POSITIVE EFFECTS OF ECO-DRIVING IN PUBLIC TRANSPORT
A Case Study of the City Novi Sad

by

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Original scientific paper
DOI: 10.2298/TSCI150219160B

Eco-driving as a concept and program is a well-developed strategy adopted to reduce fuel consumption and greenhouse gas emissions. The paper presents the findings confirming the significance of driver education about eco-driving (through theoretical and practical training initiatives) with the aim of reducing the negative environmental impact of road transport. During the study, the drivers were tested prior to and immediately after completing the theoretical and practical education on eco-training. According to the study findings, driver education resulted in approximately 11.71% reduction in fuel consumption and average CO_2 emissions. These results, along with the findings of many other studies conducted around the world, show that driver education can result in very efficient and significant reduction in fuel consumption and CO_2 emissions. Therefore, it is necessary for the drivers to undergo periodical eco-driving training with specialized coaches and well-designed programs.

Key words: *eco-driving efficiency, driver education, fuel consumption, CO_2 emissions*

Introduction

Eco-driving has a great potential for contributing to the CO_2 reduction in the transportation sector effectively and efficiently [1]. The key characteristics of eco-driving include accelerating moderately, along with anticipating traffic flow and signals, thereby avoiding sudden starts and stops. It also implies maintaining an even driving pace, driving at or safely below the speed limit, and eliminating excessive idling [2].

Graves *et al.* [3] described eco-driving as a set of driver behavior, vehicle maintenance and non-driving actions aimed at reducing fuel consumption. In their study, the authors focused on more effective adaptation to the changes in traffic and unobstructed participation in traffic as the key driver behavior.

The advantages of eco-driving are multiple, and primarily pertain to: *safety* (increased road traffic safety, improved driving capabilities), *environment* (reduced greenhouse emissions, CO_2, local harmful emissions and noise), *driving economy* (reduced fuel consumption, 5-15% in the long term, maintenance costs, and those incurred due to traffic accidents),

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and *social responsibility* (more responsible driving, reduced stress during driving, increased comfort for both drivers and passengers) [4].

Numerous studies have been conducted so far, examining the short-term impacts of eco-driving on fuel consumption. European Conference of Ministers of Transport/International Energy Agency [5] reported that, on average, 5.0% reduction was achieved in the Organization for Economic Cooperation and Development regions, based on an expert analysis of available literature. In 2002, in before-and-after driving trials conducted in Sweden, the effects of eco-driving on vehicle emissions were measured, reporting average fuel savings of 10.9% after training [6].

Few studies report on the long-term effects of driving courses aiming to increase fuel efficiency. Wahlberg [7] monitored fuel consumption reduction in buses and recorded 2.0% fuel savings during the 12 months following the driver training. In a study conducted in Greece, Zarkadoula *et al.* [8] noted that a decrease of 18% was achieved by two eco-trained bus drivers, whereby an average decrease of 10.0% was reported for all bus drivers during a two-month post-training monitoring period.

In the period from 2000 to 2008, similar eco-driving studies were carried out in many countries, aiming to achieve reduction in fuel consumption. Their findings indicate that significant reduction was achieved, 20.7% in Germany, 14.0% in Finland, 10.5% in Austria, 25.0% in Greece, and 10.0% in Switzerland [9].

Studies conducted in the public transport company "JGSP Novi Sad"

Eco-driving education and training was conducted on December 4th, 2013 in the public transport company *JGSP Novi Sad*, operating in the city of Novi Sad, Serbia, and included three drivers. The study participants were selected using purposive sampling, whereby driver 1 was chosen from a group of drivers classified as extremely cost-aware, driver 2 belonged to the group of moderately cost-aware drivers, while driver 3 was classified as an extreme fuel consumer.

