master of Science in
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Master's thesis

Understanding Eco-driving patterns Through data collected In a field test

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Alla professoressa Pronello, prima ad aver suscitato in me l’interesse nell’argomento,

al professor Monzón e alla dottoressa Wang per avermi accompagnato in questa esperienza e aver seguito il lavoro pazientemente fornendomi preziosi suggerimenti,

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A mio papà, ai miei fratelli

Alle mie nonne e ai miei nonni, a tutta la mia famiglia

Ai miei amici, quelli di sempre e quelli nuovi

Alle amiche di una vita

Alla piccola nana nuova arrivata

A Madrid e al CDC

A tutto ciò che ha fatto parte della mia vita, arrivati a questo punto dico

GRAZIE GRAZIE GRAZIE.

..E grazie a te che sei qui con me!

ABSTRACT (ENG)

The issues of climate change and air pollution are now on our agenda and road traffic is one of the major drivers of this critical situation. Road transport accounts for more than two-thirds of the transport-related Greenhouse Gas (GHG) emissions and over one-fifth of the total emissions of carbon dioxide, the main GHG (Monzón, 2017).

During the last 20 years, researches have been well oriented on the study of Eco-driving patterns, but it is still unclear what type of route, and in general under which conditions Eco-driving is more efficient.

In this thesis, the goal is to understand the efficient context of Eco-driving using data collected through an experiment carried out in April and May 2017 in Madrid-Spain, which was one of the projects of the Spanish National Plan in the context of challenge number 4-Intelligent, sustainable and integrated transport. Fourteen conductors have driven two different vehicles, along four itineraries, before and after having attended an efficient driving course.

By using an On-board diagnostic device (OBD-Key), the GPS position, the speed and others relevant variables have been obtained second by second. The fuel consumption is further calculated using the Vehicle Specific Power model (VSP). All data collected were elaborated through the software “R” and the database has been created.

In these terms the methodological approach follows four stages: data collection campaign, data base creation, database validation and data analysis.

Data have been analysed in respect to two different aspects. The first one is to compare the reduction of fuel consumption by adopting an Eco-driving behaviour, depending on the kind of itinerary (extra urban, urban or mixed), while the second one is to analyse the efficiency of eco-driving depending on the type of roads and on the traffic conditions.

Results underline that Eco-Driving in general performs its efficiency at different levels; moreover it also shows its limits on certain road sections and traffic conditions: in motorways and highways Eco-driving is more effective in congested situations than in free flow conditions. On contrary, the results show the opposite in local streets.

ABSTRACT (ITA)

Cambiamento climatico e inquinamento atmosferico sono questioni di cui ormai si parla ogni giorno e il traffico stradale é uno dei principali responsabili della situazione critica che stiamo vivendo.

Il trasporto stradale produce piú di due terzi delle emissioni totali di gas serra (GHG) generate dal settore dei trasporti e oltre un quinto delle emissioni globali di anidride carbonica, il principale gas serra (Monzón, 2017).

Negli ultimi 20 anni, numerose ricerche sono state orientate verso lo studio dell'eco-driving, ma è ancora poco chiaro quale tipo di strada, e in generale sotto quali condizioni, l'eco-driving risulti essere piú efficiente.

Con lo sviluppo di questa tesi, ci si propone di capire quale sia il contesto in cui l'eco-driving sia piú efficiente, utilizzando dati raccolti attraverso un esperimento svolto in aprile e maggio 2017 a Madrid, in Spagna, e appartenente ai progetti del piano nazionale spagnolo, nel contesto numero 4 - trasporto intelligiente, sostenibile e integrato.

Quattordici conducenti hanno guidato due veicoli diversi, lungo quattro itinerari, prima e dopo aver frequentato un corso di guida efficiente.

Utilizzando un dispositivo (OBD-Key), sono state ottenute ogni secondo la posizione GPS, la velocità e altre variabili rilevanti. Il consumo di carburante è stato poi calcolato utilizzando il modello Vehicle specific power (VSP). Successivamente sono stati elaborati tutti i dati raccolti e con l'ausilio del software "R" é stato creato il database, base per l'analisi dei dati.

In questi termini la metodología utilizzata si compone di quattro fasi: campagna di raccolta dati, creazione del database, convalida del database e analisi dei dati.

I dati sono stati successivamente analizzati utilizzando due diversi approcci. Il primo studia il confronto tra riduzione del consumo di carburante adottando un comportamento di guida ecocompatibile e non, a seconda del tipo di itinerario; il secondo analizza l'efficienza dell'eco-driving a seconda del settore stradale e della condizione del traffico.

I risultati ottenuti sottolineano che l' Eco-Driving in generale risulta avere diversi livelli di efficienza; inoltre mostra i suoi limiti per alcune sezioni stradali e condizioni di traffico: nelle strade a scorrimento veloce l'eco-driving risulta essere più efficace in situazioni di congestione rispetto che a condizioni di flusso libero. Al contrario, i risultati indicano che la situazione é opposta se si considerano le strade locali.

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CHAPTER 1: INTRODUCTION

Issues of climate change and planet resources are now on the agenda.

“By August 2, 2017, we have used more from nature than our planet can renew in the whole year” (Global Footprint Network, 2017).

The same experts explain in their report that we use more ecological resources and services than nature can regenerate through overfishing and overharvesting forests, and we are emitting more carbon dioxide into the atmosphere than forests can sequester: currently 60% of the ecological deficit is caused by the necessity to absorb carbon dioxide emissions.

In these terms, they affirm, from the 2nd of August our planet is overexploited until the end of the year, due to a tax of consume 1,7 times faster than the natural capacity of regeneration and absorption of the eco system: in seven months we emitted more amount of carbon dioxide then the one can be absorbed from oceans and lends in one year (Global Footprint Network, 2017).

It’s noticed that carbon dioxide is not the only one noxious gas causing climate change, rather climate change is caused by a range of gases, known collectively “greenhouse gases” (GHG), which alter the energy balance of the climate system, and the more important ones, in decreasing order of concentration, are: water vapor, carbon dioxide, methane, nitrous oxide and ozone, (EPA, 2014).

GHG emissions come from different sources across the economy. The magnitude of emissions and diversity of sources means that no single technology, policy, or behavioural change will be able to “solve” climate change; rather a portfolio of solutions is needed. (“Climate techbook”, C2ES center for climate and energy solutions)

During the past decades there has been an ongoing debate on how and to what extent different policies and strategies influencing the mitigation of climate change impacts of transportation.

According to the International Energy Outlook 2013 Reference case, transport sector "accounted for 26% of global energy consumption in 2010, and transportation energy use is expected to increase by 1.1% every year over the next few decades, above 2-3% in emerging economies" (Energy Information Administration, 2013).

Literature recognizes some of the possible driving forces which led to the yearly growth of world transport energy use: (Perez, 2017)

- the economic growth;
- the predicted growth in urban population;
- the predicted growth in passenger vehicles and in car ownership particularly in developing countries (there are about 1.2 billion passenger vehicles today, a figure that is expected to reach 2.6 billion by 2050 ; UN-HABITAT, 2011);
- the current trend of urban decentralization in virtually all metropolitan areas;

More in details, passenger cars and heavy duty vehicles account for more than two-thirds of the transport-related greenhouse gas emissions and over one-fifth of the total emissions of carbon dioxide (CO_2), the main greenhouse gas (Monzón, 2017). Road transport was responsible for almost 73% of all GHG transport emissions in 2013 (TERM, 2015).

Figure 1 presents the contribution on GHG emissions from different transport modes in EU-28. (Self elaboration)

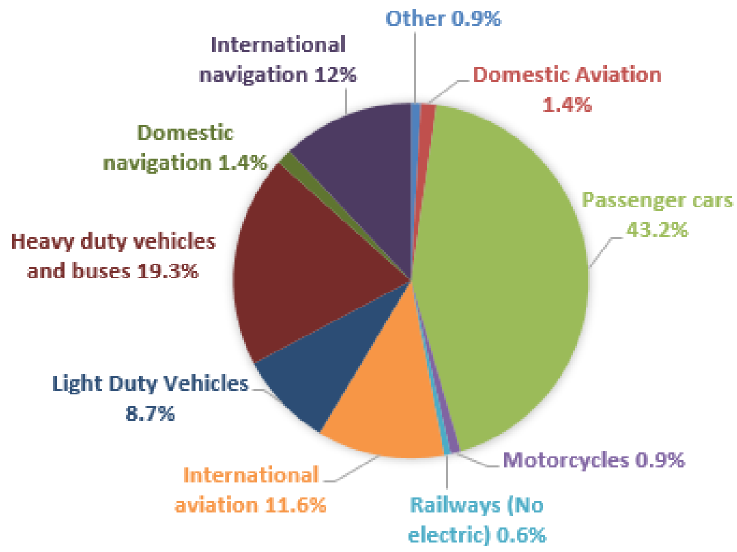


Figure 1 Contribution of different modes of transport to EU transport GHG emissions in 2013

In this context, much of the effort dedicated to reducing energy consumption and GHG emissions have been and have to be focused on road transportation sector.

The European commission, through the European Environment Agency (EEA) has defined three main common objectives in order to contrast climate change until 2020:

- the reduction of GHG emissions up to 20% compared to 1990 levels;
- to get 20% of the energy needs from renewable sources;
- to increase energy efficiency by 20%;

In this sense it results that European long-term objective is to create a low-carbon and circular economy by reducing the most possible carbon emissions in the productive cycle, while the main key challenges concerning future transport trends are divided in: (TERM report 2015, White paper of European Commission Annex I)

- modal shift away from road transport: efficient and integrated mobility system;
- reducing GHG emissions from road freight;
- promoting alternative fuels for transportation;
- implementing new technologies that address transport supply demand: innovation on technology and behaviour, modern infrastructure and smart funding;

Dalkmann and Brannigan on 2007 proposed a framework to identify transport strategies that reduce carbon emissions from transport on the demand side: the ASIF2 paradigm, avoid-shift-improve-finance framework (Tiwari et al., 2011).

“Avoid” refers to a reduction on trip length and need of travel, by integrating land use and transport planning; “shift” promotes modal shifts from high energy consuming transport modes; “Improve” refers to create strategies concerning vehicle design or fuel efficiency or management of transport system operations and networks; “Finance” refers to investment in urban development and transportation to achieve reduced CO2 levels (Dalkamann and Brannigan 2007).

The work carried out within this thesis concerns one of the ¨improve¨ strategies adopted to reduce fuel consumption, and so GHG emissions: the ECO-DRIVING technique.

Better described in the next chapters, eco-driving is a driving approach aimed at lowering fuel consumption that correspond to a reduction in CO_2 emissions. According to Barkenbus (2010) Eco-driving is an operational strategy which consists in the efficient vehicle operation following specific rules easily typified, i.e. using vehicle inertia, accelerating and braking smoothly, maintaining a steady speed, etc.

Starting from 90's the idea of an economic, safe and ecological driving (as it is defined by the term "Eco-driving") has been widely discussed in scientific literature as one of the potential measure to keep in order to fight the problem of air pollution, by promoting a different safe way of driving and by producing a save on fuel consumption, on urban network, between 5% and 10% depending on the situation.

By taking into account the real efficiency of this technique, this thesis aims to understand eco-driving patterns by studying road data collected through a real experiment conducted in Madrid-Spain, that was carried out in April and May 2017 by the transport research center of Madrid (TRANSyT), and was one of the projects (named ECO-traffic) of the Spanish National Plan in the context of challenge number 4-Intelligent, sustainable and integrated transport.

The experiment consisted on monitoring fuel consumption an others relevant variables (such as speed, revolutions per minute, distance etc) of two different vehicles conducted for two separated periods of 9 days each, by shifting 14 drivers before and after their participation to an efficient driving course (more details in chapter 3). Starting from these collected data, this research has been developed.

Beyond my indisputable interest on this subject, one of the reasons to focus my master's thesis on this argument is the opportunity that the thesis got to be completely supported by my personal experience.

Through the participation on the Erasmus+ program during the academic year 2016/2017, coming from the department of Civil engineering of Politecnico di Torino (ITA) to "Escuela Técnica Superior de Ingenieros de Caminos, Canales y

Puertos" of the Universidad Politécnica de Madrid (ESP), I had the first opportunity to come in contact with a completely new international world.

During my study at UPM, I've been also trainee in the TRANSyT Transport Investigation Centre so that I had the opportunity to directly participate on the previous mentioned three years national project Eco-Traffic.

My participation to the project has consisted not only with regards to the first practical part during which I have been supporting the coordination of the experiment and I've been driving the implicated vehicles as pilot and copilot; my participation has been also with regards to the second part of the experiment, dedicated to the data process and to the analysis of results.

In these terms the thesis has been developed starting from real data, keeping from Eco-traffic experiment and elaborated by some colleagues and me. It gave me the occasion to work in what I'm really interesting in, by adopting a multi prospective regarding sustainable transport issues.

From a literature review is not clear under which external conditions the Eco-driving behaviour shows the best results in terms of saving in fuel consumption and which are the key factors affecting its potential efficiency.

This thesis is structured in six chapters, following the consecutive steps of the research methodology.

The chapter **Introduction** presents the aim of the work, by posing the problem of road transportation emissions and their effects on climate change. The purpose of the thesis is described: to answer to the two main research questions, briefly reassumed in:

1. How is affected eco-driving efficiency under different external factors?
2. What are the effects of eco-driving on emissions and fuel consumption depending on different road sectors and traffic states?

The chapter **State of the art** presents a general review of the framework focusing afterwards on the eco-driving concept assuming it as one of the solutions to reduce GHG and pollutants emissions. This chapter shows a sort of state of the art of the Eco-driving concept, by revising its definitions and variability of results found out in different case studies, by both simulations and field tests.

On the third chapter **Research objectives and methodological approach**, a brief description of objectives and methodology used on the work is presented. The general objective is to go on the study of real efficiency of the eco-driving technique in terms of reduction in fuel consumption and emissions, by comparing effects on different road network under the same external circumstances.

As regards the methodology description, it has been created a chart flow (Figure 2) that sums up the main steps of the work: the main data collection, the data process (including the database creation and validation through a filtering process), and the data analysis and findings.

On the first part of the chapter **Case study and data process**, the work focus on the description of the study case experiment: Eco-Traffic Madrid. This part represents a summary of the global project, carried out by TRANSyT-transport investigation center of Madrid, and it contains the description of all the instruments and variables implicated in the experiment.

On the second part of the same chapter, it has presented the data process methodology applied on this research study, through which is described the procedure used to finalize the database creation and the database validation.

In the chapter **Main results**, after a brief description of the general eco-driving performances obtained through the experiment, the two remainder parts have been dedicated to analyze results obtained in order to answer to the two main research questions posed on the first chapter.

In these terms there is a first part developed to explain how is affected eco-driving efficiency depending on external factors i.e. vehicle, driver, hour, and itinerary; on the second part the focus is towards the eco-driving efficiency depending on road sector and traffic state.

Finally, on the last chapter **Conclusions and policy reccommendations**, basing on the results obtained on each sub-analysis described in the chapter five, the main findings and conclusions concerning some policies recommendations are presented, in order to give a contribution on the definition of new and more appropriated sustainable transport policies.

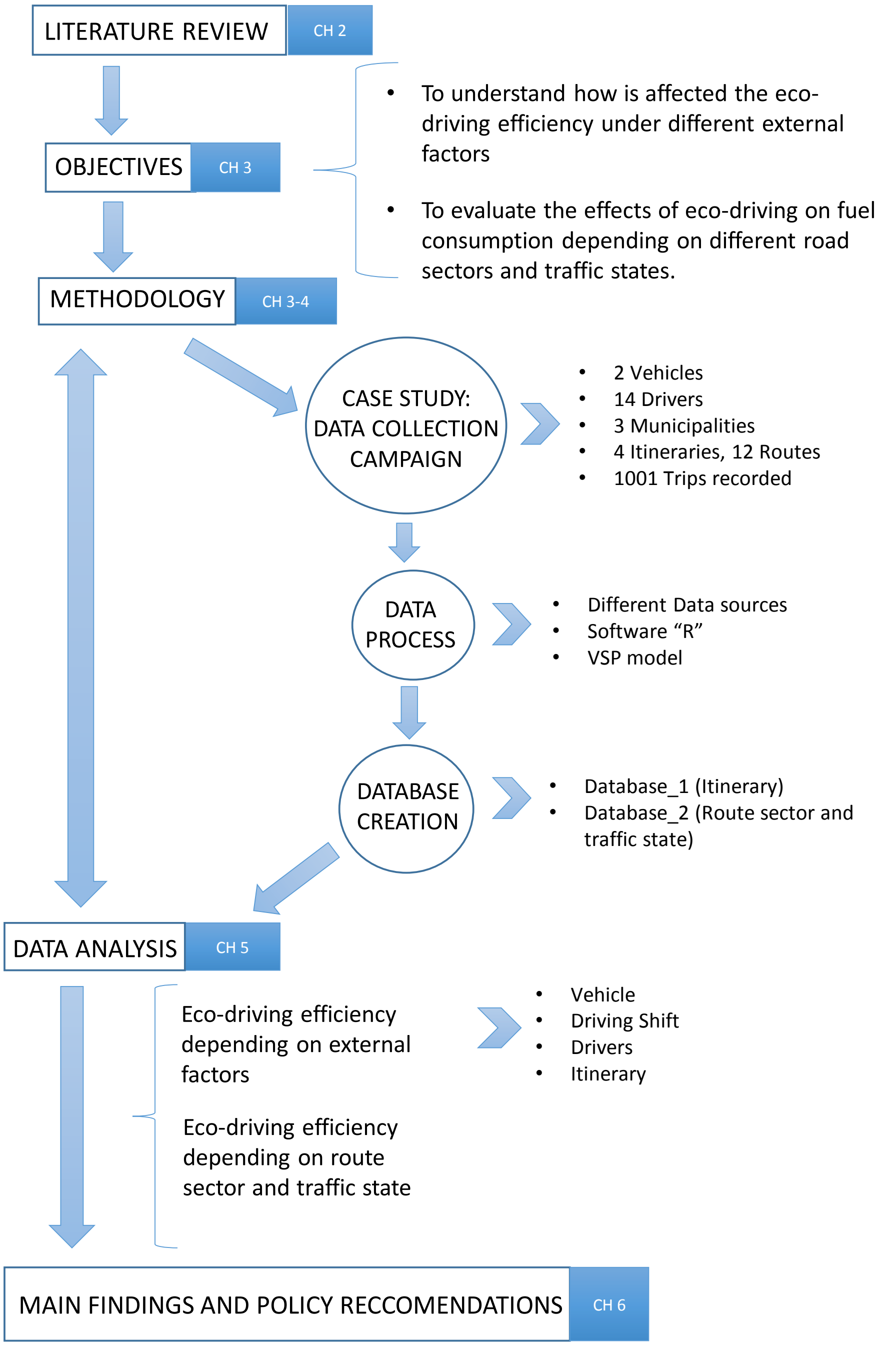


Figure 2 Structure of the work

CHAPTER 2: STATE OF THE ART

2.1 ECO-DRIVING DEFINITION AND EVOLUTION

Due to a growing concern about emissions and climate change, research interest in Eco-driving has exponentially increased from 90's to today.

Eco-driving can be considered as one of the examples of a behavioural change approach to reducing vehicle emissions, but it should be distinguished from the previously coined concept of "hypermiling". Indeed while they can share the same aim of reducing operator cost of the vehicle, they differ in the way of pursuing it: hypermiling reduces fuel consumption by getting as close as possible to the vehicle in front, clearly trading off safety for fuel consumption, while with the adoption of an eco-driving behaviour there is not this tradeoff. (Barkenbus 2010).

Regarding Eco-driving, we can define three different levels of decision-making as different aspects on which we can act to have this behavioural change (Sivak and Schoettle 2012):

- strategic decisions: vehicle selection and maintenance;
- tactical decisions: it corresponds to the eco-routing concept in literature;
- operational decisions: change on driving behavior;

We can say that Eco-driving concept includes all those decisions which can produce a reduction on the energy consume of the vehicle not only by adopting a different driving behaviour but also by changing the use and maintenance of the vehicle.

This work will deal solely on those *operational* decisions making efficient the eco-driving.

Definitely Eco-driving presents considerable strengths as approach to reducing emissions. Literature (ECO:DRIVE 2009) shows us that it can make significant and low-cost reductions in emissions and governments increasingly recognize its importance as a key component for an integrated approach to reduce vehicle emissions.

However, even eco-driving has obstacles to be overcome. In quality of behavioural approach, it opens questions about its real efficiency, about the better way to divulgate the concept, about the time of effectiveness. Moreover there are others practical limits that have to been solved i.e. the fundraising and the lack of a legislative support.

Passing from an ideal point of view which implies the full application of this technique in ideal and controlled conditions, to a real one, we still don't have valid data to prove its real efficiency, in global terms. Most of studies are based on simulations and the study cases always are limited, i.e. fixed route, fixed traffic conditions (..)

Anyhow by involving reduced costs, many politicians starts to believe that Eco-driving plays an important role in the vehicle emission reduction program. Jack Short, general secretary of the International Transport Forum, said: "It's a relatively low cost solution and easy to realize. It doesn't exist miracle, so that every solution that can give a reduction of 5-10% on fuel consumption has to be definitely taken". (Eco:Drive, FIAT 2010).

