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Eco-Driving In Small Cities. Driving Performance In Relation To Driver's Profile

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Abstract

The transportation sector is one of the largest emitters of greenhouse gases. Eco-driving has been shown to be a very efficient driving technique to reduce consumption and CO_2 emissions into the atmosphere. Specifically, this paper investigates, based on the psychological characteristics and perception of the driver, the variation in different fundamental parameters of driving when driving conventionally with respect to an eco-driving.

This research has been carried out on four types of routes and different levels of service in a small city with no congestion problems, such as the city of Caceres. Drivers are men and women in an age range of 21 and 44, driving diesel and gasoline cars, a first week with normal driving and the second after having received an efficient driving training course.

This research concludes that eco-driving reduces the fundamental parameters of driving in a conventional style in all types of drivers, with a greater reduction in those with less experience in years of driving. Therefore it would be advisable to establish eco-driving policies in the driving schools since implementing these measures in novice drivers is easier and more efficient than in experienced drivers

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1. Introduction

Greenhouse gas (GHG) emissions and overconsumption of energy resources pose a global problem in terms of both their causes and consequences (Ramanathan and Ferg, 2009). The transportation sector is one of the largest emitters of GHG (Emberguer, 2015), despite advances in the field of engine technology and improvements in fuel quality. This sector accounted for 25.6% of global energy consumption in 2015, and transportation energy use is expected to increase by 1.1% every year until 2040 (EIA, 2017).

Public authorities have different ways of achieving environmental objectives: promoting social changes in mobility patterns to achieve greater use of cleaner modes, improving vehicle technology and fuel (Bottiglione et al., 2014), reducing the number of motorized journeys through demand management (Li et al.,2016), and using information and communication technologies (ICT) to improve transport efficiency (Lin and Nguyen, 2106).

However, these objectives can only be achieved with the contribution of the consumer. Some policies need to be accepted by the public, while others depend directly on the mode of driving and on travel decisions. These measures include efficient driving or eco‑driving, which has major potential for individual fuel savings, e.g., Xia et al. (2013) developed an eco‑driving velocity planning methodology, showing individual vehicle fuel consumption and CO_2 reductions of around 10‑15% depending on corridor parameters (including traffic volume and speed), and on the other hand, Ahn and Rakha (2008) achieved significant improvements to energy and air quality (6–7% fuel and CO_2 savings) when drivers utilize a slower route although they incur additional travel time.

The Spanish Energy Saving and Efficiency Action Plan 2011–2020 (IDAE, 2011) considers the efficient driving of private cars to be a key measure for achieving energy savings over the next few years. Specifically, by 2020 this practice is expected to produce significant energy savings in Spain of 493 ktoe (5.5% of the total estimated savings for the entire transportation sector) and to avoid emissions for a value of 1703 kt2. In order to achieve its objectives, the plan lays down some clear guidelines to encourage the rational use of transport modes and to promote demand management policies for route optimization and efficient driving.

Real‑life automotive research done in EU context has identified the potential of driving styles for reducing consumption and CO_2 emissions (Fiat, 2010). It also highlights the need to provide real‑time data to use the infrastructures in the most efficient way possible. There are many devices and technologies available for travel planning but whose potential has not yet been quantified to enable a more efficient use of transport infrastructures (including eco‑driving and eco‑ routing).

In this context, efficient driving aimed at reducing fuel consumption by modifying driver behaviour has increased in importance since the 1990s. However, this simple definition includes many concepts and strategic actions, depending on the level of decision‑making considered (Sivak and Schoettle, 2012):

- Strategic decisions: vehicle selection and maintenance.
- Operational decisions: driving style geared to maintaining a constant speed, smooth acceleration, etc.
- Tactical decisions: route selection and vehicle load.

This work aims to analyses efficiency of eco-driving on fuel savings with respect to driving patterns (i.e., acceleration, braking, speed, rpm) in relation to driver's profile (i.e. age, sex and driving experience) and perception through a post-trip survey.