Methodology

The route along which the drivers commuted during the training covered the distance of 7.7 km, and it took on average 33 minutes to complete it. It was identical to the regular bus line number 12, which involved driving in inner city traffic as well as on the periphery. The study was conducted in the period 12 a. m. to 4 p. m. Previous research by *GSP Novi Sad*, Faculty of Technical Sciences in Novi Sad, and Institute for Urban Planning in Novi Sad (traffic study NOSTRAM) have shown that in this period peak loads occur both in public transport and the entire city road network. Therefore, as an initial hypothesis, it was chosen that the time periods in the testing interval and driving conducting are characterized by approximately a similar number of vehicles, conditions on the network (the network losses) and number of passengers in the vehicle (overall vehicle mass). We used testing period and public transport line with the capacity utility factor that was higher than 0.7, which represented the vehicle occupancy on the most heavily congested section. The initial operating time – Drive 1 took place in the first half of the chosen period (12 p. m. to 1 p. m.), while the second operating time – Drive 2 took place before the end of the afternoon's peak load (3 p. m. to 4 p. m.). Eco-driving training (theoretical education of drivers) was realized between two these drives. The whole programme was further added over three phases in the following.

A Neobus – Volvo bus was chosen because that model is equipped with controller area network (CAN) bus enabling reading of driving parameters. As we needed objective and comparable data, our only option was to use data produced by the vehicle. To capture that data, we have relied on CAN network using SAE J1939 protocol and specialized software – Key Driving Training System produced by Belgian company *Key Driving Competence* and a laptop. To translate data from CAN to a readable and computable data we have used two interfaces – first Squarell interface for initial selection of the data available at the vehicles CAN bus and then Kvaser interface used to translate basic CAN messages into a format that could be used on a personal computer. That procedure allows objective display of something that is deeply subjective – personal driving style, making possible individual approach and coaching to each and every driver.

Phase I – Preparation and Drive 1

The training itself consists of two drives with monitored driving style and theoretical and practical classes. The first monitored route was done on a predefined route on which the driver was driving in his unique driving style, and the trainer was just monitoring and writing the notes about the driving style. Thus, connecting the computer software to the bus's electronic system, data storing and reading by equipment which are used: laptop, diagnostic cable (SAE J1939) and two interfaces – Squarell and Kvaser, allowing the following data to be stored: diagram of engine speed time history, diagram of vehicle speed time history, diagram – engine torque demand, average fuel consumption per 100 km, current gear engaged, average driving speed, current fuel consumption, number of braking events, number of stationary periods, total duration of vehicle motion, current vehicle speed, and current engine speed.

Phase II – Theoretical training session

After the first route, theoretical eco-driving training is carried out in duration of 2 hours. Trainees are introduced to basic techniques of eco-driving and the results of their first route is presented to them along with the exact display of errors they made and segments of the route that drivers drove well and energy-efficiently, and are told which segments of their driving technique can be improved. Accordingly, drivers are given suggestions, guidelines and instructions for the second route.

Phase III – Practical driver training – Drive 2

Upon the completion of the theoretical education phase, the drivers are given practical training on the same route completed during the first operating time – Drive 1, allowing for a comparison of their driving performance and thus the evaluation of the training effectiveness. In other words, the aim is to establish whether the drivers could apply the newly acquired theoretical knowledge in practice. During this phase, the instructor actively participated in the drivers' decisions and behavior, by providing suggestions and noting objections in the event where the driver failed to apply the knowledge gained through theoretical training. As before, the pertinent information was recorded and stored for subsequent analysis.

After all three drivers completed the second operating time – Drive 2, data analysis could commence. The findings were discussed with the drivers, allowing them to appreciate the effects of the training received and identify areas for further improvement.

Practical training outcomes and discussion

The analysis of the data collected during the first and second run of each driver yielded some valuable results. Those pertaining to driver 1, driver 2, and driver 3 are contrasted in tab. 1, as they achieved the smallest and greatest fuel saving, respectively, following the training.