Concerning the operational level, decisions to take in order to act in eco-driving terms are summarized on the project ECOWILL (2011) "Golden Rules of eco-driving":

- when accelerating, shifting to a higher gear between 2,000 and 2,500 rpm for gasoline vehicles and between 1,500 and 2,000 for diesel. Shifting up the gears at these relatively low revolutions reduces fuel consumption because the engine's internal friction increases with engine speed;
- maintain a steady speed using the highest gear possible and driving with low engine speed;

- anticipate the road and traffic flow as far ahead as possible to avoid unnecessary acceleration and braking processes;
- when decelerating, driving downhill or stopping, remain in gear but step off the accelerator as early as possible, for example when approaching a red light or a roundabout;
- avoid high speeds since speeds above 80 or 90 km/h fuel consumption increases greatly;
- check tire pressures regularly as underinflated tires increases fuel consumption;
- use air conditioning sparingly as long as this does not imply opening a window at high speed;
- switch the engine off when stationary for more than a minute;
- remove roof racks, bike racks etc. when not in use;
- avoid carrying unnecessary weight.

Literature shows that is really clear the potential benefit contribution by adopting an Eco-driving behaviour, but it' s really important to understand that there is a big difference between potential and effective benefit. Indeed in literature we can find results up to 25% of saved fuel if we apply this technique, but only in certain situations: it can be for example a driving session immediately after a short-duration eco-driving lesson. (Henning W., 2008).

The main topic of Eco-driving regarding the operational prospective, is that it's really accessible to everyone: we just have to drive "in a proper way" in order to contribute to immediately reduce vehicle emissions. It could be seen as an immediate and universal target easy to be met.

Eco-driving can be actuated by every vehicle, regardless the kind of fuel or the kind of emissions or the typology of vehicle it is (electric, diesel, gasoline). Moreover, as reported on the ECO:DRIVE report, Peter Wilbers, coordinator of ERA-NET

Transport and co-manager of Electromobility+ and Electric Mobility Europe, said that with more ecological vehicles it's better to drive in the "eco" way than with old ones: Eco-driving is a driving style that fits better to a modern vehicle technology.

Furthermore, the cost of Eco-driving actuation is really low: in 2006, a study conducted by the TNO Holland institute of research, have evaluated benefits and costs of Eco-driving and they have estimated cost around 9 € every tons of CO_2 saved (Eco:drive 2009). Another time it seems a point in favor for the implementation of this technique.

Once again we are left to support the efficiency of this driving technic in respect to the concept of sustainable mobility; but what are the main problems that need to be solved to adopt this driving "approach" in real life.

First of all as this is a new modern concept, in practical terms not all streets of the world road network have been designed to implement Eco-driving technique in both terms of geometry and functionality concepts. Furthermore congested traffic and the implementation of traffic lights influence the possible adaptation.

An explication to the problem of governance and finance sustainability, and to the clear division between the ideal and real scenarios is that it is not proved and it is still unclear where real effects of Eco-driving can arrive and how its effectiveness is in a long term prospective.

Strategies to implement an Eco-driving behaviour can be different depending on the instrument that we use. They can be implemented through mass media, driving license schools, course and recommendations or Intelligent Assistant Systems. (García Castro, 2016)

All these kinds of methodologies have been explored in literature and produced different results.

With the experiment aimed and described on this work, we have found results in contrast with literature: as the experiment has been done by monitoring two vehicles conducted before and after drivers have attended an efficient driving course, we expected results of fuel saving from 5 to 25% depending on several external conditions; not always the goal was reached.

The goal of this research is, therefore, to find the key factors which lead strong efficiency or failure of Eco-driving in terms of reduction in fuel consumption and consequently in vehicle emissions.

In order to follow this research, it is useful to take a deeper look at the previous researches doing a literal review of the study cases and its results.

2.2 ECO-DRIVINIG PREVIOUS RESEARCHES

Despite the clarity of Eco-driving efficiency in ideal conditions, in order to quantify real impacts of this technique in terms of saving in fuel consumption generally there have been two main approaches: field tests and traffic simulations.

Comparing with field tests, simulation has the advantages of lower cost and greater freedom to modify different environments, vehicle type and traffic conditions to assess their relative impacts on fuel consumption. However in order to obtain more accurate and valid simulation results, the model needs to be calibrated and validated with real world data so that with this process is easy to loose accuracy on results and it is not possible to take into account some external circumstances (García Castro, 2016).

On contrary field test gives the opportunity to take into account many factors which can't be considered in laboratory test and consequently to obtain more realistic results than driving simulators. The most reliable way to assess Eco-driving in these kinds of tests is to install an onboard device on the vehicle, to record all parameters required to achieve the desired analysis (in this study an OBD-Key has been used).

2.2.1 SIMULATION

In this research, there have not been considered simulation works. In this sense we want to put our focus only on field test, having accomplished a real analysis with real field data and results.

Lots researches regarding relations between simulation of eco-driving behaviour and different topics have been developed in literature; topics already discussed are the link between simulations of eco-drivers and road sections controlled by traffic lights (Qian and Chung, 2011; De Nunzio et al. 2015), or simulation and the optimal level of eco-driving penetration (Qian and Chung 2011, García Castro 2016) or other (micro) simulations obtaining really interesting data.

As regards intersections, Sung et al. on 2015 proposed a speed control scheme of eco-driving at road intersections to avoid frequent stop-and-go driving; this approach permitted to obtain up to almost 20% of reduction in excessive carbon emission.

In the project ICT-Emissions, developed in Madrid (Spain), a number of itineraries were analysed with a floating vehicle on the M-30 urban motorway, obtaining savings of around 5.5% when applying efficient driving techniques. Using different traffic and emissions models, different percentages of eco drivers were simulated. Results have shown that during congestion periods, eco-driving produces an increment in CO_2 emissions as congestion increases.

The same procedure was used in Turin (Italy), simulating in this case an urban artery. Results have shown higher emission savings, up to 14% under almost free flow conditions, which are reduced as the traffic level increases and which can produce, like in Madrid, some scenarios of increment on emissions.

From this study it seems clear, therefore, that eco-driving can be a good measure for reducing emissions but not under all traffic conditions.

But what are these conditions? What are the real circumstances in which we can efficiently adopt an Eco-driving behaviour?

By considering the emission itself, it is noticed that there is a big gap between real world and test cycle emissions due to three main factors: (T&E, 2015; TNO 2012)

- an outdates test procedure that does not reflect real-world driving conditions;
- flexibilities in the current procedures that allow manufacturers to optimize the testing, and thereby achieve lower fuel consumption and CO_2 emission values;
- several factors which are driver dependent (as driving style) or independent (as environmental conditions);

Assuming this, in order to understand which are the key factors affecting an efficient eco-driving this thesis is based on real field test results.

2.2.2 FIELD TESTS

In 1999 Johansson, Färnlund and Engström conducted a field tests in three different cities of Sweden, and the results by monitoring different engine parameters, was that after given instructions in conductions, fuel consumption was reduced by 10,9%.

Henning (2008) presented a study with 300 participants in which after attending a full day course, short term evaluation reflects average fuel consumption saving of 25%, while the same conductors in long period time only achieved 10% of saving.

Results obtained from different studies place individual fuel savings at between 5% and 10%, and in some cases as much as 20% (FIAT, 2010; Wilbers, 1999; Onoda, 2009).

The variability of these data depends largely on the characteristics of traffic and roads in each case study. Driver's ability to learn these techniques and the vehicle's sensitivity to minor changes in driving style may also have a significant influence (Garcia Castro 2016).

Onoda (2009) published the summary of Eco-Drive Program in Europe, reporting savings from 5% to 15%, depending on the existence of feedback.

Larsson and Ericsson (2009) have demonstrated, by recording driving pattern parameters in a field test, that the rate of acceleration is not the only one factor influencing fuel consumption; it is determined also from idle time, cruising time…

Furthermore it's been demonstrated that benefits of eco-driving under rural conditions are apparently greater then in urban conditions. (Smit, Rose and Symmons 2010).

More in general, the potential benefits by adopting an eco-driving behaviour is clear, due to many experiments conducted on this field during the last years; but we still don't know enough about what is the real influence that every variable and factor can implicate.

What about the effect of an on board Eco-driving device?

A limited case study was conducted in Southern California, in 2011, by Boriboonsomsin, Barth and Vu; results showed that fuel economy on vehicle with an Eco-driving device reduces by average of 6% compared with unequipped vehicles. On contrary, H. Lee, W. Lee and Lim in 2010 reported an experiment in South Korea in which results showed that there weren't significant improvement in fuel consumption by activating Eco-driving indicator; moreover it could produce stress on the drivers.

Stillwater, Kurani and Mokhtarian (2015) have conducted a yearlong study in which it was examined how change precursor cognitive factors and driving behaviour with the introduction of an energy feedback. The study showed that with the introduction of a feedback interface, there was an overall 4,4% reduction in fuel consumption due entirely to one group that showed increment in their knowledge of fuel economy, while a second group didn’t improve and may have been confused by the feedback.

The question of how much energy can be saved realistically through eco-driving is still subject to debate. One can find claims of 25% improvements in fuel economy during short-term, contest, situations (Ford, 2008). We are more interested, however, in sustained, normal, driving practices, and in this case fuel savings are conservatively calculated at 5% where there is no support beyond initial training and 10% when there is continuous feedback (Barkenbus, 2010).

Andrieu and Saint Pierre (2014), have analysed two kinds of experiments: in the first one simple advices where given to participants, while in the second one full curses of Eco-driving experts were used: results show that Eco-driving advices are better applied after a course than just providing tips.

As concern how Eco-driving is perceived at long term period is interesting to have a look at the experiment conducted by FIAT in 2008 with the introduction of their software ECO:DRIVE on their vehicles. Conductors had to insert a pen drive in their vehicle in which there were recorded all the telemetric data. (FIAT also have created an access to Eco:Ville: it consists on the community of feedback devices users who choose to sand their Eco-driving results to a central site where individual results are ranked and compared). It could be a good way to monitoring long term behaviour. Results show that thanks to this feedback implementation, drivers have reduced their emissions of CO_2 by 6% in 30 days, with steady and constant improvements.

Participants of the experiment were 5,689 conductors who have driven for 428,048 journeys from the 9th of June to the 31st of October 2009. They were part of the top 5 Fiat market (UK, ITA, ESP, GER, FRA) and during this observation period, conductors have utilized ECO:DRIVE advice as mean of 28 days (from here, the result regards 30 days).

After these results, we can go on the research in order to understand why, in some circumstances, Eco-driving behaviour is not so efficient, or worst, it can produce more fuel consumption than the one produced adopting a normal behaviour, as occurred in our study case.

Literature (Qian and Chung 2014, García Castro 2016) shows that in traffic congestion and in certain levels of penetration rate, Eco-driving is not efficient; also we can find, as previous mentioned, texts in which is underlined the problem of the government administration and finance .

But which are the factors that really limit this potential function?

Why, in the experiment, by using an Eco-driving behaviour not always we have obtained a saved on fuel consumption? And how is influenced the saving in fuel consumption depending on the type of road section? We are going to answer to these questions developing this work.

CHAPTER 3: RESEARCH OBJECTIVES AND METHODOLOGICAL APPROACH

3.1 RESEARCH OBJECTIVES

As has been explicated on the previous chapters, the goal of this research is to understand eco-driving patterns by studying road data from a real experiment conducted in Madrid, Spain.

From literature review, it is unclear what type of route, in what area and in general under which conditions the practice of driving in such theoretical way to minimize fuel consumption and GHG emissions is really proficient. Moreover it's in my interest to understand why this driving "approach"is not always so efficient in order to give the possibility to take into account this aspect in further researches and actions regarding eco-driving concept and consequently regarding new transport policies.

It is noticed that for certain pollutants, there is a significant discrepancy between official emission measurements and real world vehicle performance. New vehicles can emit up to 40% more CO_2 under real driving conditions than official measurement would indicate (EEA, 2016).

For this reason this thesis starts with real data analysis collecting from a real experiment that was carried out in Madrid and Caceres, municipalities of Spain, and belonging to the Spanish national plan. As previous mentioned, the data collection campaign of the ECO-traffic project has been divided in two different periods by shifting 14 drivers before and after their participation to an efficient driving course.

(Eco-Traffic direct link: http://ecotraffic.transyt-projects.es)

After having filtered several times our data source cause having defects on the GPS registration or on others values, it results that despite the application of eco-driving, not always we have obtained a saving in fuel consumption, unlike to what we were expected obtain by considering previous researches.

This is what moved our interest on these two specific research objectives:

- *to understand how is affected the eco-driving efficiency under different external factors;*
- *to evaluate the effects of eco-driving on fuel consumption depending on different road sectors and traffic conditions;*

As I have presented on the previous chapters, from 90's literature has investigated this "new" concept of eco-driving, obtaining different results that mostly explained a saving on fuel consumption. There have been presented also some circumstances in which the expected result has not been obtained, but the different reasons always have been discovered on problems concerning traffic congestion or safety.

Since all conductors engaged on our experiment, after the first driving period joined the efficient driving course and were requested to drive in the second period by applying the techniques learnt, by taking into account scientific literature it was expected a minimum reduction of fuel consumption from 5% to 10%. However, regarding results received and analysed, not always has been reached the "goal" of reduction in fuel consumption.

It's possible that it depends, among others factors, on driver's attitude or vehicle type or kind of route we are analyzing. But in which terms does it occur?

Analysis about these results could seem to lead us to go on a sort of Eco routing analysis; but it is not the case.

Indeed if we have obtained increment on fuel consumption by adopting eco-driving techniques, we have also obtained under the same external situations a saving in fuel consumption, so that it can demonstrate the importance of driver himself on the perception and application of this efficient driving method.

To evaluate the effect of eco-driving under different road sections, we have divided every itinerary in different branches with same characteristics and road sections, in order to be able to achieve a sort of sectorial analysis to understand how the effect of eco-driving depending on the road sector is.

3.2 METHODOLOGICAL APPROACH

By posing the problem on the chapter 1, it is possible to understand from what emerge the aim of this thesis.

After the literature review there have been identified two main research questions:

- How is affected eco-driving efficiency by different external factors as vehicle, driver, day hour and route?
- Which are the Eco-driving effects on fuel consumption depending on different road sectors and traffic states?

The following Figure 3 summarizes the methodological approach developed to complete this reasearch in order to answer to the two main research questions.

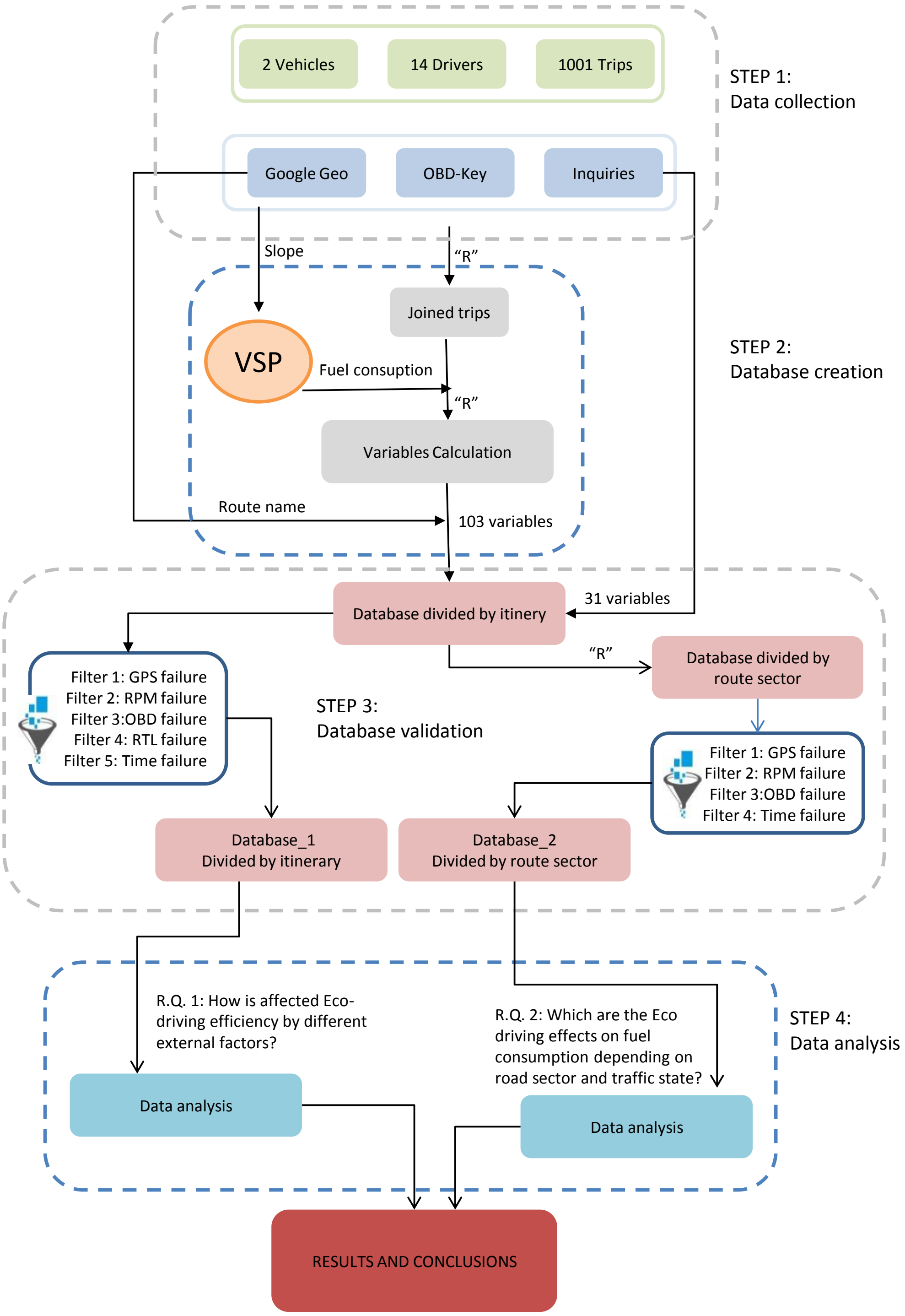


Figure 3 Flow chart of the methodological approach. Self elaboration.

As can be seen in the flow chart, the methodological approach used to develop this thesis can be divided in four different stages:

- data collection;
- Database creation
- Filtering data and database validation
- Data analysis

Stage 1: Data collection

After an initial literature review, the first stage of this research is been the creation of a data source.

It was completed over April and May 2017, in which it has been carried out the main data collection campaign of the experiment.

Two vehicles have been conducted during two driving periods, 9 days each one, with a stop period in which the 14 drivers have been enrolled in an efficient driving course.

1001 journeys were completed and data were recorded through an OBD-Key, special device preinstalled on the vehicles, obtaining second by second position, speed, revolution per minute and others relevant variables (more details on chapter 4).

From inquiries drown up from drivers after every driving shift, we have also obtained 31 new variables for each trip that will be unified with the other ones in order to obtain a global database.

At last, from Google Geo and the recorded GPS position, it has been possible to obtain second by second the name of the route and its slope; it will be useful for the next stages.

Stage 2: Database creation

This stage is the first part of the data process, better explained on the second part of the chapter four.

All data collected on the previous stage have been elaborated through the software "R" (more details in the same apart 4.4). This software permitted us to evaluate the mean value of every variables for each trip by having, as initial source data, second by second recordings.

Through Google Geo, knowing the instantaneous position recorded by the OBD-Key preinstalled on the vehicles, we have obtained the slope of the route and consequently we have been able to evaluate fuel consumption by using the VSP-Vehicle Specific Power model (more details in apart 4.3.2).

By unifying all variables obtained and by using another time the software R, we have joined all data in a unique initial database (Database_0) composed by 1001 trips, each one characterized by 134 variables.

Stage 3: Database validation

This stage is the second part of the data process.

Once obtained the initial database, containing all data previously recorded and elaborated, a filtering process has been necessary to apply.

Assuming that there were some of the variables evaluated without a significant value due to technological defects as occurs in all real experiments, database_0 has been filtrated in order to delete those data which can strongly affect the experiment results since they haven't shown a proper physical meaning.

We have applied 5 different filtering criteria, deleting those trips that didn't satisfy them:

The first one was a filtering regarding GPS positon failure, while the second one was about failures on the revolution per minute recordings. The third filter application regarded a failure in fuel consumption evaluation, the fourth one was about the real trip length with respect to the one recorded and the fifth and last one was regarding a timing failure.

By the adoption of these five different filtering process it has been created the new filtered database (Database_1): we moved from an initial data source composed by 1001 trips to a filtered data source composed by 846 valid trips.

At this point, through the re-use of the software “R”, it is been also possible the creation of a new valid database divided by sectors.

It means that the new database, basis of our second analysis (5.3), is not divided by kind of itinerary but is divided by route sector depending on the road section. In these terms we will be able to answer to the second research question: how is affected the eco-driving efficiency depending on the road section and traffic state?

Stage 4: Data analysis

To understand the Eco-driving efficiency, there have been conducted two different analysis, each one mainly based on the use of Pivot tables and concerning the variation of fuel consumption or of 5 eco-driving patterns, between the first and the second period of the experiment.

Patterns considered in these analysis are:

- average speed;
- average revolution per minute;
- % of time spending with strong acceleration (greater than 0.83 m/s^2);
- % of time spending with strong deceleration (lower than 0.83 m/s^2);
- % of time spending with speed lower than 5 km/h (stop_speed);

Each analysis has been developed to answer to each research question.

In these terms the first analysis is based on Database_1, divided por itinerary. It was analysed the eco-driving efficiency by studying results obtained along each itinerary and was studied the effect that can have different external factors on the reduction of fuel consumption by applying this driving approach.

External factors considered were:

- Vehicle;
- driving shift;
- driver;
- itinerary;

To answer to the second research questions, the respective analysis is based on the second sectorial database.

By taking into account the average speed and the percentage of time spending with speed lower than 5 km/h, we have categorized each road sector according to different traffic state (congested, medium, free). Later, through the use of several Pivot Table we have analysed the effect of different traffic levels on Eco-driving efficiency and its variation along different road sector.