The greatest potential for eco‑driving policies appears to be in areas where traffic levels are not very heavy, and yet most studies have analyzed the impact of eco‑driving in large cities suffering chronic congestion problems. To fill this gap, we set out to study the effects of eco‑driving in a small city, where traffic flow is not conditioned by peak hours or congestion, in relation to driver's profile and perception through a post-trip survey.

2. Methodology

In order to achieve the aim of this research, eco‑driving were tested under real traffic conditions, in a campaign conducted to collect data on different types of road (urban roads and access roads to the city) under different traffic conditions in a small city such as Caceres (less than 100,000 inhabitants). The field test phases were as follows:

1. The data campaigns was organized to collect data on driver behaviour following the determined routes with different road characteristics and traffic conditions. Four routes were selected with different levels of service (LOS). Level of Service is a quality measure describing operational conditions within a traffic stream; these

conditions affect by speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience (reference). The test was first performed with drivers driving normally, and then a second set of car runs was recorded after they had taken an eco-driving course, following the same routes and at the same times of day.

2. Individual driving variations produced by eco - driving were recorded using an OBD-key (KBM Systems Ltd, London, United Kingdom) installed on board (see Section 2.5), the corresponding CO2 emissions savings were estimated also.

3. Drivers were surveyed to capture the changes in their way of driving and perceptions before and after they were trained in eco - driving techniques.

2.1. Case Study: City of Caceres, Spain

The city of Caceres is located in western Spain and has a population of 95,000 inhabitants in an area of 30 km². It is a historic city with a high density of monuments and a unique medieval urban layout and was named a World Heritage site by the UNESCO in 1986 (UNESCO, 2017). The city today has succeeded in maintaining a moderate and constant economic growth (Caceres has had a GDP growth of 4.5% in 2015, 3.1% in 2016, and a population reduction of 323 inhabitants in the year 2017), despite a slight decline in its population, as has occurred in other similar cities and which is to a large extent due to the current economic crisis.

The city of Caceres needs to implement measures to encourage further use of public transport and pedestrian mobility to make it even more sustainable. Although policies for environmental protection and emission reduction have already been applied in the historic town centre, which is mostly restricted to pedestrians, they need to be extended to the more car - dependent surrounding areas to achieve sustainability targets for the whole city.

2.2. Selecting Routes to Represent Different Road Types and Traffic Conditions

The city of Caceres is quite small and can be crossed from side by side in less than 15 min. Four test routes were selected with the same origin and destination. They all start from the train station located in the western part of the city and end at the School of Technology (University of Extremadura) in the eastern part. Four alternative routes with different LOS (US Department of Transportation, 2013) were chosen to cross the city following itineraries with different characteristics and traffic volumes.

They can be ordered in terms of their increasing LOS (from lowest to highest), as follows:

Route 1 (local) runs along urban streets and passes right through the heart of Caceres city centre. It is 6.1 km long, and its travel time is around 15 min. This route has a dual carriageway with a median. Speed is limited to 50 km/h. It is regulated by traffic lights and suffers some congestion problems at peak hours.

Route 2 (collector) is 6.7 km long and its travel time is about 14 min. It is one of the most important avenues in Caceres as it provides access to the bus station, conference centre, sports arena, mortuary, and hospital, leading to some traffic delays. It also has a dual carriageway with a median, but due to its urban character, the speed limit is 50 km/h and 30 km/h in several sections.

Route 3 (perimeter) is the old bypass road, which is already integrated in the urban network. It also has a two - lane dual carriageway and a median or is demarcated by a continuous double line. The speed limit is 50 km/h. It has a length of 6.7 km and a travel time of about 13 min. It has almost no congestion.

Route 4 (bypass) follows the outer city bypass known as "Ronda Norte". It has a length of 10.3 km and can be travelled in about 12 min. It is the longest and quickest route. It runs through the north of the city with a two - lane dual carriageway with a median. Intersections are in the form of roundabouts and pedestrian crossings regulated by traffic lights. Speed limits vary between 80 km/h and 40 km/h. Traffic is usually fluid all day.