Table 1. Measuring driving quality indicators before and after training

Parameter	Unit	1	2	3	4	5	6	7	8	9
		Driver 1			Driver 2			Driver 3		
		Drive 1	Drive 2	2/1 [%]	Drive 1	Drive 2	5/4 [%]	Drive 1	Drive 2	8/7 [%]
Total time	mm:ss	0:25:30	0:28:10	10.49	0:28:35	0:29:56	4.73	0:23:44	0:23:08	2.51
Total distance	km	7.84	7.84	0.00	7.84	7.82	–0.33	7.62	7.62	0.08
Average speed	kmh^{-1}	18.44	16.69	–9.50	16.46	15.66	–4.84	19.26	19.77	2.65
Average speed – on the move	kmh^{-1}	22.51	21.16	–5.99	22.27	21.42	–3.82	25.53	22.42	–12.18
Fuel consumption – on the move	L	3.36	3.15	–6.32	3.35	2.93	–12.70	3.36	2.74	–18.37
Total fuel consumption	L	3.54	3.40	–4.00	3.65	3.25	–10.97	3.61	2.87	–20.40
Average fuel consumption	L/100 km	45.2	43.4	–4.00	46.6	41.6	–10.97	47.4	37.7	–20.40
Average CO_2 emission	kg/100 km	120.3	115.5	–4.00	123.8	110.6	–10.67	126	100.2	–20.47

A comparison of the results pertaining to the driving characteristics before and after training reveals significant improvements in the measured driving quality indicators, tab. 2.

There are a number of peer-reviewed studies investigating whether eco-driving training results in more economical driving amongst buses drivers [10-14]. Jambrović and Kalauz, [10] tested 27 drivers driving the route before and after the eco-effect training and cumulative average result is saving of 8.28% on fuel consumption for the bus drivers.

The similar problem was also evident in another study and the city of Tallinn, Estonia, developed a training program on energy-efficient driving for bus drivers. Results showed that the fuel consumption was reduced by 3.9% in average for the participants of the training and 0.9% total in the Tallinn Bus Company. The amount of emissions was reduced – depending on the type of emission, the total Tallinn Bus Company annual amount was reduced by 0.7-1.0% [11].

Stromberg and Karlsson [12] investigated the impact of eco-driving training and in-vehicle feedback using three groups of bus drivers (the third was control group). They tracked their fuel consumption before and after these interventions and reported an overall 6.8% reduction in fuel consumption (both groups combined).

Sullman *et al.* [13] showed that eco-driving training significantly reduced fuel consumption and GHG emissions in the road transport sector. A total of 29 bus drivers were tested using a simulator both before and after eco-driving course. Fuel economy was improved on average by 11.6% immediately after the training and by 16.9% six months after the training. Also, Carrese *et al.* [14] presented that fuel economy improvement six months after eco-driving training was 27%.

Similar to the findings yielded by several previous studies we have also shown here that eco-driving training resulted in a significant reduction in fuel consumption and GHG emissions. This driving mode is expected to increase the vehicle's lifespan, as well as yield other benefits. The present evaluation shows that, in comparison with the Drive 1, following the training, the first driver achieved 6.32% reduction in fuel consumption while the bus was in motion, the second driver achieved 12.7%, while the third driver improved fuel efficiency

Table 2. Analysis of measurement results of the tested driver before training and after training

Parameter	Unit	1	2	3	4	5	6	7	8	9
		Driver 1			Driver 2			Driver 3		
		Drive 1	Drive 2	2/1 [%]	Drive 1	Drive 2	5/4 [%]	Drive 1	Drive 2	8/7 [%]
Average position of gas pedal	%	28	21	–23.77	24	17	–27.68	28	26	–7.73
Maximum position of gas pedal	%	85	100	17.37	95	100	5.04	100	100	0.00
Moving time – driving without throttle	mm:ss	3:23	6:09	82.01	4:42	7:38	62.49	4:34	5:46	26.25
Time – usage of brakes	mm:ss	9:39	9:57	3.11	13:43	11:29	–16.31	9:59	5:35	–44.11
Total distance – driving without throttle	km	1.49	2.81	88.40	2.12	3.65	72.38	2.38	2.64	10.59
Total distance – usage of brakes	km	1.50	0.79	–46.89	1.95	0.8	–58.87	1.52	0.6	–60,29
Number of braking events	–	70	54	–23.02	92	49	–46.99	67	37	–45.11
Number of stopping events	–	17	27	58.82	31	32	3.23	32	25	–21.88
Idling time	mm:ss	4:36	5:57	29.19	7:27	8:03	7.89	5:50	2:44	–53.09
Number of gear changes	–	174	162	–6.90	177	168	–5.08	161	146	–9.32
Number of gear changes (upshifts)	–	87	81	–6.90	89	84	–5.62	81	73	–9.88
Total number of engine revolutions	–	22715	24252	6.77	24462	24877	1.69	21413	20822	–2.76
The average engine speed	rpm	891	861	–3.37	856	831	–2.90	902	900	–0.26