CHAPTER 4: CASE STUDY AND DATA PROCESS

4.1 RESEARCH CONTEXT: ECO-TRAFFIC PROJECT

The project Eco-Traffic, operated by the TRANSyT Transport Research Centre of Madrid with the collaboration of "Universidad Politécnica de Madrid" and "Universidad de Extremadura", has been coordinated from the main researcher Andrés Monzón de Cáceres and the investigator Yang Wang. It was carried out in April and May 2017 and it was one of the projects of the Spanish National Plan in the context of challenge number 4-Intelligent, sustainable and integrated transport.

The main idea is to deepen in knowledge about the impact that driver behaviour – as to the driving profile (eco-driving) or route choice (eco-routing) – may have in reducing GHG and pollutants emissions.

Literature reflects both advantages and disadvantages of these measures, as well as big variability depending on the penetration rate of eco-drivers and eco-routers, but there are just few study cases like this one, in which it has been collected real field data in an urban and extra urban context, by monitoring all parameters second by second through special devices, before and after attending an efficient driving course.

Thus through this project, which lasts three years, it is proposed to analyse the impact and acceptance of these driving behaviours, eco or not eco, from different prospective; it is achieved first of all by carrying out real measurements through a data collection campaign in which two vehicles have been conducted along 4 different itineraries during two driving periods, 9 days each one, with a stop period in which the 14 drivers have been enrolled in an efficient driving course.

The hypothesis on which the research is based on is the potential of measures to improve driving patterns to reduce emissions of both GHGs and pollutants. Based on these, general objectives of this national project are:

- to analyse the potential reduction of emissions (both GHGs and pollutants) from the driver's point of view: an efficient way of driving and a route choice that minimizes consumption;
- to know the degree of acceptability as well as awareness of the benefits and disadvantages that this variation in driver behaviour can produce;
- to propose recommendations that can serve planners and operators involved in traffic management;

In the following illustration it is briefly resumed the methodology proposed to achieve these objectives through the Eco-traffic project.

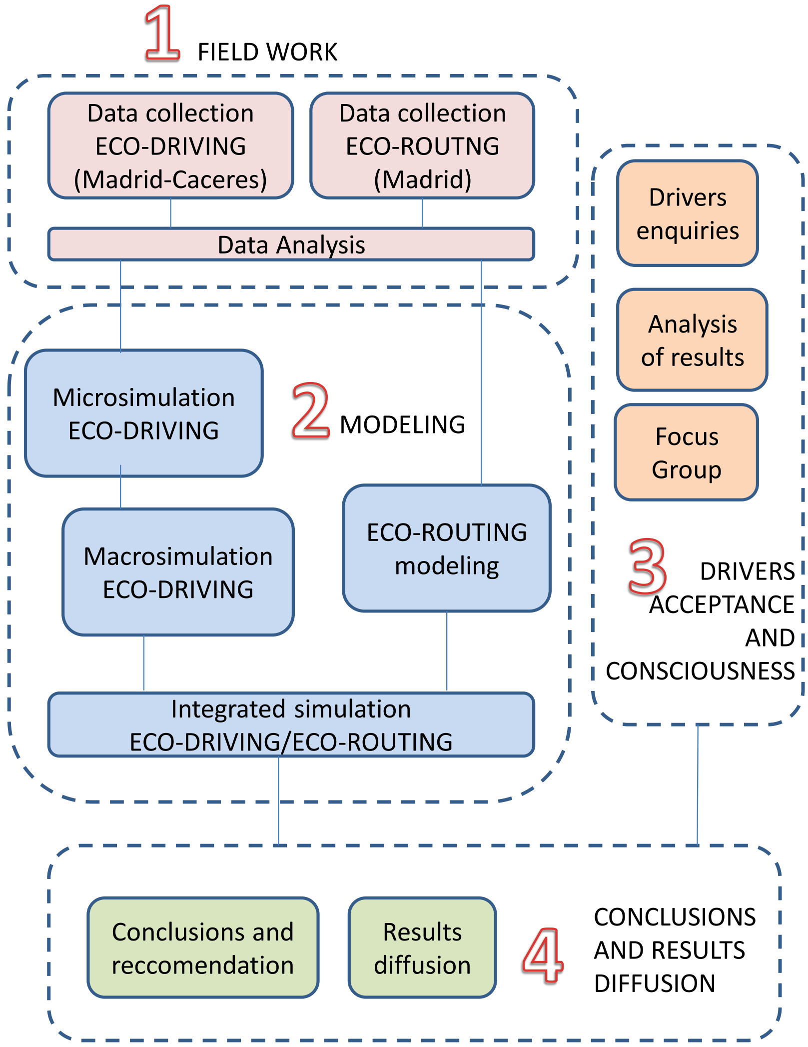


Figure 4 Flow chart regarding ECO-TRAFFIC project. Self elaboration

To this end, a data collection campaign it's been carried out to collect data in different types of road (urban roads, access roads to the city ...) under different traffic conditions (at different hours of the day) and in two Spanish cities with very different characteristics: Madrid and Cáceres.

The goal of this data campaign is the measurement of the effect that eco-driving issues have on an individual vehicle under real traffic conditions.

These measurements have been made with two different typologies of vehicle in order to analyse different impacts that can have gasoline or diesel power, not only in terms of fuel consumption but also with respect to the amount of saved fuel obtained by using on both cars all the known eco-driving patterns. By analysing both kinds of power, it will be possible to apply the concept to the fleet composition of each city when transferring the impacts to a city scale.

It seems important to underline that this work, which take part of the developed ECO-TRAFFIC experiment and starts from these real collected data, is only focused on the Madrid study case; in fact I have concretely participated on the project being part of the coordinators and conductors and by processing and analysing, in a second moment, all data collected.

Consequently my thesis will be focused on the first step of the global project, by taking into account the only case of Madrid.

4.2 GEOGRAPHICAL CONTEXT: MADRID METROPOLITAN AREA

Madrid is the capital of the as called "Comunidad Autonoma de Madrid". Located in the center of the Iberian Peninsula this region covers an area of 8,021 km^2 and counts with a population of 6,467 million of habitants, while the city of Madrid counts of 3,166 million habitants (Instituto Nacional de Estadística, 2016).

Figure 5 Madrid location, (García-Castro, 2016)

The road network of the metropolitan area has a radio centric structure with eight main motorways providing access to the city center. Other four ring motorways encircle the city of Madrid, connecting the peripheral districts and suburbs. With regards to the public transport network, the region has four main transport systems: Madrid metro and local bus systems, the regional commuter train and the metropolitan bus.

Without considering the well-developed public transport network, mobility in Madrid is mainly developed on the five circumvallation roads.

The largest one is the M-50, where is possible to achieve the maximum speed limit of 120 km/h and that is the access to all the transversal roads connecting Madrid to the Spain all. Figure 6 shows the main road network of Madrid.

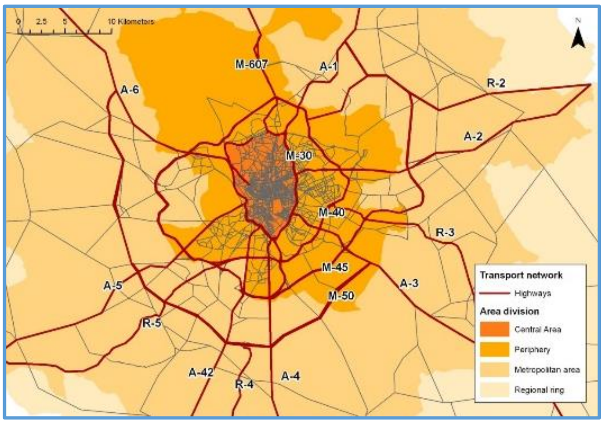


Figure 6 Madrid road network (Valdes 2012)

Actually the real context of this work consists on Madrid and two other municipalities of the Community, i.e. Majadahonda and Pozuelo Nuevo, which are different in terms of size and role but really important if it is considered the mobility between them.

Data collection campaign has been focused on these two municipalities due to the results of a mobility survey made in 2014, in which it was shown the amount of trips between both municipalities and Madrid.

Indeed mobility between them is really developed, due to the fact that being really near to Madrid, the municipalities of Majadahonda and Pozuelo Nuevo now cover one of the main roles regarding traffic demand around the city.

Both Pozuelo Nuevo and Majadahonda, as other municipalities of the community of Madrid, have extremely increased their populations during the last 20 years, passing in the case of Pozuelo Nuevo from less than 50,000 habitants in 90's to 84,989 habitants who have been registered in the 2016. Something similar have occurred in Majadahonda, that counted less than 40,000 habitants in 90's and hosts 70,755 habitants in 2016.

Population growth has not come alone, increasing the number of companies, education centers and entertainment venues; by looking on a land use map, it's possible to observe how is developed all this part of the Community, near to Madrid, in terms of offices and activities of the third sector.

Owning to such rapid development, there has been produced an increment on the amount of vehicles and each day there are many outsiders who are coming to live or work to these locations: an estimation done on 2011 affirms that only the 7% of the habitants rounding Madrid, has their residence in the same municipality of their work center.

These and other reasons that are not developed in this work led to the choice of these three different but connected municipalities as base of the study.

Figure 7 Madrid context

As it's possible to observe on the figure above, both municipalities of Pozuelo Nuevo de Alarcon and Majadahonda are very well served by a road network that allows people to have different kind of access thanks to the nearness of the main road connectors of Madrid.

Depending on the zone, north south east or west, Pozuelo Nuevo has the main accesses from A6, M40, M502 and M503, while Majadahonda from A6, M40, M503, M515 and M50 (M509).

As last and main observation demonstrating the fundamental role covered by these two municipalities regarding the mobility on the Community of Madrid, the imagine below is taken from the "Dirección general de carreteras y infraestructuras de la Comunidad de Madrid", and it shows the medium intensity of traffic demand at different mile points of the road network around Madrid. There, it is easy to observe that values of IMD are greater in the points of our interest than those in other parts.

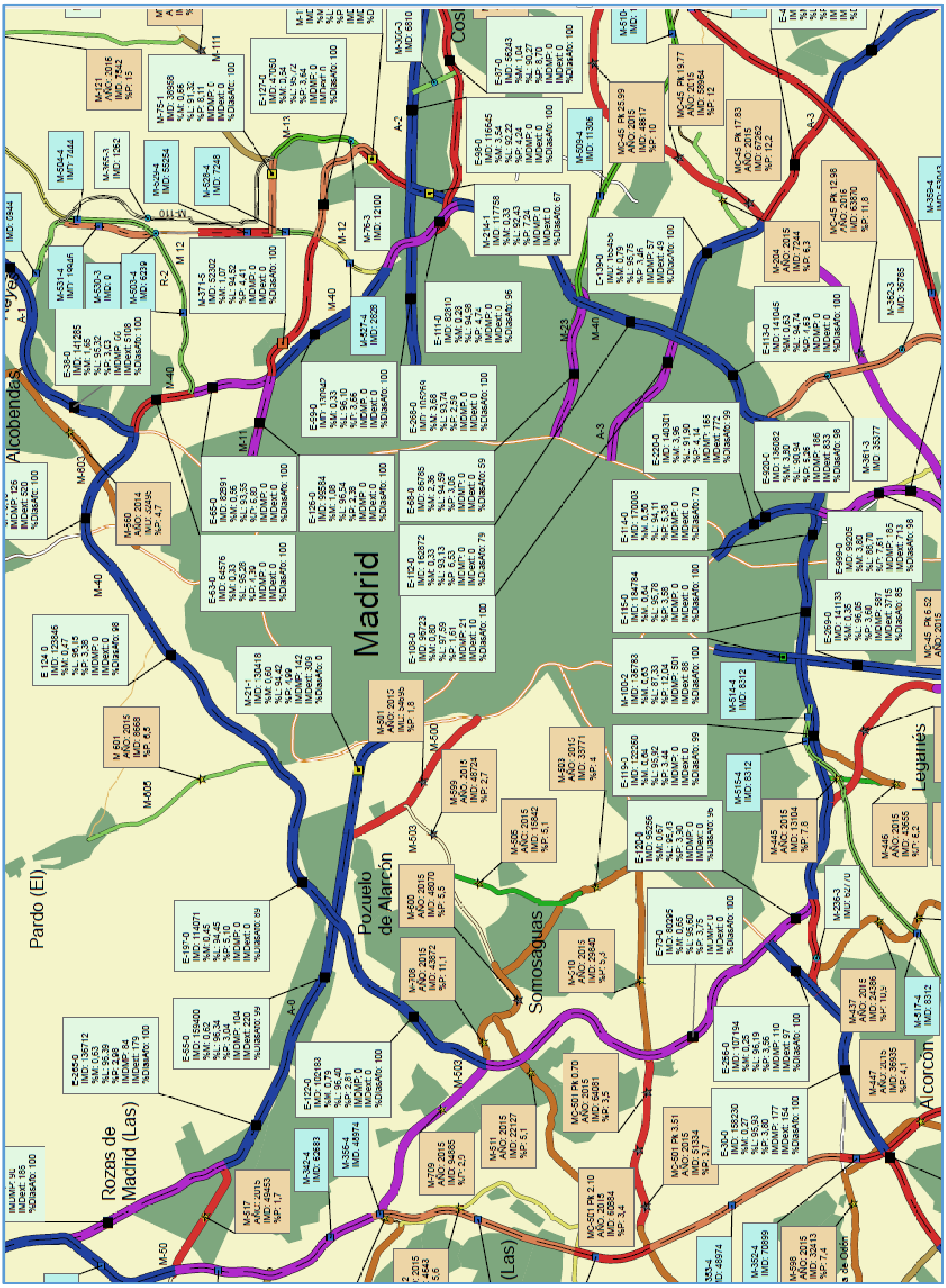


Figure 8 IMD of the main Madrid road network

Consequently, in this experiment itineraries with roads passing through the mile points in question have been chosen, but it will be better explained in the next paragraph.

4.3 DATA COLLECTION CAMPAIGN

In April and May 2017, the main data collection campaign took place in coordination with the Transport Research Centre of the Universidad Politécnica de Madrid (UPM); as previously mentioned it has been conducted in two driving periods, with a stop period in which all conductors have been enrolled in an efficient driving course, so that it could result easy to compare the fuel consumption produced by eco or not eco behaviour. Furthermore according to the report from Madrid Local Government (Dirección General de Sostenibilidad y Planificación de la Movilidad, 2013), 68% of passenger cars are diesel and 31% gasoline; in this sense, due to the use of two different vehicles, one diesel and one gasoline, the sample is representative of the Madrid fleet composition.

In order to obtain a sufficient data sample for different traffic situations (free circulation, moderate traffic and congestion), as well as to avoid alterations in the way of driving as consequence of meteorology (rains, snow, mist ...), driving periods have lasted 12 hours a day, divided on three shifts of four hours each one from Monday to Friday, so that they always covered the peak hours of the day.

Furthermore it’s right to underline that Saturdays and Sundays have not been included on the experiment; the final intent of this project regards a logical goal of participation (giving information, analysis and results) on the creation of new eco sustainable policies of transport. By analysing trips between Madrid-Moncloa, Pozuelo Nuevo and Majadahonda, it’s not useful to analyse data about weekends because demand traffic between these areas is developed more than ever from Monday to Friday due to the configuration, composition, role and geographic position of these areas.

First conductions have been performed by following a normal kind of driving; it's fundamental that drivers have different profiles in terms of sex, age, driving experience and other significant variables according to literature.

For many applications, the speed and GPS information recorded by smartphones may be enough. However, the vehicles participating in this campaign also provided information extracted from the on-board diagnostics (OBD) system; measurements of parameters that configure driving profile (instantaneous speeds, accelerations ...) as well as the consumptions have been obtained by the installation in vehicles of an OBD device, which allows to obtain and store these information with instantaneous character, in addition to the geographic location of the vehicle at any time.

The number of drivers involved was 14 and the total number of recorded trips was initially 1001 (after different filtering process, to develop this work I've analysed 846 trips).

The first step of the methodology implemented to develop this work has been this data collection campaign, in which drivers have followed the established itineraries iteratively, driving according to their usual driving pattern; during the second period, after being attending to an efficient driving course, they have driven the same itineraries as the first month.

Information collected by the OBD-Key devices installed on the vehicles have been reserved in the webserver of the company which have been accessed by registered users. In this way, the work team could confirm the goodness of data and if there was any incident occurring.

There have been determined four different itineraries, and for each of them three alternative routes with the same origin and destination.

After having processed all data recorded, has been created a relational database. Subsequently, it's been carried out a profile classification (type of driver, type of vehicle, type of route, traffic level, meteorological conditions ...) which allows making comparisons between the scenarios without and with each one of the considered Eco-driving patterns.

This analysis will allow to compare savings on fuel consumption for different scenarios, in terms of itineraries and according to different traffic conditions, obtaining different type of driving profiles for the eco-drivers and a future possible estimation of consumption curves.

The purpose of this thesis is to keep on a deep analysis regarding eco-driving efficiency starting by taking into account results obtained during the ECO-TRAFFIC "experiment". In order to do it, it's useful to describe the experiment in details, by analysing and characterizing everything that has been involved on it (as different cars, different shift of conduction, different drivers..) and by analysing in depth every significant step of the data collection campaign.

Starting from these data the analysis of results will be presented, trying to understand which are the main factors affecting the efficiency of Eco-driving and how it is affected by different road sections.

Once presented in 4.2 the general context of the data collection campaign, now it's presented a more detailed explanation concerning all issues included in the experiment.

4.3.1. VEHICLES

To carry out the data campaign two different cars have been used: an Opel Astra (diesel) and a Fiat 500 (gasoline). The cars were rented to the car sharing company Bluemove: two new cars were available on a weekly basis, so that the maximum number of kilometres would be made to each car, given the limitation imposed by the company. These kinds of vehicles can be classified as small (Fiat 500) and medium segment (Opel Astra), which corresponds approximately to 75% of the fleet in Madrid (DGT, Dirección General de Tráfico de España). Moreover these vehicles are registered under Euro 5 standards, while the average fleet age in

Madrid is 9.3 years (Dirección General de Sostenibilidad y Planificación de la Movilidad, 2013).

Features	Astra Values	Fiat Values
Name	Opel Astra 1.6 CDTI 110 cv	Fiat 500 1.2 69 CV
Commercial section	Saloon	Minis
Engine type	Diesel	Gasoline
Cylinder capacity (cm^3)	1598	1242
Gear Shift Type	Manual	Manual
Maximum Authorized Mass	2010	1305
Power CV	110,05	93,75
Dimensions (WxDxH) (mm)	4419 x 1814 x 1510	3546 x 1627 x 1488
Maximum Seating Number	5	4
Average fuel consumption	4,1	4,9
Emissions (gCO_2/km)	109	115
Emissions (gCO_2/l)	2,658	2,347
Classification by Relative Consumption	A	D

Figure 9 Vehicle data

4.3.2 DRIVERS, SHIFTS AND TIMETABLE

DRIVERS

For the various conductions required in the experiment, 14 drivers were involved for one month. Due to the contract limitations, drivers were students of Universidad Politécnica de Madrid (UPM) and academic staff, aged between 23 to 57 years old; the sample was almost gender balanced, being 8 males and 6 females.

Figure 10 Some of drivers with the cars

Drivers were hired to cover 12 hours / day of driving, always covering peak hours of the day, with 3 shifts of 4 hours covered by 2 people (pilot and co-pilot took turns). Iteratively, routes along the series of itineraries previously agreed by the research team, were performed. As already said a period of 12 hours is covered in order to obtain a sufficient data sample concerning different traffic situations, as well as to avoid alterations in the way of driving as consequence of the meteorology.

Moreover in this experiment we tried to hire drivers with significant different driving experiences. At the time of signing up, conductors had to fill in a format indicating the number of years of driving experience and the typical driving behaviour, in order to give us the possibility to include these information in our database to get a wider range of possible analysis. The fact that people engaged had different driving experience has permitted to do an analysis regarding different level of eco-driving penetration after attending the efficient driving course, as function of the ability of the conductor; in other words, how different person perceive and change their behaviour receiving at the same time the same advices (Course developed at Autoescuela Abril in Madrid).

The course has been structured with a first driving session in which drivers have driven vehicles through the established route and in the cabin sheet different parameters about their driving like the average speed, gear changes made, and consumption have been recorded. After that, there has been a theoretical class in which a professional of the Autoescuela has explained base concepts and have given to conductors all the necessary material to support his explanations. As last, it took place a second driving session in which people who have attending this training have repeated the driving on the same route as before, to check the effectiveness on the application of the information that have been provided; again the parameters were picked up to comparethese with the previous ones.

As expected, the comparison of results has showed that all conductors have reduced their fuel consumption; this case can be considered as an ideal situation, because there was an efficient driving expert as co-pilot who could give driving tips instantly to the pilot. Moreover, the road was exactly the same and the conduction were performed just after the theoretical class, so that results don't surprise us: under ideal conditions of fluid traffic (it has never been congestion problems) and by correctly applying eco-driving techniques, CO_2 consumption decreases.

For this reason the development of this thesis in which we really want to pass from an ideal situation to a more realistic analysis (covering peaks hours, congestion times, different behaviours etc.) in order to understand, among other concepts, on what the real efficiency (or not) of the eco-driving technique depends.

SHIFTS AND TIMETABLE

As previously mentioned each day of driving consists of three shifts (for each vehicle), which covered the peak hours of traffic in the marked itineraries.

Shifts have a duration of 4 hours and have been covered by 2 person, who drive two hours each one, being respectively pilot and co-pilot during the same shift.

The first driving period begins on Monday, April 17. Because this day is considered non-academic in the city of Madrid, so being able to significantly alter traffic conditions in relation to the rest of the week, this day aims to raise awareness of drivers with the role they will play within the project, as well as to explain in detail the operation of the OBD key II, the different itineraries that had to be performed, the convenient refuelling points, etc.