2.3. Driver Selection, Eco - Driving Training, and Assignment

Twelve drivers of different sexes were recruited in a wide range of ages and driving types, comprising eight men and four women aged between 21 and 44, in a fairly representative sample of the driving population in the city of Caceres. (The 2016 directory of the general traffic management (DGT, 2016a) indicates that the range between 25 - 44 years exceeds 51% of the census. In addition, the distribution of male/female drivers is 62% and 38%, respectively). The 12 drivers received an eco‑driving course so they could deploy these techniques during the second driving week and compare the results with the first week's driving.

During the driving test, six people were assigned to each vehicle, with two people taking turns to drive (driver and assistant, changing every hour) who iteratively performed trips along the four selected routes. They drove 12 h a day to obtain enough data on the different traffic situations (free circulation, moderate traffic, and congestion) and weather conditions (rain, fog, etc.).

The driving turns were adjusted to cover peak hours according to the mobility records for Caceres. The following driving turns were selected:

- 1st period. Morning peak: 7:30–11:30 am
- 2nd period. Lunchtime: 12:00–4:00 pm
- 3rd period. Evening peak: 4:30–8:30 pm

The first test was done from May 2 to May 5, 2017, and the second the following week, from May 9 to May 12, after taking the eco‑driving training course.

2.4. Experimental Car Data Collection

Caceres has a fleet of 48,554 passenger cars (approximately one vehicle for every two people), of which 60% are diesel and 40% gasoline. Two different cars were used for the data campaign, an Opel Astra 1600 cc diesel and a Fiat 500 1200 cc gasoline. These vehicles correspond to the small (Fiat 500) and medium (Opel Astra) car segments, which represent approximately 75% of the fleet in Caceres (DGT, 2016b). The sample is therefore quite representative of the Caceres fleet composition. Driving was 2.5. Measured Variables

Data was collected using an OBD‑key (OBDKEY, 2017) installed on board to obtain and store the parameters that define driving profiles. The geographical location of the vehicle was recorded at all times.

The following parameters were collected before and after the drivers took the eco‑driving training course:

1. GPS position (longitude and latitude) and distance travelled (km);
2. Travel time (h);
3. Instantaneous speed (km/h);
4. Fuel consumption (l);
5. Number of stops, rpm, acceleration, and deceleration (m/s2).

These data are necessary to measure the variation in speeds, accelerations and emissions produced by eco‑driving at the individual level.

2.6. Survey to Capture Individual Driving Perceptions

After each driving turn, the drivers filled out a brief questionnaire that included four attitudinal items. The aim was to address drivers´ perceived differences in comfort and ease with and without eco-driving, and other external circumstances that may have influenced drivers adopting eco-driving techniques, such as weather and/or traffic conditions. The survey was done after each driving turn and drivers were asked to rate four questions from 1 to 7 on a Likert scale (Nemoto et al. 2013), shown below in Table 1. The items were designed based on the works of Betella and Verschure (2016), measuring main emotions experienced in the trip (bored-entertained, relaxed-stressed), perception of self-efficacy and the appraisal of circumstances associated with car driving. A Likert scale is a psychometric scale with multiple categories from which respondents choose to indicate their opinions, attitudes, or feelings about a particular issue. Likert scale questionnaires have predominantly been used in research into individual difference variables, such as motivation, anxiety, and self‑confidence. Some advantages of Likert scale questionnaires are that (a) data can be gathered relatively quickly from large numbers of respondents, (b) they can provide highly reliable person ability estimates, (c) the validity of the interpretations of the data can be established through a variety of means, and (d) the data can be profitably compared, contrasted, and combined with qualitative data- gathering techniques such as open‑ended questions, participant observation, and interviews.

Table 1. Survey for capturing individual driving perception.

QUESTIONS	ANSWERS						
DRIVING							
Driving the vehicle was easy (1)—difficult (7).	1	2	3	4	5	6	7
The driving environment was easy (1)—difficult (7) to handle	1	2	3	4	5	6	7
During the trip you were bored (1)—entertained (7)	1	2	3	4	5	6	7
During the trip you felt relaxed (1)—stressed (7)	1	2	3	4	5	6	7

Based on the four pre-designed attitudinal items, it calculated the average score that each participant marked in terms of each question. Afterwards it compared the average score with the mean value among the 12 participants, and group the drivers into four groups (easy-relaxed, difficult-relaxed, easy-stressed and difficult-stressed) depending on their average score is lower or higher than the mean value of each question.