by 18.37%. Upon completion of the eco-driving training, driver 1, driver 2, and driver 3 reduced the total fuel consumption by 4.00, 10.97, and 20.40%, respectively. Identical findings pertain to the fuel consumption per 100 km. All three drivers also contributed to the decrease in CO_2 emissions, which has economic and well as environmental value.

When total driving time is analyzed, it can be noted that, upon completion of training, driver 1 took 168 seconds longer to complete the route, driver 2 took 81 seconds longer, while the time taken by driver 3 was shorter by 36 seconds compared to the baseline data. However, all three drivers met the predetermined bus route schedule.

While, after training, the first driver reduced the average speed relative to the Drive 1 by 9.50%, the second driver reduced by 4.84%, and the third driver increased it by 2.65%. On the other hand, while the vehicle was in motion, the speed achieved by all three drivers was lower than in the Drive 1, by 5.99, 3.82, and 12.18%, respectively. This indicates that all drivers, in particular driver 3 understood that in the inner city traffic reaching higher speed does not necessarily mean faster travel. Result of this was a bit lower average speeds without harsh accelerations and harsh braking which is more convenient for passengers and improves road safety.

The duration of bus operation without throttle after education increased by 82.01, 62.49, and 26.25%, for drivers 1, 2, and 3, respectively. This is a particularly significant finding, as, in this driving mode, fuel consumption was 0.001 L/km, and again road safety is improved. Ability to drive without throttle is only possible if driver is anticipating traffic well. Only with good anticipation driver can disengage throttle on earlier allowing driving and thus increase fuel economy, achieving also more convenient deceleration which is especially useful while approaching bus stations.

Eco-driving does not only reduce GHG emissions and save fuel, but also all other consumable parts and assemblies on the vehicle, because the driver does not put the vehicle in risky traffic situation. For example, after completing the training, drivers 1, 2, and 3 reduced the number of braking events by cca. 23.02, 47.0, and 45.11%, respectively. This results in extending the longevity of the brake system, while also limiting the need for replacing the vehicle pneumatics. The total distance travelled by driver 1 without using brakes increased by 46.89% after completing the training, at driver 2 increased by 58.87%, while 60.29% was measured for driver 3. This results in a significant reduction in the energy waste.

The number of gear changes reduced after the training by 6.90% (driver 1), 5.08% (driver 2), and 9.32% (driver 3), thus proportionally prolonging the life of the gear and engine components.

The average engine speed reduced after training by 3.37% (driver 1), 2.90% (driver 2), and 0.26% (driver 3). While these changes were minimal, they still contribute to the reduction in the operating load, thus increasing vehicle longevity.

The difference in the driving quality indicators before and after training is presented as an average value for all drivers that took part in the eco-training project and is shown in figs. 1-12.