Based on the different travel time obtained from Google Map data, driving shifts have been adjusted so that all pick hours were covered by the experiment to have a more complete study, so that always starting 15 to 20 minutes before the rush hour starts, and ending the same, 15 or 20 minutes after finish the rush hour.

1º Shift	7:00-11:00
2º Shift	11:30-15:30
3º Shift	16:00-20:00

Table 1 Driving shift

All journeys have begun on the same parking of the university UPM-Caminos, canals y puertos. The half hour between shifts is created to permit a gap time between them, because of different external reasons; it explains the great variety of data among others in terms of different number of trips recorded for each itinerary, due to a limited time and a total realistic experiment.

4.3.3 ROUTES AND ITINERARIES

As previous mentioned, data collection campaign was focused on Madrid and on two others municipalities of the Madrid Autonomous Community, Pozuelo Nuevo and Majadahonda, which have been selected due to results obtained from a mobility survey made in 2014, in which it was shown the amount of trips between both municipalities.

The campaign was performed including four itineraries between these two municipalities and the Universidad Politécnica de Madrid (UPM), and for each itinerary, three different routes were chosen.

All itineraries selected are interurban routes, connecting “UPM-Escuela técnica superior de ingenieros de Caminos, Canales y Puertos” with a fixed place previous established in Pozuelo Nuevo and this one with Majadahonda; these are composed by different kinds of routes, with different traffic demand level and different possible offers. It was known, besides others, that road sections can influence the perception of roads and as consequence the traffic in itself, so that it can be really interesting to study how different kind of roads are affected by different way of driving (with or without eco-driving techniques), or if there are some kinds of roads that produce less efficiency in adopting an eco-driving behaviour and why.

The first itinerary of the experiment (named CP) links the University with Pozuelo Nuevo, the second one (named PC) Pozuelo Nuevo and Majadahonda, the third one (named MP) is between Majadahonda and Pozuelo Nuevo while the fourth one links Pozuelo Nuevo and the University in question (PC). All the itineraries have three different possible routes, each one with different characteristics.

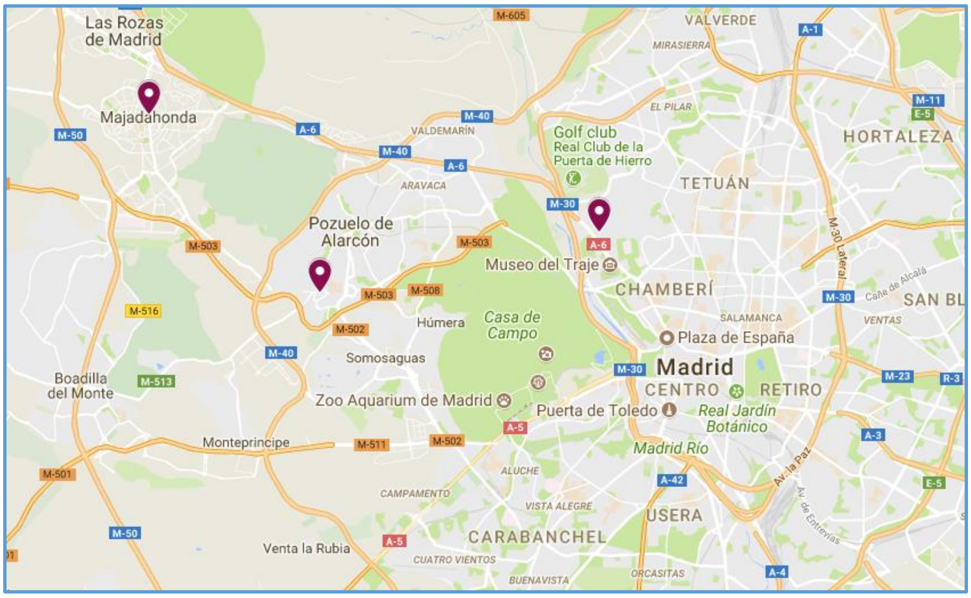


Figure 11 Location of the starting and arrival point of the itineraries

On the previous Figure 11, it’s possible to have a global vision of the position of the three municipalities; three signs correspond to the initial and final points of the itineraries and are located respectively in correspondence of the “Escuela técnica superior de ingenieros de caminos, canals y puertos” de Madrid, in Calle

Tomás Pierri de Pozuelo Nuevo, and in Avenida de España (M515) de Majadahonda; places in which there have been concluded every routes.

Three different type or route have been chosen to complete every itinerary. Each one of them is presented more in details in the following images in which each road sector is represented through different colours.

Itinerary CP = University-Pozuelo

Itinerary PC = Pozuelo-University

Itinerary PM = Pozuelo-Majadahonda

Itinerary MP = Majadahonda-Pozuelo

University-Pozuelo / Pozuelo-University

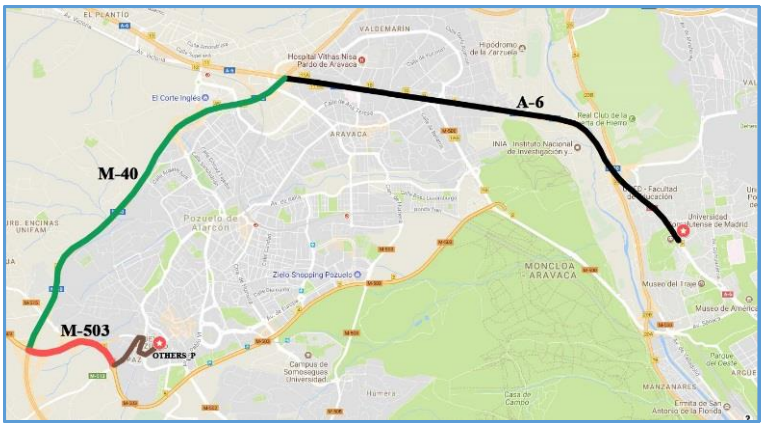


Figure 12 Route 1 between University/Pozuelo and Pozuelo/University

Figure 13 Route 2 between University/Pozuelo and Pozuelo/University

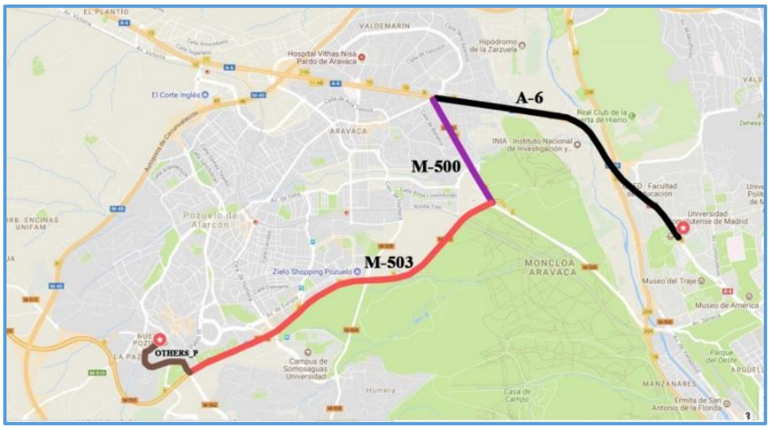


Figure 14 Route 3 between University/Pozuelo and Pozuelo/University

Pozuelo-Majadahonda / Majadahonda-Pozuelo

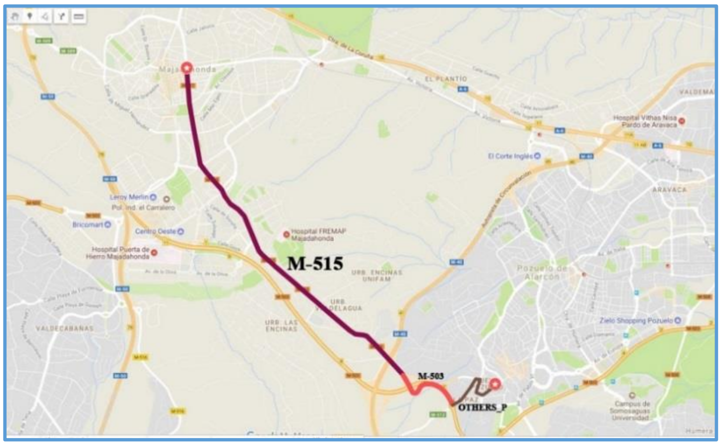


Figure 15 Route 1 between Pozuelo/Majadahonda and Majadahonda/Pozuelo

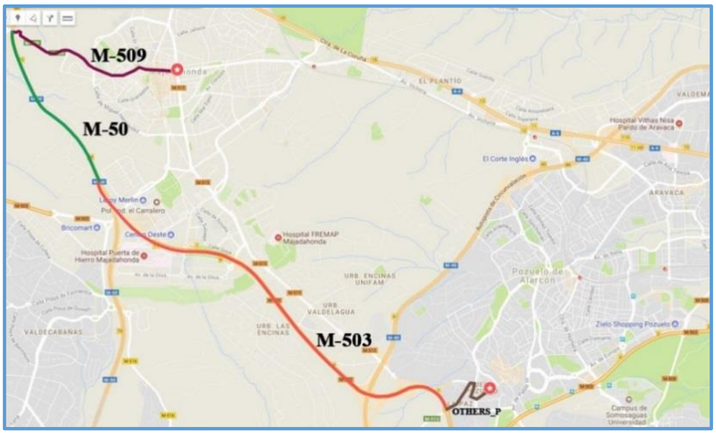


Figure 16 Route 2 between Pozuelo/Majadahonda and Majadahonda/Pozuelo

Figure 17 Route 3 between Pozuelo/Majadahonda and Majadahonda/Pozuelo

As the intent is to understand the real efficiency or not on the application of an eco-driving behaviour depending on route sectors and others several parameters, it has been useful to do the analysis by dividing itineraries into homogeneous street-type branches; indeed along every itinerary drivers have been driving through different types of road with different structural characteristics, and it can affects in different way the efficiency of Eco-driving in terms of fuel saving.

According to the traditional classification of urban roads (AASHTO, 2001), these can be classified in four categories: Principal arterial, Minor arterial, Collector street and Local street.

Following this classification for the case of Spain, urban roads are defined as follows (Kraemer et al., 2009):

-Motorways and speedways: these roads are needed in cities with over one million inhabitants where the length of trips makes high speed roads necessary. These roads are characterized by:

- they are designed for through traffic only, and the access to adjacent properties is not allowed;
- trip longitude in such roads may exceed 5 kilometers;
- the junctions are built at different levels, sometimes regulated by traffic lights, but preferably with multi-level interchanges in order to enable high speeds;
- urban motorways are designed for lower speeds and with closer junctions than the interurban motorway;

-Arterials: They are necessary to communicate different parts of the city. They capture traffic that comes mostly from local streets and collector-distributor, and are characterized by:

- these rarely provide direct access to adjacent properties;
- the trips in such streets are normally longer than 2 km;

- the intersections are built at the same level (regulated by traffic lights) or at different levels with over- or underpasses;

-Collectors: These roads lead directly traffic from its origin to its destination or connecting local stress. They are distinguished by:

- access to surrounding buildings is allowed;
- trips are around 1 km long and at lower speeds than arterial;
- intersections with local streets or other collectors are at the same level, regulated by traffic signals or just priority rules;

-Local streets: lead traffic from its origin to its destination or to collectors. They are distinguished by:

- access to adjacent buildings and properties is allowed;
- trips are normally shorter than 1 km and with low speeds;
- intersections with local streets or collectors are at the same level and rarely regulated by traffic signals;

With respect to our study case, tables below summarize the main characteristics of the implicated roads.

Route	Total distance (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)	IMD	IMD pesados	%pesados
CP1	15.1	OTHERS-Caminos	Local street		50	0.45-1.45			
		A-6	Natinoal Highway. Dynamic message sign	3*3 and 4*4 (from M30) seperated by HOV lane	80	5.7	130,364	6,500	4.99%
		ACCESS M-40	ACCESS	1 lane	40	0.6			
		M-40	Urban Motorway	3*3, seperated by barrier	100	5	77,333	2,871	3.71%
		ACCESS M-503	ACCESS	1 lane	40	0.6			
		M-503	Urban Motorway	2*2,seperated by barrier	90	1.3-2.7			
		OTHERS-Pozuelo	Urban arterial, collector and Local street	3*3, seperated by barrier	100	0.5-2			
CP2	11	OTHERS-Caminos	Local street			0.45-1.45			
		A-6	Natinoal Highway. Dynamic message sign	3*3 and 4*4 (from M30) seperated by HOV lane	80	0.65-1			
		OTHERS-Moncloa	Urban collector	1*1	40	1.3			
		Others-Seneca	Urban collector	1*1 with double continued line, on-street parking both side	40	1.1			
		M-500	Urban Motorway	2*2, seperated by barrier	90	2.6	54,695	991	1.81%
		ACCESS M-503	ACCESS	1 lane	40	0.6			
		M-503	Urban Motorway	2*2,seperated by barrier	90	4.5	48,724	1,323	2.72%
		OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
CP3	12.5	OTHERS-Caminos	Local street		50	0.45-1.45			
		A6	Natinoal Highway. Dynamic message sign	3*3 and 4*4 (from M30) seperated by HOV lane	80	3.8	130,364	6,500	4.99%
		ACCESS M-500	ACCESS	1 lane	40	0.6			
		M-500	Urban Motorway	2*2, seperated by barrier	90	1.5	54,695	991	1.81%
		ACCESS M-503	ACCESS	1 lane	40	0.6			
		M-503	Urban Motorway	2*2, seperated by barrier	90	4.5	48,724	1,323	2.72%
		OTHERS-Pozuelo	Urban arterial, collector and Local street		90	0.5-2			

Table 2 Road description - Itinerary CP

Route	Total Distance (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)	IMD	IMD pesados	%pesados
PC1	13	OTHERS-Pozuelo	Urban arterial, collector and Local street	including M-515	50	0.5-2			
		M-40	Urban Motorway	3*3, seperated by barrier	100	4.1	77,333	2,871	3.71%
		ACCESS A-6	ACCESS	2 lanes to 1 lane	60	0.95			
		A-6	Natinoal Highway. Dynamic message sign	3*3 and 4*4 (from M30) seperated by HOV lane	80-120	5.8	130,364	6,500	4.99%
		Salida A-6	ACCESS	1 lane	30	0.13			
		OTHERS-Caminos	Local street		50	0.45-1.45			
PC2	11.6	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
		M-503	Urban Motorway	2*2,seperated by barrier	90	3.3	48,724	1,323	2.72%
		ACCESS M-500	ACCESS	1 lane	40	0.4			
		M-500	Urban Motorway	2*2, seperated by barrier	90	1.7	54,695	991	1.81%
		OTHERS-Moncloa	Urban collector	1*1	40	1.4			
		OTHERS-Seneca	Urban collector	1*1 with double continued line, on-street parking both side	40	2			
		A-6	Natinoal Highway. Dynamic message sign	3*3 seperated by HOV lane	80	0.8			
		OTHERS-Caminos	Local street		50	0.45-1.45			
PC3	12	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
		M-503	Urban Motorway	2*2,seperated by barrier	90	3.6	48,724	1,323	2.72%
		ACCESS M-500	ACCESS	1 lane	40	0.25			
		M-500	Urban Motorway	2*2, seperated by barrier	90	1.7	54,695	991	1.81%
		A-6	Natinoal Highway. Dynamic message sign	3*3 and 4*4 (from M30) seperated by HOV lane	80-120	3.5	130,364	6,500	4.99%
		Salida A-6	ACCESS	1 lane	40	0.13			
		OTHERS-Caminos	Local street		50	0.45-1.45			

Table 3 Road description - Itinerary PC

Route	Total Distance (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)	IMD	IMD pesados	%pesados
PM1	8	OTHERS-Pozuelo	Urban roads		50	0.5-2			
		M515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 20km/h.	2 and 2, seperated by bicycle lane,Both sides haveon-road parking which influence traffic	50	6			
PM2	12.5	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 seperated by barrier	90	6.2	43,872	4,883	11.13%
		M-50	Urban Motorway	3*3, seperated by barrier	120-100	2.6	61,870	6,408	10.36%
		M509	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 30km/h.	2*2 seperated by barrier	50	1.3	17,663	590	3.34%
		OTHERS-Majadahonda	Urban arterial	Av. Dr.Marañón & Av. Dr.Calero	50	1.4			
PM3	8	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 seperated by barrier	90	3.9	43,872	4,883	11.13%
		M-515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 20km/h.	2 and 2, seperated by bicycle lane,Both sides haveon-road parking which influence traffic	50	3.1			

Table 4 Road description - Itinerary PM

Route	Total Distance (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)	IMD	IMD pesados	%pesados
MP1	8.5	M-515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to	2 and 2, seperated by bicycle lane,Both sides haveon-road parking which influence traffic	50	6			
		M-503	Urban Motorway	2*2, seperated by barrier	90	1.2	48,724	1,323	2.72%
		OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
MP2	13	OTHERS-Majadahonda	Urban arterial	Av. Dr.Marañón & Av. Dr.Calero	50	1.3			
		M-509	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 30km/h.	2*2 seperated by barrier	50	1.6	17,663	590	3.34%
		M-50	Urban Motorway	3*3, seperated by barrier	120/100	2.1	61,870	6,408	10.36%
		ACCESS M-503	ACCESS	2 Lanes with tunel	100	1			
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 seperated by barrier	90	5.6	43,872	4,883	11.13%
		OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
MP3	8	M-515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 20km/h.	2 and 2, seperated by bicycle lane,Both sides haveon-road parking which influence traffic	50	3.7			
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 seperated by barrier	90	3.8	43,872	4,883	11.13%
		OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			

Table 5 Road description - Itinerary MP

To go on the characterization of itineraries, we should have to speak about the Average Annual Daily Traffic (AADT). As known the AADT is a number that represents the medium volume of traffic passing through a certain section during a day; this value is really important when we have to think on transport planning or about a determination in the trend use of roads.

From “Dirección General de Carreteras e Infraestructuras de la Comunidad de Madrid”, the AADTs have been collected through permanent, primary and secondary stations installed along the road network of the Madrid community. Table 6 shows data of the AADT in our study and have been encountered in our routes at different points of the itineraries (Reference years 2016 and 2015 where missing data). It can give us an idea about the magnitude of the vehicular traffic met in our study.

Itinerary	Road	Station Type	PK	IMD	IMD (hv)	% h.v.	Reference year	km going		km returns	
	A6	Primary	7.5	130,418	6,520.9	5	2015	5.6		5.6	
CP1	M-40	Permanent		102,183	2,831.3	2.81	2016	5.3	15.2	4	13.8
	M-503	Primary	6.48	41,029	3,692.6	9	2016	1.4		1.4	
	M-500	Permanent	3.46	54,742	908.7	1.66	2016	2.6		2.6	
CP2	M-503	Permanent	1.02	52,364	1,099.6	2.1	2016	4.5	13.3	3.4	11.7
		Primary	6.48	41,029	3,692.6	9	2016				
	A-6	Primary	7.5	130,418	6,520.9	5	2015	3.7		3.4	
	M-500	Permanent		54,695	984.5	1.8	2015	1.5		1.4	
CP3	M-503	Permanent	1.02	52,364	1,099.6	2.1	2016	4.5	13.5	4.7	13
		Primary	6.48	41,029	3,692.6	9	2016				
PM1	M-515							6.4	8.2	7.2	7.7
	M-503	Primary	6.48	41,029	3,692.6	9	2016	5.8			
PM2		Permanent	8.67	94,876	2,732.4	2.88	2016		13.2		12.5
	M-50	Coverage		62,683			2016	2.3		2.3	
	M-509			17,663	590	3.34		1.3		1.5	
	M-503	Permanent	1.02	52,364	1,099.64	2.1	2016	5.3		5.1	
PM3		Primary	6.48	41,029	3,692.6	9	2016		8.6		8.1
	M-515							2.8		2.8	

Table 6 Itineraries Data from "Dirección General de Carreteras e Infraestructuras de la Comunidad de Madrid"

N.B. “km going” means the distance evaluated as indicated on the correspondent column “itinerary”; for example in the first line of Table 6, with regards to the itinerary CP1, kilometers on M40 to go from the university to Pozuelo (CP1) are 5.3, while the ones to go from Pozuelo to the University (PC1) are indicated on the column “km return”, equal in this case to 4 kms.

We do not have data concerning the average daily intensity of traffic with respect to arterial and urban roads, so that another time it seems really useful to characterize each itinerary in different branches according to its section and its function, and evaluate how many kms of each kind of road are included on the itinerary; in this way, it’s more intuitive to understand the relation between fuel consumption and type of road.

Finally in Table 7 below the number of trips initially recorded is briefly resumed depending on the itinerary and the vehicle, and if it was driven with ECO-Driving techniques or if not.

ITINERARY	ASTRA		FIAT		TOT
	Without ECO	With ECO	Without ECO	With ECO	
CP1	23	23	22	19	87
CP2	24	25	29	19	97
CP3	24	23	24	17	88
MP1	17	20	20	17	74
MP2	20	23	20	18	81
MP3	21	19	19	14	73
PC1	25	22	28	20	95
PC2	25	25	24	20	94
PC3	20	23	21	15	79
PM1	19	20	19	16	74
PM2	20	22	23	20	85
PM3	21	20	19	14	74
TOT	259	265	268	209	1,001

Table 7 Trips recorded

4.3.4 **DATA EQUIPMENT**

For many applications, the speed and GPS information recorded by smartphones may be enough. However, the vehicles participating on this data collection campaign also provided information extracted from the on-board diagnostics (OBD) system.

The methodology included the installation of an OBD key to extract data from each vehicle's OBD system. This was used to record instantaneous position, speed, acceleration, fuel consumption (l/h down to a precision level of five significant digits) and revolutions per minute (rpm) second by second.

This device was easily installed by the user in the vehicle diagnostic port, and sent data to a mobile phone via Wi-Fi with a frequency of 1 Hz.