3. Results and Conclusions

Table 2 shows the average results of each question for each driver before and after eco-driving training. Comparing the average results obtained before and after the training course, the eco-driving does not present any major difficulty when it comes to handling the vehicle, nor does it produce greater stress during the journey to the drivers. However, the average results show a significant increase in the difficulty of driving circumstances and a less boredom in the management of it.

Table 2 Average points of each question before and after eco-driving

Driver	NON ECO				ECO			
	Average of Question 1	Average of Question 2	Average of Question 3	Average of Question 4	Average of Question 1	Average of Question 2	Average of Question 3	Average of Question 4
Cristina	1.3	1.8	6.7	1.5	1.3	4.7	6.2	3.5
David	1.0	1.5	6.2	1.3	1.7	3.2	4.7	4.0
Eduardo	2.5	3.8	5.5	3.3	1.3	2.5	5.3	2.0
Ignacio	2.3	3.3	5.5	3.3	1.8	2.3	4.5	2.0
Isabel	1.0	1.0	6.5	1.0	1.0	1.2	6.2	1.0
Jairo	1.2	1.0	6.5	1.5	1.2	1.5	5.7	2.0
Jesús Oliden	2.7	2.0	6.0	1.5	1.2	2.0	6.8	1.2
Jose María	1.2	1.5	5.7	1.5	1.2	1.8	5.3	2.0
Juan	2.0	2.7	4.7	3.6	3.0	3.2	4.3	3.4
Marta	1.0	1.7	4.8	2.2	1.2	1.3	4.8	1.5
Pablo	1.4	1.8	6.0	2.8	1.6	1.8	6.0	2.0
Yolanda	1.0	2.5	6.0	2.5	1.7	2.7	5.8	2.0
Average	1.55	2.0	5.8	2.2	1.5	2.3	5.5	2.2

Table 3 shows a psychological classification of the drivers based on the results obtained in the non-eco condition for each question with respect to the average. Values have been compared in non-eco mode to know the "natural" way of driving of each driver when classifying it psychologically. The one is less than average, then mark as 0. Drivers were grouped as easy or difficult depending on the first two questions, and relaxed or stressed depending on the 4th question.

The description of the groups is as follows:

- Group 1 easy-relaxed: the drivers consider the handling of the vehicle and the circumstances of the driving easy and feel relaxed during the trip.
- Group 2 easy-stressed: the drivers consider the handling of the vehicle and the circumstances of the driving easy but they are stressed during the journey.
- Group 3 difficult-relaxed: drivers consider the handling of the vehicle and the driving circumstances difficult but feel relaxed during the trip.

• Group 4 difficult-stressed: drivers consider the handling of the vehicle and the driving circumstances difficult and are also stressed during the trip.

Table 3 Classification of drivers according to their psychological characteristics.

Driver	Factor				Scale1	Scale2
Cristina	0	0	1	1	easy	stressed
David	0	0	1	1	easy	stressed
Eduardo	1	1	0	0	difficult	relaxed
Ignacio	1	1	0	0	difficult	relaxed
Isabel	0	0	1	1	easy	stressed
Jairo	0	0	1	1	easy	stressed
Jesús Oliden	1	0	1	1	difficult	stressed
Jose María	0	0	1	1	easy	stressed
Juan	1	1	0	0	difficult	relaxed
Marta	0	0	0	1	easy	stressed
Pablo	0	0	1	0	easy	relaxed
Yolanda	0	1	1	0	easy	relaxed

It should be noted that the character of 50% of drivers shows that they drive easily but that they are somewhat stressed during the trip, as shown in table 5. 3 drivers who perceived difficulty in handling the vehicle and road environment are with less driving experience (table 4).

Table 4 Classification by groups of the psychological nature of drivers.