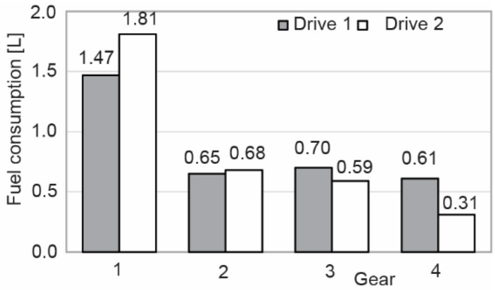

Figure 1. Fuel consumption – driver 1

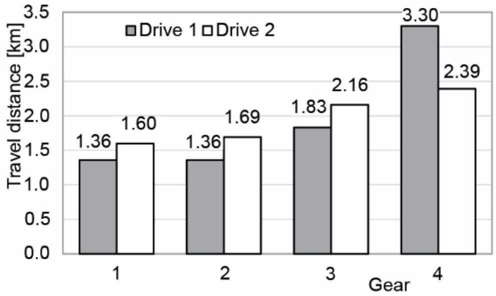

Figure 2. Travel distance – driver 1

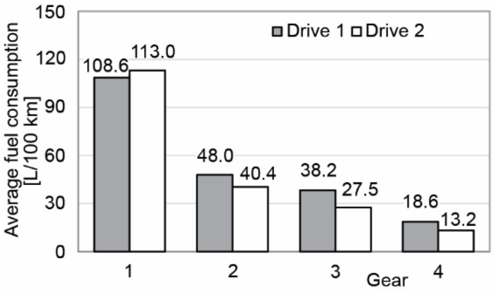

Figure 3. Average fuel consumption – driver 1

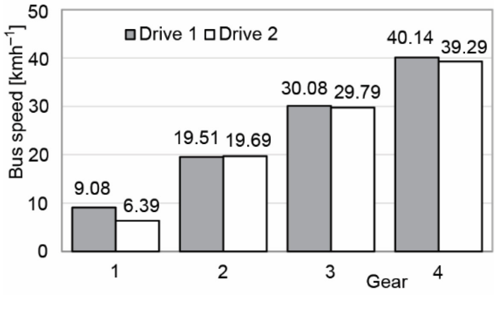

Figure 4. Average bus speed – driver 1

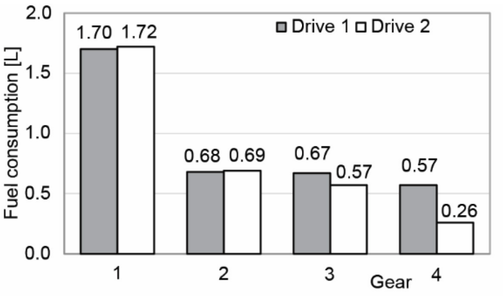

Figure 5. Fuel consumption – driver 2

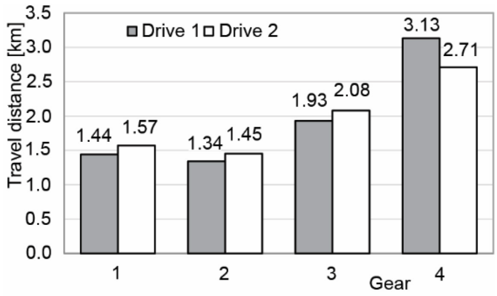

Figure 6. Travel distance – driver 2

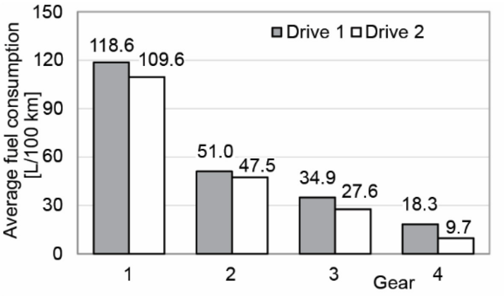

Figure 7. Average fuel consumption – driver 2

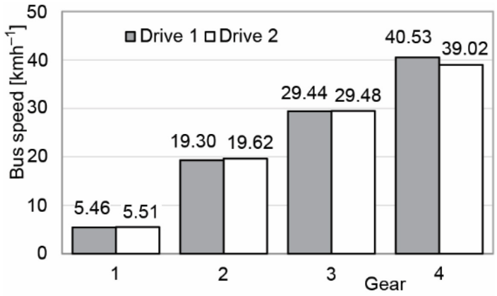

Figure 8. Average bus speed – driver 2

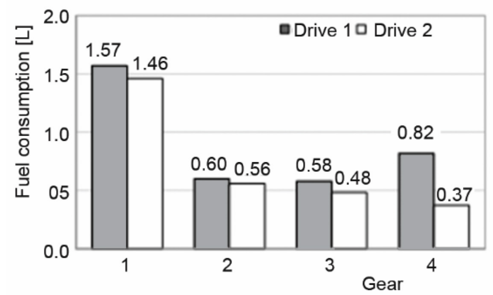

Figure 9. Fuel consumption – driver 3

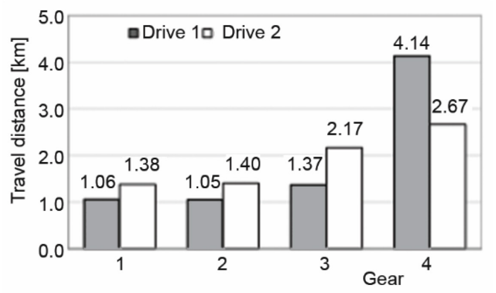

Figure 10. Travel distance – driver 3

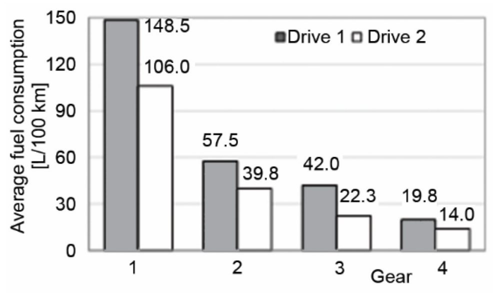

Figure 11. Average fuel consumption – driver 3

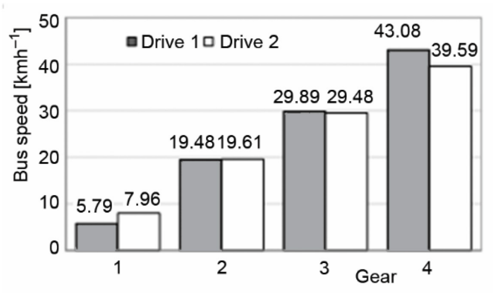

Figure 12. Average bus speed – driver 3

System sustainability – monitoring and correction measures

In order for this system to be sustainable and yield the desired results in the long term, it is necessary to carry out the daily system monitoring and driver evaluation. Below, the authors propose such a system.

Monitoring systems, available to the market today allows us to monitor various characteristics of the vehicle. This system needs to have the driver's identification system, so that all monitored results would be assigned to the driver who made them. However, the driver's identification does not solve the problem of monitoring the driving styles. One driver might accelerate harshly every time he starts, other driver might braking harshly, the third one might over speed, *etc.