Figure 18 Data equipment

Once downloaded data from each mobile phone into the computers of the research center, they were reorganized in Excel spreadsheet and it could start the stage of the data process (4.5).

4.4. VSP MODEL

Through the OBD-key, information of instant fuel consumption can be obtained. However, in this context were adopted a well spread fuel consumption model, called Vehicle Specific Power to estimate the instantaneous fuel consumption of each vehicle.

The VSP model is a convenient single measure that can be used directly to predict emissions. VSP approach to emissions characterization was developed by several researchers (Jimenez-Palacios, 1999) and further developed as part of the MOVES motor vehicle emissions simulator (MOVES) model.

VSP is a direct measure of the road load on a vehicle: it is an accredited methodology demonstrated to characterize vehicles and driving profiles using real-world on-road measured data (Duarte, 2013).

Informally it represents the ratio between the instantaneous energy requested by the vehicle and its mass. To estimate the power demand of the vehicle, VSP methodology combines speed, acceleration and road grade, according to the following equation, which is applicable to light-duty vehicles (Jimenez-Palacio, 1999).

$$VSP\left[\frac{W}{kg}\right] = \frac{Power}{Mass} = \frac{\frac{d}{dt}\left(E_{kinetic} + E_{potential}\right) + F_{rolling} * v - F_{aerodynamic} * v}{m} = v(1.1 * a + 9.81 * grade + 0.132) + 3.02 * 10^{-4} * v$$

Equation 1 VSP model

In which:

$E_{kinetic}$ is the kinetic energy

$E_{potential}$ is the potential energy

$F_{rolling}$ is the rolling resistance force

$F_{aerodynamic}$ is the aerodynamic resistance force

v is the instantaneous speed (m/s)

m is the mass (kg)

a is the acceleration (m/s^2)

$grade$ is the road grade (m/m)

Each second of driving was associated to a VSP bin, as presented in the next table, in which are shown the 14 VSP modes and the corresponding power requirements interval for each modes. (Faria et al., 2017)

VSP mode	W/kg	VSP mode	W/kg
1	VSP < -2	8	13 ≤ VSP < 16
2	-2 ≤ VSP < 0	9	16 ≤ VSP < 19
3	0 ≤ VSP < 1	10	19 ≤ VSP < 23
4	1 ≤ VSP < 4	11	23 ≤ VSP < 28
5	4 ≤ VSP < 7	12	28 ≤ VSP < 33
6	7 ≤ VSP < 10	13	33 ≤ VSP < 39
7	10 ≤ VSP < 13	14	VSP ≥ 39

Table 8 Correlation between VSP mode and W/Kg

Once we have obtained second by second the corresponding VSP mode, it's possible to correlate every mode with emissions by using the following table (Faria et al., 2017).

VSP mode	Pollutant							
	CO_2 (g/s)		CO (mg/s)		NO_x (mg/s)		HC (mg/s)	
	G	D	G	D	G	D	G	D
1	0.63	0.21	0.50	0.03	0.23	1.29	0.03	0.14
2	1.05	0.61	0.27	0.07	0.68	2.62	0.03	0.11
3	1.02	0.73	0.15	0.14	0.60	3.38	0.03	0.11
4	2.07	1.50	0.58	0.25	1.75	6.05	0.07	0.17
5	2.79	2.34	1.14	0.29	2.52	9.36	0.10	0.20
6	3.47	3.29	1.76	0.69	3.34	12.53	0.15	0.23
7	4.31	4.20	4.05	0.58	4.04	15.48	0.22	0.24
8	5.19	4.94	6.13	0.64	2.63	17.82	0.35	0.23
9	5.81	5.57	9.06	0.61	3.51	21.32	0.42	0.24
10	6.43	6.26	18.97	1.01	2.89	32.53	0.52	0.28
11	7.37	7.40	44.98	1.15	1.27	55.75	0.62	0.37

Table 9 Correlation between VSP mode and emissions

Finally, through the conversion model drawn from the same article (Fara et al., 2017) it has been obtained the instantaneous fuel consumption related to each VSP mode depending on the typology of vehicle.

	Instantaneous fuel consumption (l)	
VSP mode	GASOLINE	DIESEL
1	0.01244	0.01116
2	0.01866	0.01674
3	0.020526	0.018414
4	0.0622	0.0558
5	0.08397	0.07533
6	0.11507	0.10323
7	0.14306	0.12834
8	0.16794	0.15066
9	0.19904	0.17856
10	0.22703	0.20367
11	0.27368	0.24552

Table 10 Relation between VSP mode and fuel consumption

In this way, energy power requested by a vehicle and the respective emissions were calculated and compared for each itinerary.

Consequently, by using this method, we can do a comparison regarding the association between emissions and different driving behaviour patterns or different type of vehicles (gasoline and diesel).

4.5 DATA PROCESS

4.5.1 VARIABLES EVALUATED

According to the traffic and emission literature, records were processed in order to obtain through the OBD-Key the following 103 variables for each trip (Ericsson 2001, Smit et al 2007, Greenwood Dunn and Raine 2007, Beusen et al 2009), to which have been added on a second time 31 variables obtained from the drivers' attitude survey. Variables included were maximum speed, mean speed, maximum acceleration, maximum deceleration, number of stops and other values statistically derived such as standard deviation, 95th percentile among others. Idling time, average rpm, coasting time and others engine variables were also calculated as they can be useful for further researches concerning fuel consumption and emissions.

The variables finally calculated and introduced into the databases can be found in the following Table 11:

Variables in Database	**Description**	**Unit**
No	Number	
File ID	File ID	
Vehicle	vehicle ID	
Route	Routes ID	
Itinerary	Itinerary ID	
Roads	Roads name	
Duration	trip duration in HH:MM:SS	sec
Error	failed trips	
Eco-driving	if it is eco-driving day is 1	
Kilometer	traveled distance recorded by OBD	km
Fuel consumption OBD	average fuel consumption by OBD	l
Fuel consumption OBD	total fuel consumption by OBD	l
driver ID	name of the driver	
Copiloto ID	name of the co-driver	
Question 1	The handling of the vehicle has resulted easy/difficult	
Question 2	The circumstances of driving have been easy/difficult	
Question 3	During the journey you have felt boring/entertaining	
Question 4	During the journey you have felt relaxed/stressed	
Incident		
Kilometro_recorded	Kilometer recorded by the car meter	Km/h
Weather	Weather of the recording day	
Window	Window	
Aire condition	Air condition is on	
Temperature outside	Temperature outside of the car	°C
Temperature inside	Temperature inside of the car	°C
date	Recording Date	
weekday	Day of the week	
start_time_s3	trip start time_filtered data	

end_time_s3	trip end time_filtered data	
duration_calculated_s3	trip duration using end time minus start time_filtered data	sec
duration_recorded_s3	trip duration recorded by OBD_filtered data	sec
lpk_sum_s3	Total litro per kilometer_OBD	l
lpk_ave_s3	average total litro per kilometer_OBD	l
trip_length_s3	trip length_filtered data	km
max_speed	maximum speed	km/h
avg_speed	average speed	km/h
lpk_ave_mp_trip_length	average total litro per kilometer_OBD*trip length_Filtered data	l
avg_rpm	average rpm	rev/min
max_rpm	maximum rpm	rev/min
min_rpm	minimum rpm	rev/min
min_acc_pos	minimum positive acceleration	m/s^2
max_acc_pos	maximum positive acceleration	m/s^2
min_acc_neg	minimum negative acceleration	m/s^2
max_acc_neg	maxmum negative acceleration	m/s^2
ave_acc_pos	average positive acceleration	m/s^2
ave_acc_neg	average negative acceleration	m/s^2
p95_acc_pos	95 percentile of positive accelerations	m/s^2
p95_acc_neg	95 percentile of negative accelerations	m/s^2
sd_acc_pos	standard deviation of positive accelaration	m/s^2
sd_acc_neg	standard deviation of negative accelaration	m/s^2
Pacc_0.1	time with more than 0.1 m/s^2 accelaration	Sec
Pacc_3	time with more than 0.83m/s^2 accelaration	Sec
Pacc_5	time with more than 1.389m/s^2 accelaration	Sec
Pdec_0.1	time wit less than -0.1m/s^2 accelaration	Sec
Pdec_3	time wit less than -0.83m/s^2 accelaration	Sec

Pdec_5	time wit less than -1.389m/s² accelaration	Sec
Pcru_0.1	time with accelaration rate between -0.1 and 0.1 m/s²	Sec
Pcru_3	time with accelaration rate between -0.83 and 0.83 m/s²	Sec
Pcru_5	time with accelaration rate between -1.389 and 1.389 m/s²	Sec
perc_spd_0	percentage of 0 velocity	%
perc_spd_0_50	percentage of velocity between 0 to 50 km/h	%
perc_spd_50_70	percentage of velocity between 50 to 70 km/h	%
perc_spd_70	percentage of velocity more than 70%	%
PAA	Positive accumulated acceleration: Summation of V(i+1)-v(i) if V(i+1)>V(i)	
PAA_km	Positive accumulated acceleration per km: Summation of V(i+1)-v(i) if V(i+1)>V(i)	
PKE	Positive kinetic energy: Summation of V^2(i+1)-v^2(i) if V(i+1)>V(i)	
Nstop_aux_3	Number of stops being stop speed under 3km/h	
st_t_aux_3	Stop time being stop speed under 3km/h	s
Nstop_aux_3_per_km	Number of stops per km being stop speed under 3km/h	
st_t_aux_3_per_km	Stop time per km being stop speed under 3km/h	s/km
st_t_aux_3_percent	%Stop time being stop speed under 3km/h	%
Nstop_aux_5	Number of stops being stop speed under 5km/h	
st_t_aux_5	Stop time being stop speed under 5km/h	
Nstop_aux_5_per_km	Number of stops per km being stop speed under 5km/h	
st_t_aux_5_per_km	Stop time per km being stop speed under 5km/h	
st_t_aux_5_percent	%Stop time being stop speed under 5km/h	
Nstop_aux_3_144	Number of stops being stop speed under 3km/h and starting to count when speed >14.4	

st_t_aux_3_144	Stop time being stop speed under 3km/h and starting to count when speed >14.4	
Nstop_aux_3_144_per_km	Number of stops per km being stop speed under 3km/h and starting to count when speed >14.5	
st_t_aux_3_144_per_km	Stop time per km being stop speed under 3km/h and starting to count when speed >14.5	
st_t_aux_3_144_percent	%Stop time being stop speed under 3km/h and starting to count when speed >14.4	
Nstop_aux_5_144	Number of stops being stop speed under 5km/h and starting to count when speed >14.4	
st_t_aux_5_144	Stop time being stop speed under 5km/h and starting to count when speed >14.4	
Nstop_aux_5_144_per_km	Number of stops per km being stop speed under 5km/h and starting to count when speed >14.5	
st_t_aux_5_144_per_km	Stop time per km being stop speed under 5km/h and starting to count when speed >14.5	
st_t_aux_5_144_percent	%Stop time being stop speed under 5km/h and starting to count when speed >14.4	
Vmax	Maximum recorded speed	Km/h
Vave_t	Average speed as lenght/time	Km/h
Vave_vi	Average speed as average of recorded speeds	Km/h
Vave_wo_3	Average speed without considering speeds under 3 km/h	Km/h
Vave_wo_5	Average speed without considering speeds under 5 km/h	Km/h
V95	95 Percentile of instantaneus recorded speed	Km/h
Vmedian	Speed median	Km/h
cov	Speed variation coeficient (Ratio of standard deviation to the mean %)	
sum_fc	sum of fuel consumption using VSP model	litro/s

avg_fc	average fuel consumption using VSP model	litro/s
max_fc	maximum fuel consumption using VSP model	litro/s
min_fc	minimum fuel consumption using VSP model	litro/s
sum_co2	sum of CO2 using VSP model	g/s
avg_co2	average CO2 using VSP model	g/s
max_co2	maximum CO2 using VSP model	g/s
min_co2	minimum CO2 using VSP model	g/s
sum_co	sum of CO using VSP model	mg/s
avg_co	average CO using VSP model	mg/s
max_co	maximum CO using VSP model	mg/s
min_co	minimum CO using VSP model	mg/s
sum_hc	sum of HC using VSP model	mg/s
avg_hc	average HC using VSP model	mg/s
max_hc	maximum HC using VSP model	mg/s
min_hc	minimum HC using VSP model	mg/s
sum_nox	sum of NOx using VSP model	mg/s
avg_nox	average NOx using VSP model	mg/s
max_nox	maximum NOx using VSP model	mg/s
min_nox	minimum NOx using VSP model	mg/s
max_slp_pos	Maximum positive slope	
min_slp_pos	Minimum positive slope	
max_slp_neg	Maximum negative slope	
min_slp_neg	Minimum negative slope	
avg_slp	Average slope	
avg_slp_pos	Average positive slope	
avg_slp_neg	Average negative slope	
%vsp1	Percentage of time spent in VSP mode 1 (%)	%
%vsp2	Percentage of time spent in VSP mode 2 (%)	%
%vsp3	Percentage of time spent in VSP mode 3 (%)	%

%vsp4	Percentage of time spent in VSP mode 4 (%)	%
%vsp5	Percentage of time spent in VSP mode 5 (%)	%
%vsp6	Percentage of time spent in VSP mode 6 (%)	%
%vsp7	Percentage of time spent in VSP mode 7 (%)	%
%vsp8	Percentage of time spent in VSP mode 8 (%)	%
%vsp9	Percentage of time spent in VSP mode 9 (%)	%
%vsp10	Percentage of time spent in VSP mode 10 (%)	%
%vsp11	Percentage of time spent in VSP mode 11 (%)	%

Table 11 Variables description

In the previous Table 11, the variables estimated for each trip are described (look at methodology flow chart, Figure 2).

In the next paragraphs is described more in detail the data process methodology which has been used to obtain these values relating to each trip and which consisted in two different stages: the database creation and the database validation.

4.5.2 DATABASE CREATION

Data obtained through the data collection campaign are summarised in the following table:

	Total	Without ECO	With ECO
Total experimental Days	18	9	9
Nº of Trips recorded	1,001	527	474
Total Distance recorded [km]	11,264	6,107	5,157
Nº of Drivers	14	14	12
Total Data collected*	1,052,821	557,834	494,987
Nº of Samples collected	279	155	124

*Total number of data collected from the field experiment, including instant speed, GPS, RPM, distance in every second.

Table 12 Data collection

In order to create the first unfiltered database, containing all data recorded and registered despite its values, is being followed the procedure described below.

First of all, from the Torque web site, related to the used OBD system, were downloaded all the trip files correlated to each journey.

By entering in the load-file interface and by inserting some specific credentials it was possible to choose the one which refers to a single trip according to its start time and immediately view the related route on the screen. In a second moment, by saving the file with a specific proper name, it was possible to use the software “R”, a software which permitted us to evaluate the mean value of every variables of each trip by having as initial source data second by second recordings.

An example of what was possible to see on the screen during the Torque website session is represented in Figure 19, in which it’s possible to observe the GPS recording of a typical MP2 trip (in this specific case is represented the trip covered by Astra on 26th of May at 17:56 h along the itinerary MP2).

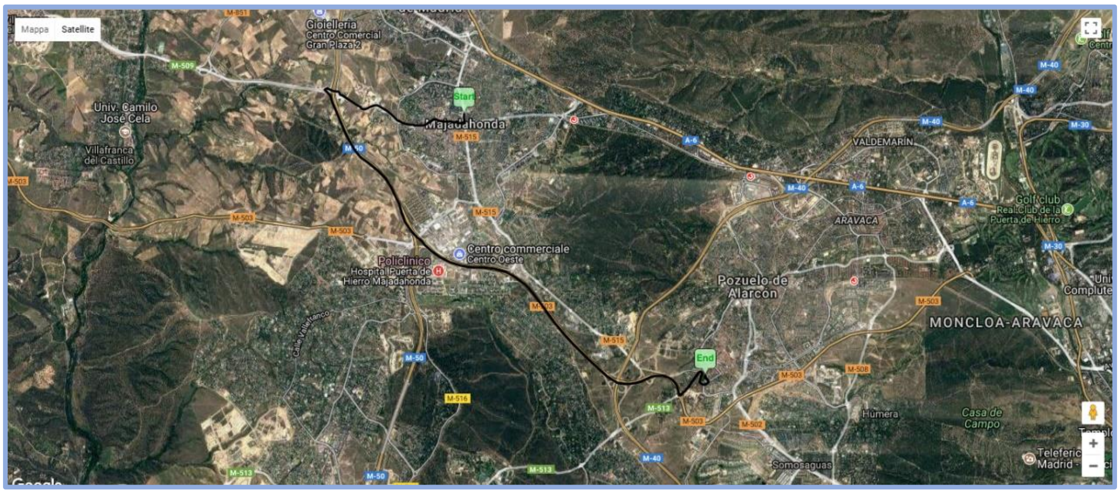


Figure 19 View of an MP2 trip-file on the Torque web site

Through this process it was possible to check immediately if there were any problems in practical terms, it means for example if there was any route deviation during the experiment; in this case we could filter in a second moment all data related to this deviation to obtain only data filtered concerning the itinerary.

After have obtained all the trip files, next step was the run of “R” software.

In addition to R, Rstudio and Rtools, it became necessary the installation of one tool package named “openxlsx” to be able to take advantages of the “R” features in terms of reorganizing data on excel .

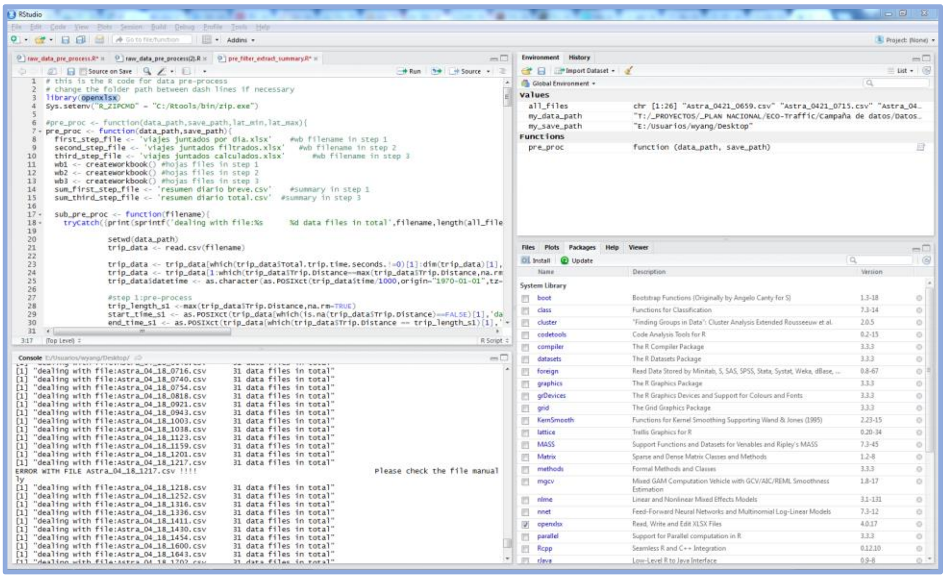


Figure 20 Data process, Rstudio

At a first moment, for each vehicle we got an excel file related to each travel day, in which each spreadsheet was dedicated to a single trip.

Once generating the spreadsheets we have completed and edit all the files by manually adding some information and next step has been the calculation of fuel consumption and emissions through the application of the VSP model (4.3.2).

Through Goggle Geo and by using the code of ¨main.R¨ has been obtained the elevation of each GPS points “covered” during the experiment. Then, using the code of ¨vsp_11.R¨, was possible to evaluate the VSP model as well as the CO_2, CO,

NO_x, HC emissions and the fuel consumption by each time range (1 second normally), paying attention on the necessity to distinguish between the fuel type of the vehicle: gasoline or diesel.

Subsequently, by using the R code of ¨add_columns¨ to add total and average information with regards to emissions and fuel consumption and by using the code¨add route_name¨ to obtain the road name by the GPS points covered, it has been possible to obtain the % of time spent during every trip on each route on each VSP mode. Data source came from GIS GEO platform.

Finally, through the road name, we have categorized all the roads in several key “road sections” (like A-6, M-40, M-503 etc); working on the excel spreadsheets, by input the information of route type recorded, we have generated the corresponding itinerary and the corresponding route sector.

Summing up, by running more times different R-codes, we have been able to create an initial database in which every trip was defined by 134 variables (Look at Figure 2).

We have set up 3 rules to filter the raw data and those data which not met the conditions were deleted. The rules were: the trip time of each recorded data had to be equal or less than 3 seconds; if the acceleration value were between -3 and 3 data with 0 speed were excluded; if the distance calculated using the longitude and latitude was equals to 0, or the distance was not equals to 0 but the GPS speed was 0, then data were deleted.

On the main spreadsheet, once marked problems like GPS failure in certain cells, pilot and co-pilot information were input for each trip, were imported the responds of the survey of each driver and were generated different PivotTables to summarize trip data of each day.

In this way it has been obtained the first initial database, composed by 1001 trips, each one characterized by 134 variables.

As have been individuate two main research questions, there have been created two different databases, useful to answer respectively to each one of the questions.

The first one is characterized by trips, so characterized mainly by itineraries, in order to answer to the first research question that is: *how is affected the eco-driving efficiency, with regards to several factors and depending on different kind of itinerary?*

The second database is characterized by route sector, so that we have eliminated all data which had regards with the global trip and we only kept data about different road sectors (A6, M500, M40…) in order to answer to the second research question*: which are the effects of Eco-driving on fuel consumption depending on different road sectors and traffic states?*

With respect to the first database, the second one not only contains information about every route sector, but also has been enhanced with traffic state information. To add them it was analysed the mean average speed and also the mean % of time with speed lower than 5km/h for each trip, in order to have a more complete and detailed set of results.