Group1 Easy-Relaxed	Pablo, Yolanda
Group 2 Easy-Stressed	Cristina, David, Isabel, Jose María, Jairo y Marta
Group 3 Diff-relaxed	Eduardo, Ignacio y Juan
Group 4 Diff-Stressed	Jesús Oliden

The driving performance was studied using the following fundamental driving parameters that were further calculated using the logged data from OBD-Key:

1. Maximum rpm: max_rpm
2. Average negative acceleration: ace_acc_neg
3. Maximum speed: max_speed
4. Speed variation coefficient (Ratio of standard deviation to the mean %): cov
5. Average fuel consumption using VSP model: avg_fc

These parameters have been measured for each driver in non-eco mode and in eco mode, evaluating later the percentage reduction between them. The results can be seen in table 5.

Table 5 The variation of driving parameters and drivers´ profile.

			INCREASE						
		sex	max_rpm	ave_acc_neg	max_speed	cov	avg_fc	age	driving experience
Group1 Easy-Relaxed	Pablo	Male	-9%	-9%	-20%	-5%	-10%	31	3
	Yolanda	Femail	-14%	-32%	-13%	-8%	-10%	41	20
Group 2 Easy-Stressed	Cristina	Femail	-22%	-27%	-21%	-17%	4%	25	6
	David	Male	-29%	-34%	-25%	-17%	-13%	27	7
	Isabel	Femail	-23%	-33%	-22%	-16%	-10%	31	12
	Jose María	Male	-25%	-15%	-19%	-14%	-7%	21	3
	Marta	Femail	-15%	-20%	-15%	-10%	0%	44	22
Group 3 Diff-relaxed	Eduardo	Male	-14%	-28%	-20%	-5%	-10%	24	3
	Ignacio	Male	-36%	-39%	-33%	-17%	-20%	28	8
Group 4 Diff-Stressed	Jesús Oliden	Male	-29%	-17%	-18%	-6%	-7%	23	5

These results have been grouped for the four groups of drivers that are shown in table 6.

Table 6 Average value of each variable for each group of drivers.

	max_rpm	ave_acc_neg	max_speed	cov	avg_fc	avg_age	avg_driving experience
Group 1 Easy-Relaxed	-12%	-21%	-17%	-7%	-10%	36	12
Group 2 Easy-Stressed	-23%	-26%	-20%	-15%	-5%	30	10
Group 3 Diff-relaxed	-25%	-34%	-26%	-11%	-15%	26	6
Group 4 Diff-Stressed	-29%	-17%	-18%	-6%	-7%	23	5

Next, the variation of each driving parameters for the different groups between conventional driving style and the eco-driving is analysed.

1. Maximum revolutions per minute

There is a decrease in the maximum rpm in all groups, being much more significant in groups that have greater difficulty in handling the vehicle and consider the circumstances of driving more difficult. In addition, this decrease in maximum rpm is greater in groups with younger drivers and with fewer years of driving experience.

2. Average negative acceleration

Negative accelerations (braking) are reduced in all groups, in values about 25% since efficient driving avoids the use of the brake as much as possible and as long as road safety conditions allow. The reduction in braking rate among the 4 groups is quite even except for the Diff-relaxed group which made 34% less braking. The two drivers (Eduardo and Ignacio) of this group showed a significant less difficult in the second period because of more familiar with the vehicle and driving conditions (table 3).

3. Maximum speed: max_speed

Maximum speed is another key factor that correlates to fuel consumption (Ericsson, 2001). All groups reduced the maximum speed in the eco-driving period and the difference among the groups is relatively small.

4. Speed variation coefficient (Ratio of standard deviation to the mean %): cov
5. The cov is the speed variation comparing the average speed during the trip, and it is negatively corresponding to the level of drivers capable of maintaining the steady speed. Considering the changes among the four groups, the easy group received a better result to maintain a steady speed comparing with the ´difficult´ groups.

Average fuel consumption using VSP model: avg_fc

The parameter avg_fc used for the analysis is the average fuel consumption per second which does not take into account the influence of current traffic. The results shows relaxed drivers reduce double fuel consumption when practicing eco-driving than the stressed group.

4. Conclusions

It can be conclude that eco-driving reduces the fundamental parameters of driving in a conventional style in all types of drivers, with a greater reduction in those with less experience in years of driving. Therefore it would be advisable to establish eco-driving policies in the driving schools since implementing these measures in novice drivers is easier and more efficient than in experienced drivers.

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