4.5.3 DATABASE VALIDATION

Once all data obtained on the experiment have been processed, it has been created a first global database containing all the previous mentioned 134 variables registered for each one of the 1001 trips recorded on the experiment (Database_1).

As previously mentioned, there have been created two different and it results that the global amount of data for each Database is:

Database_1:

- 1,001 trips recorded
- 527 trips Without ECO
- 474 trips With ECO
- 130,552 data registered

Database_2:

- 5,630 road sectors recorded
- 2,955 sectors Without ECO
- 2,675 sectors With ECO
- 741,602 data registered

Assuming that there were some of the evaluated variables without a significant value due for example to practical or technological defects (as occurs in all real experiments), databases have been filtrated in order to delete those data which could strongly affect the experiment results since they had not shown a proper physical meaning.

Due to their different purposes, databases were filtered assuming different criteria; for that reason this paragraph is divided into two subparagraphs, each one dedicated to explain the filtering process, as means the database validation, of each ones.

Database divided for itinerary

Concerning the unfiltered database obtained at the end of the data process, for each itinerary we had covered a certain amount of mileage reported on next tables. To shows the process used to validate the databases, Table 13 represents the validation of all data which refers to the ASTRA vehicle.

	Unfiltered database_ASTRA_			
	Without ECO		With ECO	
Itinerary	N' of rips recorded	Mileage covered [km]	N' of rips recorded	Mileage covered [km]
CP1	23	347	23	318
CP2	23	284	25	273
CP3	23	296	23	265
MP1	17	136	20	148
MP2	20	271	23	275
MP3	20	155	20	151
PC1	25	344	22	265
PC2	24	283	25	262
PC3	20	262	23	275
PM1	19	147	20	140
PM2	18	231	22	265
PM3	21	161	20	161
TOT	253*	2,917	266	2,799

Table 13 Unfiltered mileage covered by ASTRA vehicle

*N.B. It results 998 trips recorded; 3 trips were totally disturbed during the experiment.

In order to validate this database 6 different filtering criteria have been applied, each one affecting at different level the data source, due to measurement errors (as failure in GPS recordings) or practical errors (as failure on route deviation) and we have deleted those trips that didn’t satisfy them. Results are summarized on the following tables:

Nº of trips with failure recording_ASTRA_		
GPS	34	6.4%
OBD	21	4%
RPM	45	8.6%
TIMING	2	0.4%
ROUTE DEVIATION	15	2.9%
OTHERS	3	0.6%
TOT	120	22.9%

Table 14 Filtering process ASTRA vehicle

Assuming these filtering criteria, we have obtained the filtered valid data, data source of the next analysis of results.

The same procedure has been used to validate data which refers to FIAT vehicle and the following data source has been obtained.

		ASTRA		FIAT	
		Nº OF TRIPS RECORDED	DISTANCE TRAVELLED [km]	Nº OF TRIPS RECORDED	DISTANCE TRAVELLED [km]
CP1	Without ECO	17	257	22	323
	With ECO	20	289	18	264
CP2	Without ECO	18	219	29	341
	With ECO	14	162	18	211
CP3	Without ECO	21	261	23	269
	With ECO	16	194	16	190
MP1	Without ECO	13	104	18	140
	With ECO	16	121	14	107
MP2	Without ECO	16	210	19	242
	With ECO	17	207	14	178
MP3	Without ECO	18	151	15	123
	With ECO	16	119	12	99
PC1	Without ECO	21	289	27	371
	With ECO	13	168	18	236
PC2	Without ECO	17	202	24	277
	With ECO	16	169	19	219
PC3	Without ECO	18	235	19	240
	With ECO	16	196	13	164
PM1	Without ECO	19	147	18	132
	With ECO	13	97	15	112
PM2	Without ECO	16	203	21	255
	With ECO	21	253	20	242
PM3	Without ECO	18	147	18	143
	With ECO	14	107	12	97
	TOT	404	4,508	442	4,976

Table 15 Data source Database_1, N' of trips and distance travelled (km)

These specific data have been used as starting point of the analysis of results, developed on the next chapter 5. From them, I try to understand how is affected the Eco-driving efficiency following different itineraries depending on several factors, as different vehicles, shifts and drivers.

Database divided for route sector

Due to the different goal of this second analysis, the filtering criteria used on this stage has been different from the previous one. It means that, for example, if before all trips which had suffered a route deviation due to external causes were deleted from the database, in this second data source we have not deleted the concerning data: it has been studied in which route the deviation occurred and we have add on database the "part" of deviation as a proper road sector; it always occurred excepted in those cases in which the deviation was done in road sector that we had not considered on the study.

Results obtained through the filtering process applied to data concerning the ASTRA vehicle are summarized in the next Table 16.

Nº of trips with failure recording_ASTRA_		
GPS	17	0.6%
OBD	1	0.0%
RPM	217	7.2%
TIMING	3	0.1%
REAL TRIP LENGHT	23	0.8%
ROUTE DEVIATION	6	0.2%
OTHERS	24	0.8%
TOT	291	9.7%

Table 16 Number of sectors with failure recordings

The same procedure has been used to validate data which refers to FIAT vehicle and the following data source, database for the sectorial analysis, has been obtained.

		ASTRA		FIAT	
		Nº OF SECTORS RECORDED	DISTANCE TRAVELLED [km]	Nº OF SECTORS RECORDED	DISTANCE TRAVELLED [km]
A-6	Without ECO	121	421	145	504
	With ECO	119	386	105	355
ACCESS AND EXIT A-6	Without ECO	136	25	102	25
	With ECO	121	17	69	18
M-40	Without ECO	43	200	52	227
	With ECO	40	173	38	172
ACCESS M-40 AND M-50	Without ECO	20	15	26	16
	With ECO	22	17	20	14
M-50	Without ECO	35	100	42	106
	With ECO	37	91	37	90
M-500	Without ECO	83	197	97	216
	With ECO	75	173	68	155
ACCESS M-500	Without ECO	92	20	49	7
	With ECO	91	19	44	9
M-503	Without ECO	235	832	237	938
	With ECO	217	737	173	707
ACCESS M-503	Without ECO	65	14	71	20
	With ECO	56	11	69	22
M-509	Without ECO	36	57	42	62
	With ECO	37	47	37	54
M-515	Without ECO	99	331	106	328
	With ECO	85	275	87	272
OTHERS-Caminos	Without ECO	114	63	141	72
	With ECO	108	49	102	48
OTHERS-Moncloa	Without ECO	38	28	36	32
	With ECO	42	28	26	26
OTHERS-Seneca	Without ECO	21	14	24	18
	With ECO	14	11	12	13
OTHERS-Majadahonda	Without ECO	38	54	42	50
	With ECO	38	54	37	45
OTHERS-Pozuelo	Without ECO	231	274	261	318
	With ECO	213	243	200	240
	TOT	2,722	4,975	2,597	5,176

Table 17 Data source Database_2, N' of trips and distance travelled (km)

These specific data have been used as starting point of the data analysis, developed on the next chapter 5. From these data I try to understand how is affected eco-driving in terms of fuel consumption, depending on the road sector and the traffic level.

CHAPTER 5: MAIN RESULTS

Starting from data obtained through the data process, two different databases have been obtained; one containing data categorized through the whole trip and another one containing data about the same trip but categorized by route sectors. For example a simple “line” of the spreadsheet in Database_1 (Table 18) summarizes data of different sectors of the same trip in Database_2 (Table 19).

File ID	Date	Day	Start time	End time	Vehicle	Route	Category	Eco-driving
A05261252	26/05/2017	viernes	12:53:34	13:09:34	A	CP2	M500-M503	1

Table 18 Database_1

File ID	Date	Weekday	Start time	End time	Vehicle	Route	Category	Eco-driving
A05261252	26/05/2017	viernes	12:53:26	12:55:35	A	CP2	OTHERS-Caminos	1
A05261252	26/05/2017	viernes	12:55:36	12:55:45	A	CP2	ACCESS A-6	1
A05261252	26/05/2017	viernes	12:55:46	12:56:30	A	CP2	A-6	1
A05261252	26/05/2017	viernes	12:56:31	12:58:47	A	CP2	OTHERS-Moncloa	1
A05261252	26/05/2017	viernes	12:58:48	12:59:45	A	CP2	OTHERS-Seneca	1
A05261252	26/05/2017	viernes	12:59:46	13:00:40	A	CP2	ACCESS M-500	1
A05261252	26/05/2017	viernes	13:00:41	13:03:20	A	CP2	M-500	1
A05261252	26/05/2017	viernes	13:03:21	13:03:25	A	CP2	ACCESS M-503	1
A05261252	26/05/2017	viernes	13:03:26	13:06:55	A	CP2	M-503	1
A05261252	26/05/2017	viernes	13:06:56	13:09:36	A	CP2	OTHERS-Pozuelo	1

Table 19 Database_2

The ID of the considered trip is A05261252: it has been covered by the Astra vehicle, on 26th of May and it started at 12:52 p.m. As we can see, on the first spreadsheet the journey is represented by a single line, described by 134 different variables that summarize all the trip data recorded (in the image it has been reported only 9 of the 134 columns defining the same “line”). On the second database, the same trip is split into different lines regarding different route sectors of the same trip.

In this way, the data analysis related to fuel consumption can be conducted in two different aspects. The first one is by using the first database to figure out the changes in fuel consumption considering different external factors (as vehicle, driver route, etc.) and the second one is by analyzing the different fuel consumption required by each road sector in order to understand the best eco-driving context.

5.1 DESCRIPTIVE ANALYSIS OF VARIABLES

Data were registered for all the 14 drivers before and after attending the efficient driving course. The total registered driving distances of the 1,001 initial journeys was 11,276.8 km, divided into 527 trips without the application of eco-driving, corresponding to 6,115 km of the total, and the rest of mileage (5,157 km) covered by 474 trips along which has been adopted an eco-driving skill.

The overall reduction in fuel consumption through the adoption of an eco- driving behaviour has been lower than 1% (0.76% less) ; performing features of the experiment are shown in Table 21.

As defined in the project ECOWILL (ECOWILL, 2013) there are several possible variables which can define eco-driving efficiency: some depend on vehicle and others depend on the behavioural approach. In these terms the mean values of some variables that cover a representative role on the eco-driving efficiency (like average speed, number of stops, etc.) has been assessed.

The observations considered in my study were about the average percentage of time with strong acceleration or deceleration more than +-0.83 m/s2 (%strong acc, %strong dec), the percentage of time spending with speed lower then 5km/h (% speed_stop) and the mean revolution per minute (average rpm). Table 20 presents the mean values of these variables.

	Fc (l/100km)	%stop_speed	%strong acc	%strong dec	average rpm	average speed km/h
Without ECO	5.17	7.7%	5%	6%	1,783	44
With ECO	5.13	6.2%	3%	4%	1,565	42.5
% reduction	0.76%	20%	39%	31%	12%	3%

Table 20 Average values of the ECO-driving efficiency

From literature review, it was found out the general fuel saving of eco-driving could be 5% to 10% in certain experimental conditions. However, there was also evidence showing the application of eco-driving could have no changes in fuel saving (H Lee et al., 2010; Larsson & Ericsson,2009). For our case, a relative small fuel savings is received.

Though the general reduction of fuel consumption (FC) and average speed is not great, drivers indeed modified their driving behaviour with less aggressive acceleration/deceleration, and avoiding stops during the trip.

An interesting result is found regarding the percentage of time with speed lower than 5 km/h. This value describes the vehicle at stagnation state in qualitative terms , as literature teaches it covers an important role with regards to the fuel consumption. The ¨%speed stop¨ reduced 20% comparing the values obtained before and after the efficient driving course; it can indicate the application of a really efficient driving style, but it may also indicate a situation in which there are a strong traffic congestion and the vehicle could not travel above 5km/h. To clarify this ambiguity of results, it has been divided each itinerary in several road sectors and has been conducted the sectorial analysis by grouping traffic situation into congested, medium congested and free flow, by taking into account average speed and percentage of time with speed lower than 5 km/h.

Moreover, the changes on the ¨%strong acc/dec¨ also proves the fact of driver's reduced sharp acceleration/deceleration, which normally lead more fuel consumption. 12% of less rpm also reveals the same fact.

The average speed for all fourteen drivers was 44 km/h before the course and 42.5 km/h after the course. This reduction (3% less) is not significant in global terms, due to the number of different itinerary recorded. Indeed the experiment is based on different routes in terms of both functional and structural characteristics. This can implicate different average speeds not due to behavioural reasons but to practical reasons.

Generally, eco-driving patterns considered in this thesis seem to have different effects at different level over the fuel consumption; in order to understand each real influence a further research will develop a linear regression.

In the next paragraph eco-driving efficiency depending on vehicle, departure time, itinerary and drivers is analyzed

. It results that not all drivers have reduced their fuel consumption between the first and the second driving period and possible reasons can depend, among others, on driving experience or on driver’s attitude.

5.2 DATA ANALYSIS

To develop this part of the analysis, researches have been supported by using the first database, which contains data recorded with a “perfect recording” of the all trip from the beginning to the end, in order to be able to distinguish between results, depending on different itinerary. It means that all the trips during which there have been a failure under any aspect have not been considered.

Previous field practices of eco-driving reveals that average fuel consumption could decrease by 5% to 25% after instructions.

In this study, by considering the liter of combustible necessary to cover 100 km, we have obtained reduction up to 14% depending on the route section and traffic condition, better described on the next part 5.3.

In these terms the amount of data on which this analysis is based, are summarized on the table 16, corresponding to a global amount of mileage well recorded (trips without any failure recording): 9,483 km of which 5,283 km without and 4,201 km with the application of Eco-driving behaviour.

The big variability of results led us to think on the strong influence that external factors can have over fuel consumption.

Doing a general analysis of results depending on the typology of itinerary and without taking into account any congestion problem (in any case weekdays of both the two driving periods were the same), it results that with the adoption of an eco-driving behaviour the mean decrement on fuel consumption is small 0.76%.

Eco-driving efficiency has different effects not only depending on the itinerary but also depending on other external factors.

5.2.1 ANALYSIS BY VEHICLE

To carry out the experiment, two different vehicles have been used, a FIAT 500 powered by gasoline and an OPEL ASTRA powered by diesel.

We attempt to compare how reacts two different vehicles with respect to the implementation of an ECO-driving behaviour.

From this comparative analysis, it results that the mean average fuel consumption with respect to both vehicles and regarding the total number of trips recorded without and with the application of ECO-Driving patterns, has been 5.15 l/100 km valued through a distance of 9,483 km.

More in detail:

	Distance covered [km]	Fc [l]	Fc [l/100km]
Without ECO	5,282.6	272.99	5.17
With ECO	4,201.2	215.41	5.13
% reduction			0.76%

Table 21 Fuel consumption Without and With ECO

It should be taken into account that the experiment was made without a monitoring process and drivers did not receive any feedback during the trip. Moreover, eco-driving course was given to all drivers together for no more than two hours,and then the conduction with the expert lasted around 15 km for each ones.

Furthermore we have not considered the really important difference existing between the itineraries and the distribution of the number of routes recorded for each typology of itinerary, as traffic congestion, driving attitude and more external circumstances.

All these aspects will be taken into account in different way on the next paragraphs.

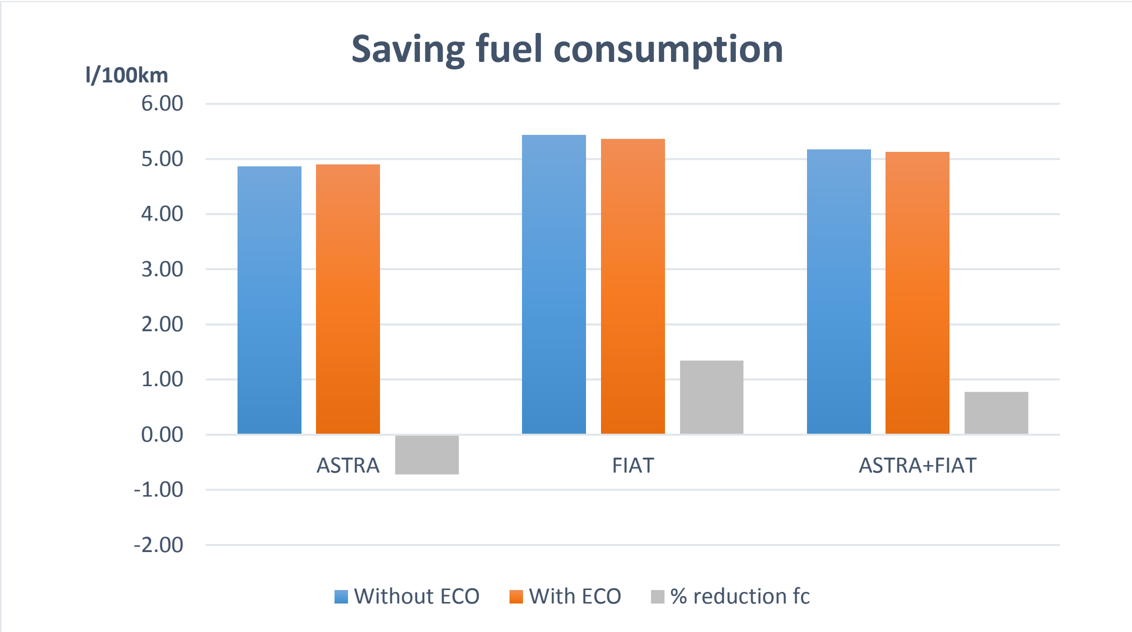
		%strong_acc	avg_rpm	%strong_dec	%stop_speed	avg_speed (km)	Fc (l/100km)
ASTRA	Without ECO	10.7%	1592	15.4%	8%	44.10	4.86
	With ECO	6.6%	1394	10.9%	6%	43.23	4.89
FIAT	Without ECO	9.8%	1941	16%	8%	43.71	5.43
	With ECO	4.7%	1713	9.9%	6%	41.85	5.36
%reduction ASTRA		38.5%	12.4%	29.2%	22.1%	2.0%	-0.7%
%reduction FIAT		51.4%	11.8%	38.3%	17.8%	4.3%	1.3%

Table 22 ECO-driving pattern reduction depending on the vehicle.

From data obtained in Table 22, we can deduce some conclusions:

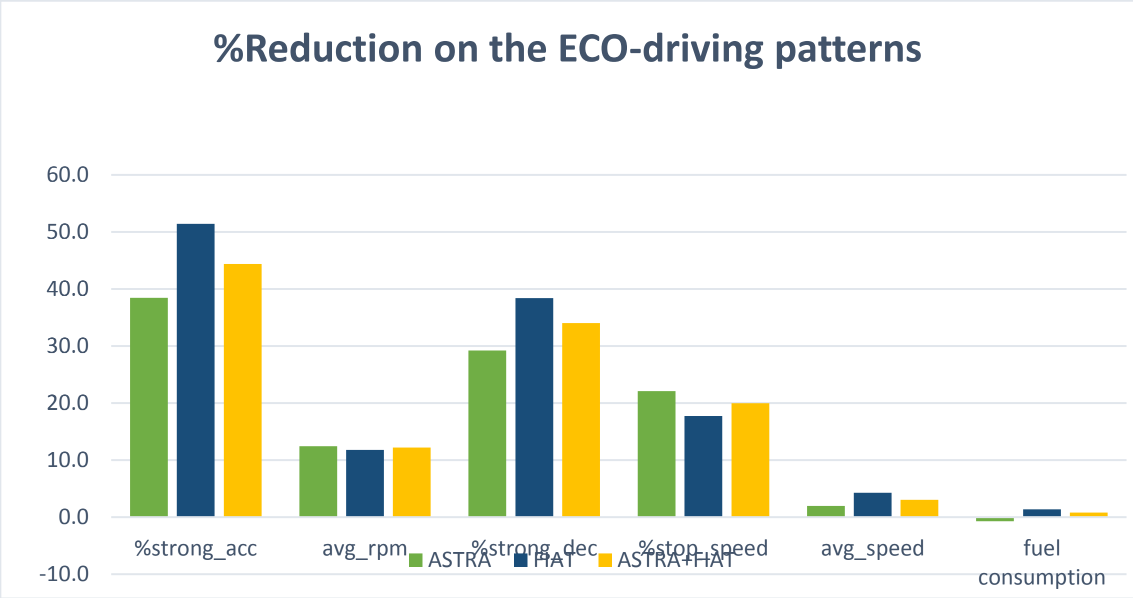
- There is a very small changes on fuel saving without considering traffic state and type of roads.
- Through literature review, there is not a significant difference in fuel saving regarding type of vehicles, however there is a slight difference between FIAT and ASTRA: it is clearly seeing that FIAT achieve better results in changing driving patterns, among others with a greater reduction in strong acceleration and deceleration.

Graph 1 shows the fuel saving depending on the types of vehicle (look at Figure 8).



Graph 1 Saving in fuel consumption depending on the vehicle

While FIAT reduces its consumption around 1.3% passing from 5.43 l/100km to 5.36 l/100km by adopting an Eco-driving behaviour, in the ASTRA case results are not the same; indeed we can even observe a slight increment on fuel consumption between eco and not eco-driving, passing from 4.86 l/100km to 4.89 l/100km. However, it should be taken into account that the negative fuel saving by the ASTRA was achieved considering different kinds of itineraries.



Graph 2 Reduction of the Eco-driving patterns considered on the study

According to the diagram, results shows that the reduction on eco-driving patterns have been clear.

The percentage of time spending in strong acceleration (mayor than 0.83 m/s^2) or strong deceleration (minor than -0.83 m/s^2) have been reduced up to 50 % in FIAT and up to 38% in ASTRA: clear signal of the correct application of the eco-driving behaviour.

The same occurs with respect to the reduction on the percentage of time spent with speed lower than 5 km/h (% stop_speed) and at lower level on the average speed and the average revolution per minute: it reaches in the case of FIAT 18% and in the ASTRA case 22% of reduction.

Assuming a clear overall downward trend on the values by adopting an Eco-driving behaviour, it results that the correspondent drop on fuel consumption only reaches value lower than 1% of saving.

In these terms we can speak about a general efficiency of the efficient driving course, as main as concern the application of the Eco-driving patterns, but we can't assume an efficiency on the application of them in terms of reduction in fuel consumption.

It can be due mainly to a not equal distribution of the recorded different routes and drivers attitudes or due to problems of traffic congestion; these results will be analysed in details on the second part of the analysis.

Assuming the different kinds of power, gasoline FIAT or diesel ASTRA, effects on reduction in emissions through the application of an eco-driving behaviour are different.

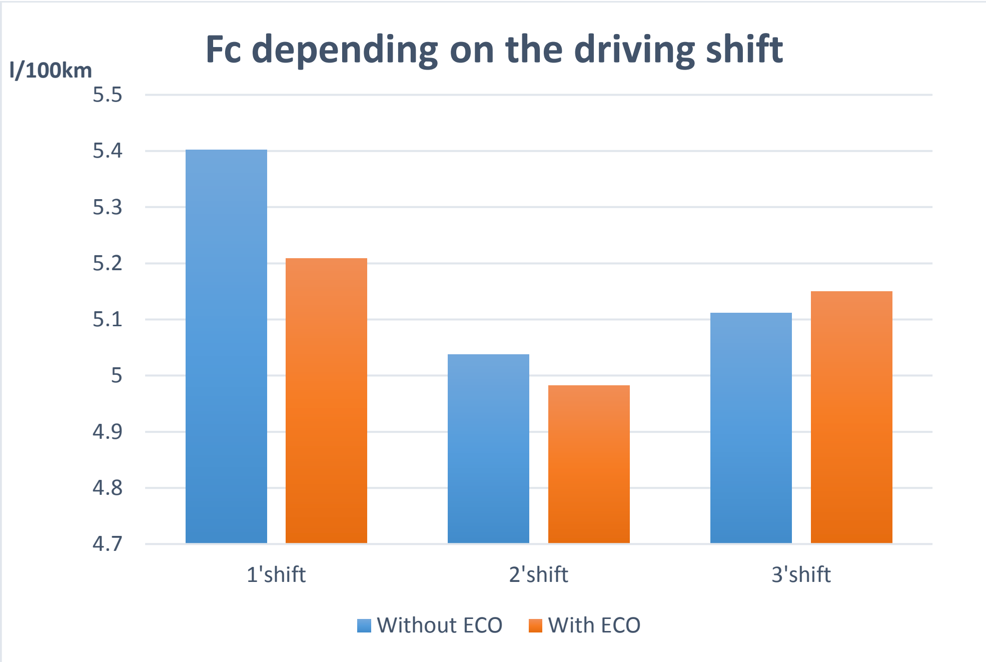
		CO_2 (g/km)	CO (mg/km)	HC (mg/km)	NOx (mg/km)
ASTRA	Without ECO	152	23	14	677
	With ECO	151	23	14	649
FIAT	Without ECO	185	204	9	132
	With ECO	183	152	8	138
% Reduction	ASTRA	0.8%	0.3%	-2.3%	4%
% Reduction	FIAT	1.3%	25.6%	8.8%	-4.8%

Table 23 Emissions depending on vehicle

What makes the difference between diesel and gasoline in terms of environmental pollution is the type of emissions. If only CO_2 is taken into account, Diesel produces lower emissions: about 15% less than a petrol engine. However, this type of engine is also known to generate more nitrogen oxides (NOx) and especially fine dust than other engines; in our case NOx emissions caused by Diesel power are five times greater than those released into the atmosphere by the petrol engine.

Results indicate that there has been a general reduction in emissions especially on the gasoline power, excepted in the case of NOx which have increased between the first and the second driving periods

5.2.2 ANALYSIS BY SHIFT



Graph 3 Fuel consumption depending on the shift

By distinguishing the analysis in different shifts, defined on the Table 1 , there have been obtained the following values on fuel consumption:

	Fuel consumption (l/100km)		
	Without ECO	With ECO	% reduction
1'shift	5.40	5.21	3.6%
2'shift	5.04	4.98	1.1%
3'shift	5.11	5.15	-0.8%

Table 24 Eco-driving efficiency in fuel consumption depending on the shift.

By considering only the first driving shift, reduction in fuel consumption greater than 3.5% has been obtained, but it is different the case of the third shift.

This difference can be explicated in three different ways:

First of all we know that there have been covered different itineraries during the all day so that the source data has not been always the same between the shifts, and it could affect in a certain sense the results: there exist some itineraries that request more combustible per km with respect to other ones, and if the number of these environmentally worst itineraries covered on the third shift is greater than the one covered during the first shift, results can be in a certain sense influenced.

Other reason regards the influence of traffic; due to traffic mobility reasons, during the first driving shift, the most congested situations have been met and it corresponds to a greater saving in fuel consumption (section 5.3).

The third explication regards different drivers. Every third shift has been covered by mayor persons, having all more than 40 years and having more than 10 years of driving experience. We can't speak in categorical way because results regard just few drivers, but it seems that with a mayor age/driving experience the application of "new" driving technique can results more difficult due to long years of driving experience, in other terms due to a more steady way of driving that results difficult to change.

These results will be better explicated on the next paragraph dedicated to the driver analysis.

5.2.3 ANALYSIS BY DRIVERS

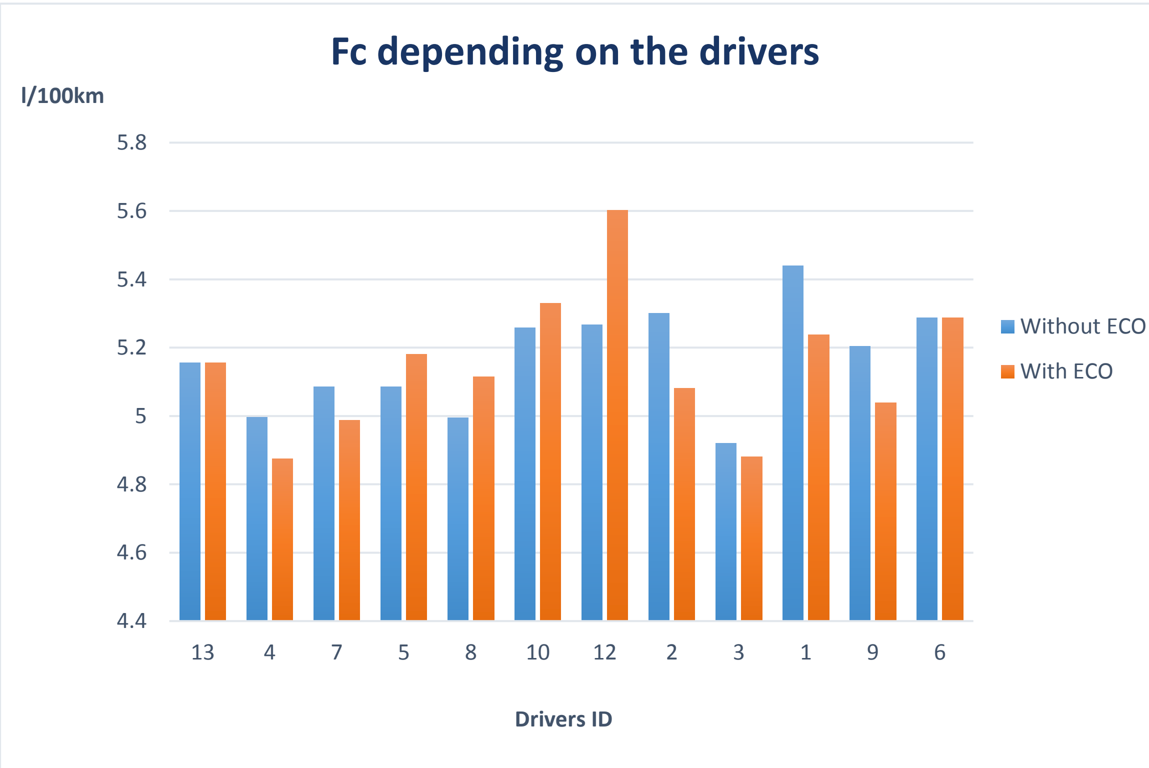
The column graphs below represent the effect on saving fuel consumption depending on the drivers (identified by a driver ID).

The graph provide strong support to the assumption that Eco-driving efficiency, being a behavioural approach, depends also on driving attitude.

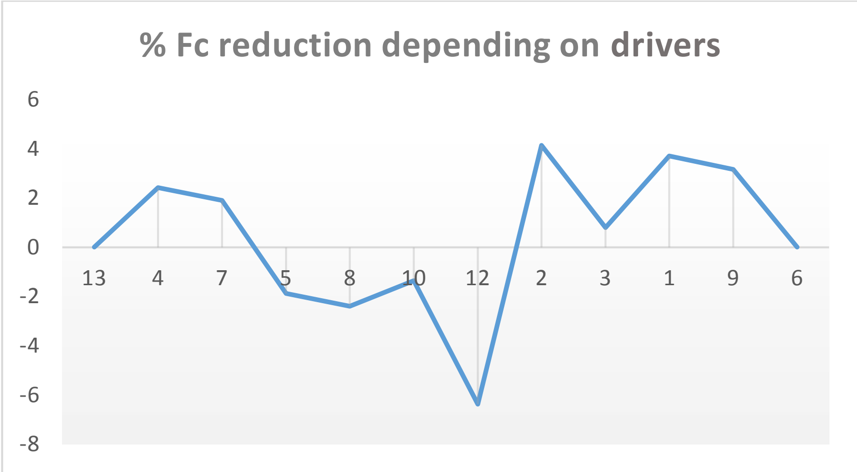
In this thesis there is not a focus about it due to the lack of data available, but we can draw some general conclusions by taking into account performing data regards 12 drivers, briefly described on the next table.

ID	SEX	DRIVING EXPERIENCE
Driver 1	F	5 to 10 years
Driver 2	M	< 5 years
Driver 3	M	>10 years
Driver 4	M	5 to 10 years
Driver 5	F	>10 years
Driver 6	F	>10 years
Driver 7	M	>10 years
Driver 8	M	>10 years
Driver 9	M	5 to 10 years
Driver 10	M	< 5 years
Driver 12	F	5 to 10 years
Driver 13	F	5 to 10 years

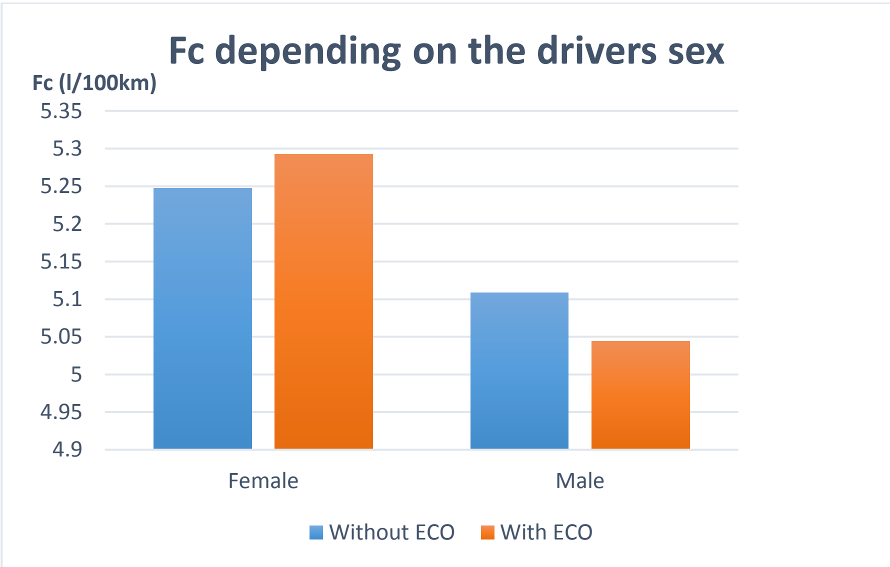
Table 25 Drivers description



Graph 4 Fuel consumption depending on the driver



Graph 5 ECO-driving efficiency depending on the driver



Graph 6 Reduction in fuel consumption depending on the driver sex

As reported on these graphs, it seems that the amount of saving in fuel consumption has a strong relation with the driver: the behavioural aspect really influences the eco-driving efficiency.

We can't speak in general terms, but in our study it results that Males request less litres of combustible to cover the same mileage of females. Furthermore, while women didn't reach the goal of less fuel consumption in the second period, men reached it with a mean reduction of 1.3% between the adoption of a not eco and eco-driving behaviour.

By a deeper analysis, distinguishing between different driving experiences, there have been obtained these following values:

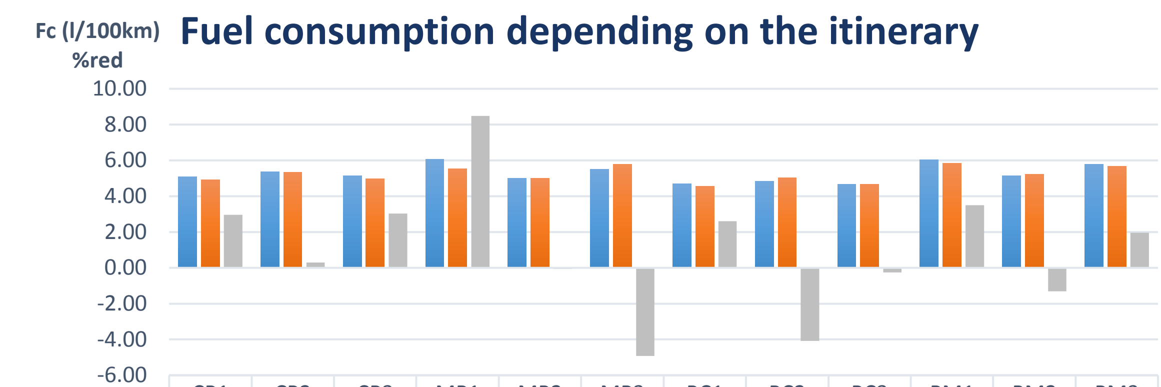
Type	Driving Experience	%Reduction fc
A	< 5 years	1.39
B	5 to 10 years	0.59
C	>10 years	-0.31

Table 26 Eco-driving efficiency depending on the driving experience

As these values indicate, it results that the more experience you have and the less eco-driving efficiency you reach. This data is not really supported by the amount of data but it can be really useful for further researches and policy reccommendations; for example by assuming that driving behaviour is really difficult to change when it is already consolidate, it appear useful to maybe implement an efficient driving course at the beginning of the driving experience, or better to teach this technique from the beginning of the experience in order to perceive a better effect in fuel consumption reduction.

5.2.2 ANALYSIS BY ITINERARY

In this section we just want to compare the effect of eco-driving in different itinerary, by having characterized them in the previous chapter 4.



	CP1	CP2	CP3	MP1	MP2	MP3	PC1	PC2	PC3	PM1	PM2	PM3
Without ECO	5.08	5.37	5.14	6.06	5.01	5.51	4.69	4.84	4.67	6.05	5.15	5.79
With ECO	4.93	5.35	4.99	5.55	5.01	5.79	4.57	5.04	4.68	5.84	5.22	5.67
%Reduction	2.97	0.30	3.04	8.49	-0.06	-4.92	2.60	-4.09	-0.26	3.50	-1.30	1.95

Without ECO With ECO %Reduction

Graph 7 Fuel consumption dependning on the itinerary

As previously mentioned, by adopting an eco-driving behaviour not always we have obtained the expected saving on fuel consumption, on contrary there have been any cases in which the fuel consumption increases.

These is the case regarding the itinerary MP3, PC2, PC3 and PM2, but the most relevant results are the ones about MP3 (5% more) and PC2 (4% more) in which it seems that fuel consumption have clearly increased, apparently due to external facts, as for example traffic congestion.

A really good results regards the saving in MP1 itinerary. In fact this itinerary is covered by several number of deceleration slope, speed bumps and roundabouts in which the application of ECO-Driving issues results really efficient: it is in these cases in which we can apply the technique of reducing strong acceleration by "leaving the car going alone" and in fact a saving on fuel consumption up to 8.5% has been reached.

A detailed results of the reduction of the eco-driving patterns depending on the itinerary is reported on the table below:

	% Reduction of the ECO-driving patterns					
	Fuel consumption	avg_speed	avg_rpm	%strong_acc	%strong_dec	%stop_speed
CP1	2.97%	-6.13%	9.04%	10.28%	13.65%	46.32%
CP2	0.30%	8.58%	13.78%	32.73%	27.70%	-4.51%
CP3	3.04%	-0.23%	9.20%	30.67%	21.30%	30.17%
MP1	8.49%	-8.38%	13.82%	44.19%	38.61%	56.89%
MP2	-0.06%	9.62%	15.91%	46.04%	34.04%	-26.18%
MP3	-4.92%	5.94%	12.55%	37.87%	27.44%	9.66%
PC1	2.60%	-3.40%	8.54%	34.20%	28.06%	39.73%
PC2	-4.09%	2.84%	10.37%	36.16%	21.91%	19.42%
PC3	-0.26%	9.70%	14.77%	38.08%	23.97%	0.02%
PM1	3.50%	1.09%	13.47%	56.21%	49.99%	45.46%
PM2	-1.30%	8.82%	14.31%	46.77%	34.93%	0.45%
PM3	1.95%	1.58%	12.03%	36.06%	27.30%	31.96%

Table 27 ECO-driving efficiency depending on the itinerary

As it results evident from the table, almost in any case we have reach a big reduction in strong acceleration and deceleration. It seems that the percentage of time spent with a speed lower than 5 km/h influences deeply the reduction in fuel consumption as shows the comparison between results obtained on table and graphic representation.

As mentioned, the biggest reduction in fuel consumption has been obtained along MP1 itinerary (8.49% reduction). This one links the municipality of Majadahonda with the municipality of Pozuelo, it is composed by 14 roundabouts and 27 intersections and characterized moreover by routes with speed limits lower than 50 km/h and

It can explicate the big efficiency on the application of eco-driving patterns. It is underlined also in the itinerary PM1, that follow the main streets but in different order: the big reduction of the strong acceleration, strong deceleration and “speed_stop” seems to indicate the efficiency on the application of an Eco-driving behaviour, due to the multiples points on which we can apply this technique.

On contrary, the average speed of these itineraries results reduced with a very small percentage or increased: it is explicated another time through the presence of roundabouts. In fact one of the ECO-driving tips is the one in which on a roundabout it’s not necessary to stop the car but just to decrease the speed, not by braking but by trying to step off the accelerator as early as possible.

In these terms, the efficiency of adopting eco-driving patterns in roads with roundabouts and intersections seems to be proved.

Other question regards the mean average revolution per minute and the mean average speed; these values have not suffered a strong decrement in every itinerary because can be really affected from traffic congestion.

Another time seems fundamental the traffic level suffered during the trip: for this reason we will pass on the next paragraph from an itinerary prospective to a sectorial road one.

Concerning the average speed, depending on the itinerary there is a big dispersion of results with respect to the mean value. This aspect indicates a big dependency of the average speed with respect to external circumstances that can be for example the driver’s attitude or more probably the traffic conditions.

To overpass this influencing aspect the sectorial analysis has been developed.

5.3 SECTORIAL ANALYSIS

The big variation of results obtained by developing the previous analysis has led to develop the sectorial analysis, in which every itinerary recorded has been split into different route sectors, depending on the road characteristics.

Acting in this way, we have considered a different amount of filtered data, briefly reassumed on the table 18 of the chapter 4.

To analyze more in details how can change the eco-driving efficiency depending on different route sectors, this sectorial analysis has been conducted, and by knowing the sectorial characteristics some conclusions can be drawn.

For this reason, depending on the speed limits and road sections, different roads have been grouped in a unique sector. It occurs for example with the road sector M-500 and M-503: as better described on the chapter 4, these are two urban motorways composed by 2·2 lanes separated by barrier, which both impose a speed limit equal to 90 km/h, so that these sectors have been considered as a unique one in the analysis. By unifying the ones that presented similar characteristics in terms of geometry and functionality, 4 different "route sectors" have been obtained.

	Street Type	Nº of lanes	Speed limit (km/h)
A-6	National Highway	3·3 or 4·4 seperated by HOV lane	80/120
M40/50	Urban Motorway	3·3 seperated by barrier	100/120
M500/503	Urban Motorway	2·2 seperated by barrier	90
M515/509	Urban arterial	2·2 seperated by barrier	30/50

Table 28 Route sectors

The next Table 29 reassumes the average fuel consumption obtained before and after drivers have attended the efficient driving course depending on the route sectors described above.

	Fuel Consumption (l/100km)		
	Without ECO	With ECO	% reduction
A-6	5.33	5.26	1.22%
M40/50	4.62	4.69	-1.47%
M500/503	5.25	5.02	4.37%
M515/509	6.44	6.18	3.94%

Table 29 % Reduction in fuel consumption depending on the route sector, fc (l/100km)

Despite an apparently not clear relation between the percentage of fuel reduction and the sector type, surely affected by different traffic states, the most relevant result regards the fuel consumption evaluated along the sectors M515 and M509.

It results that this road sectors can require a fuel consumption 18% greater than the one which refers to the average fuel consumption obtained by considering all the road sectors.

M515 and M509 are characterized by several roundabouts along its longitudes and it implicates a less steady average speed. It is a relevant result due to the importance of the GHG emissions in the transport planning: is it really useful the implementation of roundabouts?

As these results can demonstrate, the efficiency of the eco-driving application in terms of reduction on fuel consumption presents a certain ambiguity: it results that on M-40 and M-50 an increment on fuel consumption has been obtained, so that it led us thinking about the strong influence of traffic state on this efficiency. For this reason it is necessary to differenciate each sector between different traffic states.

To define the traffic conditions of each sector, it has been differentiated between congested, medium and free flow states. To do it , we have distinguished them by analyzing the average speed and the percentage of stop_speed (% of time with speed lower than 5 km/h).

For each sector different intervals of speed values have been considered depending on the different speed limits imposed, while as regards the percentage of stop_speed, intervals have been the same for all the sectors except to M515 and M509, in which we only have considered congested and free traffic state. In these terms there have been categorized every road sector with two values correspondent to the traffic level: one dependent on % speed_stop and the other one dependent on the average speed. Better described, the percentage of time with stop speed lower than 5% corresponded to free flow conditions, a percentage of time between 5 and 15 % corresponded to a medium traffic state while a value greater than 15% was indicating a congested traffic situation.

By characterizing every sector through these two new variables, the influence of traffic condition with respect to the eco-driving efficiency has been analyzed.

Without the application of ECO-driving behaviour, the values of the ECO-driving patterns considered in this study are summarized on the following Table 30.

	avg_rpm	% strong dec	% strong acc	avg_speed (km/h)	%speed_stop	Fc (l/100km)
FREE	2138	5.29%	5.01%	70.54	0%	4.81
MEDIUM	1812	5.93%	5.32%	43.71	5%	5.36
CONGESTED	1493	7.06%	5.53%	25.52	20%	6.99

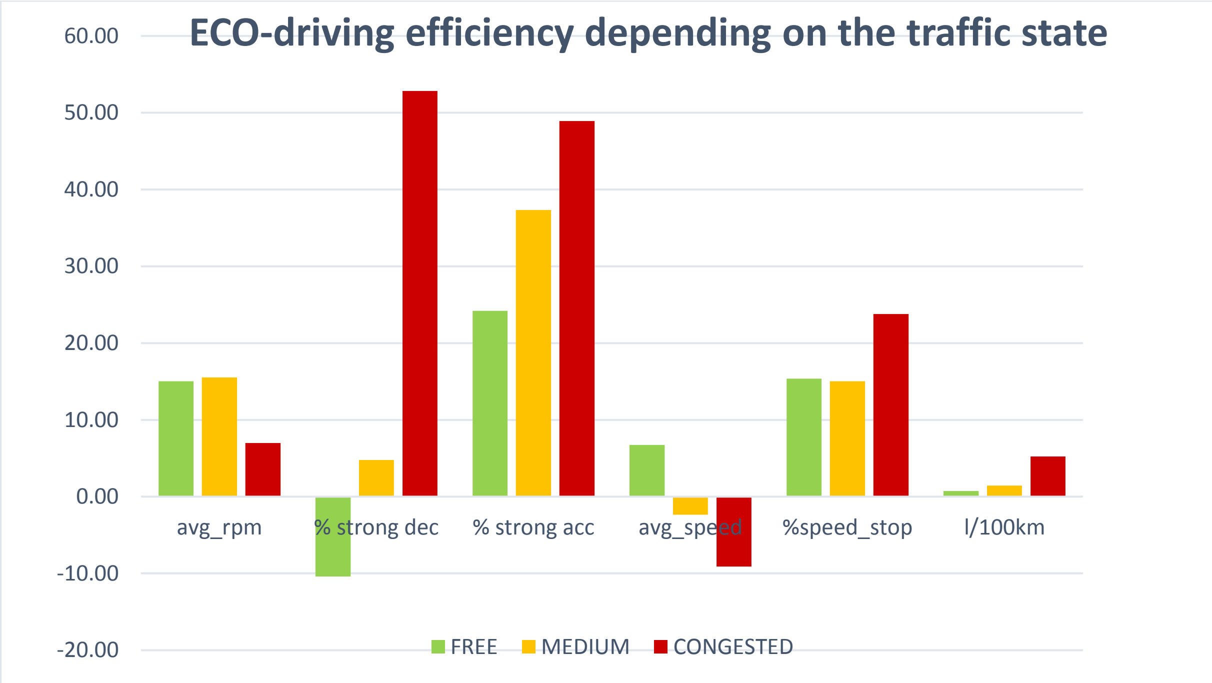
Table 30 Values Without-ECO, depending on the traffic state

Through the application of ECO-driving, the previous variables have assumed these values:

	avg_rpm	% strong dec	% strong acc	avg_speed (km/h)	%speed_stop	Fc (l/100km)
FREE	1817	5.84%	3.82%	65.80	0%	4.77
MEDIUM	1530	5.65%	3.33%	44.74	4%	5.29
CONGESTED	1389	3.33%	2.82%	27.85	15%	6.62

Table 31 Values With ECO

The graph below shows the reduction of the Eco-driving patterns depending on the three different traffic states:



Graph 8 %Reduction of the ECO-driving patterns depending on the traffic state

	% Reduction of the ECO-driving patterns					
	avg_rpm	% strong dec	% strong acc	avg_speed (km/h)	%speed_stop	Fc (l/100km)
FREE	15.04%	-10.41%	24.22%	6.73%	15.36%	0.72%
MEDIUM	15.55%	4.76%	37.34%	-2.35%	15.05%	1.42%
CONGESTED	7.00%	52.83%	48.92%	-9.12%	23.78%	5.22%

Table 32 %Reduction of the ECO-driving patterns depending on the traffic state

Differently from what we were expected to obtain from literature review, the efficiency of Eco-driving, evaluated as reduction on fuel consumption, increases in relation to the traffic condition.

It results that the more congested is the traffic state and the more saving on fuel we can obtain.

It is another relevant result, which can demonstrate the efficiency on the application of eco-driving techniques not only in those free flow situations in which can result easier the reduction of the average speed for example, but also in congested ones. Actually eco-driving technique results more efficient in congested conditions than in free flow ones.

Indeed with the presence of these congested traffic states, a big reduction on the percentage of time spending with strong acceleration and deceleration, in both cases around 50%, has been obtained due to the fact that by starting and stopping the vehicle more time compared with a free flow condition, there is more possibility to apply the technique of soft acceleration and deceleration learned during the efficient driving course.

These obtained results led us to develop a further and last analysis: a sectorial analysis divided by traffic states as way to unificate effects that road section and traffic state can implicate on the Eco-driving efficiency.

Results are summarized on the tables below, in which units of measure used are km/h regards the average speed and l/100km with regards to the fuel consumption

Table 33 Values of the ECO-driving patterns obteined Without-ECO, With-ECO and their % reduction

	Without ECO					
	avg_rpm	%strong dec	% strong acc	avg_speed	% stop_speed	Fc
A-6	1913	5.3%	5.1%	55.7	9.7%	5.33
CONGESTED	1421	7.6%	6.2%	23.3	34%	7.18
FREE	2161	4.0%	4.4%	74.6	0.1%	4.48
MEDIUM	1815	6.1%	5.8%	40.2	5.4%	5.40
M40/50	2193	3.4%	2.2%	76.4	2.3%	4.62
CONGESTED	1396	5.1%	3.3%	24.8	22.9%	6.46
FREE	2311	2.9%	2.0%	85.1	0.1%	4.36
MEDIUM	1871	5.6%	3.0%	47.1	4.4%	5.29
M500/503	1988	5.2%	4.8%	61.5	5.4%	5.25
CONGESTED	1426	5.4%	3.6%	26.1	23.0%	7.04
FREE	2193	5.0%	5.0%	75.5	0.2%	4.70
MEDIUM	1801	5.9%	5.5%	44.8	5.3%	5.36
M515/509	1683	9.2%	8.0%	31.0	5.4%	6.44
CONGESTED	1597	8.5%	7.1%	26.2	9.7%	6.91
FREE	1772	9.9%	9.0%	36.0	1.0%	5.95

	With ECO					
	avg_rpm	%strong dec	% strong acc	avg_speed	% stop_speed	fc
A-6	1705	4.6%	3.4%	56.6	6.5%	5.26
CONGESTED	1357	6.4%	3.9%	25.0	26.0%	7.00
FREE	1896	3.3%	3.1%	73.3	0.1%	4.47
MEDIUM	1516	6.3%	3.5%	41.2	2.9%	5.69
M40/50	1894	2.6%	1.5%	72.1	2.4%	4.69
CONGESTED	1460	5.1%	2.5%	30.0	21.1%	6.02
FREE	1972	2.0%	1.4%	79.2	0.0%	4.51
MEDIUM	1578	5.8%	2.0%	46.8	6.0%	5.06
M500/503	1720	4.0%	3.0%	58.6	4.3%	5.02
CONGESTED	1374	4.5%	2.3%	31.3	18.0%	6.05
FREE	1887	3.3%	3.0%	71.0	0.2%	4.67
MEDIUM	1531	5.4%	3.4%	45.7	4.8%	5.17
M515/509	1427	5.5%	4.2%	30.8	3.2%	6.18
CONGESTED	1409	6.8%	5.3%	25.9	6.2%	7.03
FREE	1441	4.5%	3.3%	34.5	0.8%	5.54

	% Reduction through Eco-driving					
	avg_rpm	%strong dec	% strong acc	avg_speed	% stop_speed	fc
A-6	11%	13.3%	33.7%	-1.6%	33.1%	1.22%
CONGESTED	5%	15.6%	37.6%	-7.2%	23.6%	2.45%
FREE	12%	16.6%	28.5%	1.7%	34.9%	0.39%
MEDIUM	16%	-4.3%	39.1%	-2.5%	47.3%	-5.38%
M40/50	14%	23.3%	31.5%	5.6%	-4.5%	-1.47%
CONGESTED	-5%	1.0%	23.7%	-21.0%	8.0%	6.76%
FREE	15%	31.3%	32.6%	6.9%	45.1%	-3.38%
MEDIUM	16%	-2.0%	32.3%	0.6%	-38.9%	4.30%
M500/503	13%	23.8%	37.4%	4.7%	20.1%	4.37%
CONGESTED	4%	15.6%	35.6%	-20.3%	21.8%	14%
FREE	14%	33.9%	38.8%	5.9%	27.6%	0.65%
MEDIUM	15%	8.7%	38.3%	-2.2%	8.9%	3.55%
M515/509	15%	39.9%	48.2%	0.6%	41.2%	3.94%
CONGESTED	12%	19.4%	25.8%	1.2%	35.3%	-1.78%
FREE	19%	54.4%	63.1%	4.0%	13.9%	6.85%

Some results from Table 33 draw up our attention:

Concerning the average rpm we can conclude that it has almost always efficiently decreased between the first and the second driving period, mostly in free flow conditions, but also in the congested ones, except the case of M-40/M-50.

With regards to the percentage of time with strong acceleration or deceleration (respectively greater than 0.83 m/s2 and lower than -0.83 m/s2), results indicate a global strong reduction in every road sector: the average reduction on the percentage of time with strong deceleration is 20%, while the one regards strong acceleration reaches 37%. Moreover we can observe that along the road sector M515/509, characterized by lower speed limits and several, these reductions are greater than the ones obtained along other road sections, getting respectively up to 40 % on the deceleration case and almost 50 % on the acceleration one.

This big reduction on acceleration and deceleration, joined to the reduction in fuel consumption, are being the main factors implicating the eco-driving efficiency; in these terms our results seem represent a positive effect on the implementation of this behavioural approach.

The variation on the average speed doesn't represent a relevant meaning regarding eco-driving efficiency; to have more appropriate results, should be done an analysis over the percentage of time spent with constant speed for example (it will be developed on further researches).

An apparently rare data is the one relative of the 38% of increment in the percentage of time spent with speed lower than 5 km/h which regards M40/50 sector in medium traffic state situations, moreover it results that the mean average value of this reduction, taking into account all the sectors and all the traffic states is 21%, as confirmation of the "rare" value obtained.

To understand the reason of this value, by deepening the analysis, I have encountered data about several trips carried out along the M40/50 in which mainly due to traffic congestion, there have been generate in "short sector" a fuel consumption up to 13 l/100km.

It occurred for example in the case of a trip carried out on 18th of April, at 08:32 am, in which the mean average speed along the sector was 9 km/h, with a total number of stop being speed under 3 km/h equal to 39, clear demonstration of the congested situation. The same occurs regards others trips with average speed equal to 11, 12, 13 km/h but with a percentage of time spent with speed lower than 5 km/h not so high, so that they have been categorized as “Medium” traffic level but have produced a big amount of fuel consumption.

In these terms, the increment on the percentage of time spending with speed lower than 5 km/h between the two driving periods is not unexpected, because it has an explication.

Strong focus on the result of 14% of fuel saving obtaind along the M40/M50 sector in congested conditions.

After have understood the big influence of the traffic state in the fuel consumption, we can come back on the analysis by itinerary with a new prospective, presented on the table below.

		Nº of Recorded Sectors		
		FREE	MEDIUM	CONGESTED
CP1	Without ECO	74	19	28
	With ECO	89	25	7
CP2	Without ECO	85	23	45
	With ECO	51	25	43
CP3	Without ECO	111	10	14
	With ECO	88	11	9
MP1	Without ECO	15	26	29
	With ECO	18	26	22
MP2	Without ECO	79	29	10
	With ECO	71	27	14
MP3	Without ECO	21	40	14
	With ECO	15	30	17
PC1	Without ECO	117	53	16
	With ECO	80	43	7
PC2	Without ECO	80	21	34
	With ECO	68	21	26
PC3	Without ECO	98	9	8
	With ECO	70	16	6
PM1	Without ECO	37	29	4
	With ECO	36	14	0
PM2	Without ECO	100	12	6
	With ECO	100	14	8
PM3	Without ECO	48	27	1
	With ECO	38	20	0

Table 34 Sector traffic state

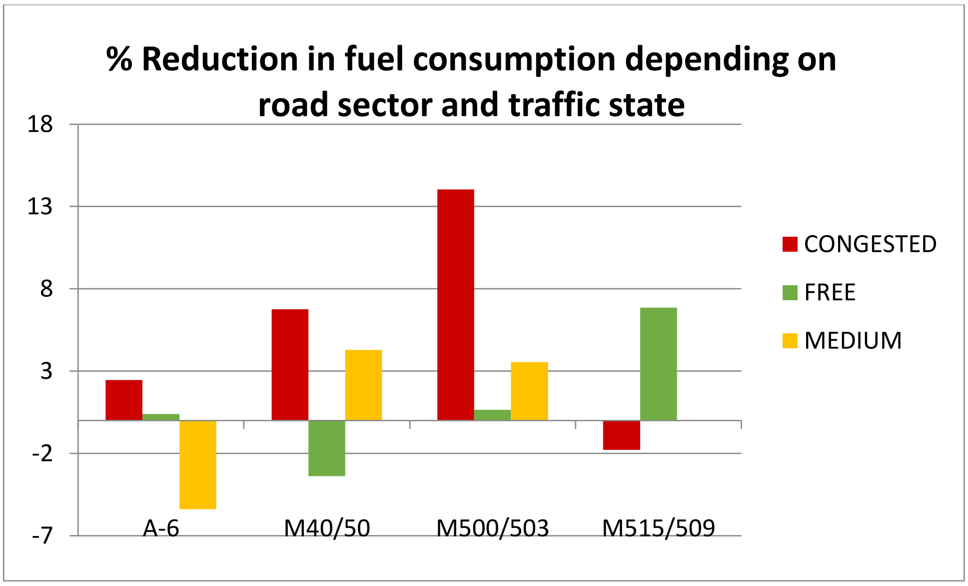
Table 34 shows how many sectors, for each itinerary, have suffered congestion problems. Taking into account the difference on traffic states between mirrored itineraries composed by the same route sectors (CP1-PC1, CP2-PC2, CP3-PC3..) we can understand the big difference of results obtained on Table 28 regards the saving in fuel consumption, as confirmation of the strong influence of the traffic state on the ECO-driving efficiency: this is the case of itineraries MP3-PM3, PC2-CP2, PC3-CP3.

Between the sectors considered in this study, the one that requests a mayor fuel consumption (and consequently produces a mayor amount of emissions) is the one of M515/M509, which corresponds to lower speed limits and several decelerating points along the route.

From results obtained through this last analysis we can also conclude that on those sectors characterized by lower speed limits, we reach the mayor saving in fuel consumption by applying the Eco-driving tips under free flow conditions.

On contrary, on road sectors characterized by higher speed limits (i.e. A-6) saving in fuel consumption is limited on free flow conditions, while it increases in congested situations, due to the increment of time in which is possible the application of eco-driving patterns.

The graph below give an idea of the saving in fuel consumption through the application of Eco-Driving depending on road sector and traffic state.



Graph 9 Eco-driving efficiency depending on road sector and traffic state

Finally, in this last analysis in which to compare different road sectors all data regarding road access sectors and others roads (urban roads) have been deleted from the sectorial database, the average fuel reduction between the two driving periods results 2.44 %, while on the previous analysis based on the Database_1 (divided by itinerary) the mean average fuel consumption was lower (0.78%) .

It induces us thinking about the strong influence that urban roads and access sectors have on fuel consumption: covering a travel distance of 1,682 km, road access produce an increment on the average fuel consumption of 4.3%, passing from 4.94 l/100km without considering them to 5.17 l/100 km by considering.

CHAPTER 6: CONCLUSIONS AND POLICY RECOMMENDATIONS

6.1 MAIN FINDINGS

This research aims to understand how the eco-driving efficiency is affected by different external factors as well as to deepen the knowledge on fuel consumption depending on different road sectors and traffic conditions, through data collected in a field test.

The methodology used in this thesis follows a systematic approach and was divided in four stages: Data collection before and after an efficient driving course, Database creation using R code, Filtering data and database validation, and Data analysis in terms of certain external factors.

The analysis were carried out both considering the whole trip recorded and splitting it in different road secors, thus analysing the data in terms of road sections and traffic flow.

Here are the main findings of the analysis carried out considering the whole trip.

- By considering all data collected, the saving in fuel consumption obtained adopting an eco-driving behavior did not reach 1%; regardless in some cases, as along itineraries whit speed limits lower than 50 km/h, eco-driving has been really efficient producing up to 8.5% saving.
- The eco-driving patterns considered in the study (% time with strong acceleration/deceleration, % time at stop_speed, average speed and average rpm) have strongly decreased, reaching reduction up to 50% under certain circumstances. It was seen that drivers indeed modified their driving behaviour with less aggressive acceleration/deceleration, and avoiding stops during the trip.
- From these data the first important conclusion of the study can be drawn: fuel consumption can be really influenced by external circumstances, but

the attendance on the efficient driving course results positive impacts to drivers in terms of driving style.

- As regards vehicle/fuel typology, in comparison with OPEL ASTRA (diesel), FIAT 500 (gasoline) turned out to be more efficient not only in saving fuel consumption but also on emissions, producing a greater reduction in CO_2, CO, and HC.
- The analysis by driving shift indicates that eco-driving efficiency is influenced by traffic condition and driving experience. During traffic congestion more fuel consumption is produced, however eco-driving has been more efficient in these conditions. Moreover, the same analysis shows that the more driving experience you have and the less you perceive the eco-driving tips: signal of the importance on attending an efficient driving course as soon as possible.
- Through the analysis of eco-driving efficiency depending on the itinerary, really interesting results have been obtained. Fuel consumption varies by different routes, as signal of the importance of the geometrical and functional aspects on the construction of roads. In an itinerary mainly composed of highways, in free flow conditions fuel consumption almost didn't change between the not ECO and the Eco-driving period. On the contrary, itineraries with speed limit of 50 km/h, in free flow conditions produced up to 8.5% of fuel saving: Eco-driving achieves better results with high fuel consumption routes.

The second analysis was about the influence of the traffic conditions and road section on the eco driving efficiency. The main findings are listed below.

- Generally it results that the eco-driving efficiency is stronger in congested situations on which more frequently the ECO-tips can be applied, but it is a result that strongly depends on the considered sectorial road. For highways sectors, the efficiency of eco-driving improves in congestion situations, while on roads with lower speed limits the efficiency on eco-driving is greater on free flow conditions.

- Access sectors and urban road can strongly affect the average fuel consumption of a route.
- The fuel savings by road section shows that sectors with lots of intersections and roundabouts generate bigger fuel consumption, but also bigger savings than the mean one.

6.2 POLICY RECOMMEDATIONS

As regards the contribution on transport planning, the efficiency got through the eco-driving opens a wider view to policy makers.

As the reduction on fuel consumption is relatively linked to the reduction in number of stops per km and % of time spent with speed lower than 5 km/h, the fact that frequently stop/start the vehicle produces more fuel consumption has been demonstred.

This study confirms that in roundabouts drivers should apply eco-driving technique in order to save fuel; one of the ECO-tips learned during the course was for example to remain in gear but step off the accelerator as early as possible in the access of a roundabout, but if there are consistent traffic flows, this eco-tip can produce safety problems.

It would then be useful to implement “green wave” of traffic lights on roads with heavy traffic flows, trying to produce a constant speed (and reduce strong accelerations/decelerations) in order to set the roundabouts free from big flows and permit the implementations of eco driving.

Data indicating the big dependency of eco-driving efficiency on external causes, often not controllable, have been obtained.

Due to its almost null cost to implement the technique it results really favourable in any case, but due to the big dependency on external forces we have to improve and act on the road transport planning.

The big strength of this thesis regards the amount of data analysed; indeed there have been investigated data regarding the effect of an efficient driving course, by monitoring data before and after the attending of the course, along different itineraries, through the conduction of different vehicles by different drivers at different day hours and both the urban and the extra urban contexts were analysed.

In line with the boundary conditions, a greater awareness of the role the driver has in limiting the emissive impact of his vehicle should be created.

In some circumstances, eco-driving can significantly reduce fuel consumption: its social and financial value could be promoted and included in driving lessons, and to encourage the consciousness of its value it could be useful to promote in-car equipment to measure fuel consumption.

Further analysis can focus on the influence of the drivers' attitude on eco-driving efficiency, and develop factorial analysis to investigate the external key factors of affecting eco-driving applications.

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