* All these parameters can be monitored by installing an additional module that records the driver's driving style and gives the driver a negative point for each mistake he makes, and sends both an audio and light signal to the driver which informs the driver of every mistake he made reminding him what he has been through (for example RIBAS). Whenever a parameter comes close to being exceeded, audio and light signals alert the driver to a potential problem, tab. 3.

Table 3. Examples for RIBAS panel calibration

R	Too high engine revolutions (n > 1500 rpm longer than 1 second)
I	Too long idling time (n = 550 rpm longer than 2 minutes)
B	Harsh braking (deceleration) (d > 1.9 m/s^2 longer than 1 second)
A	Harsh acceleration (a > 1.7 m/s^2 longer than 1 second)
S	Over speed (v > 55 km/h longer than 2 seconds)

For being objective when deciding which driver was the most efficient, the number of kilometers driven by each driver in the observed period should be considered, *i. e.*, it is necessary to make related correlation between *kilometers travelled* and *negative points – number of mistakes*. Once the data has been analyzed, it can be tabulated, thus providing visual cues that can help the drivers adjust their mode of operation. For example, in tab. 4, the first three drivers are the best performers, while the last three drivers require improvement and can be subjected to appropriate disincentives.

Potential for system improvements

The system aimed at achieving savings in fuel consumption can be further enhanced. This primarily relates to the synergy between the systems for monitoring the driver performance with that used for informing the drivers of upcoming traffic lights at intersections along their route. Specifically, at these intersections, it is possible to install a device that could display the remaining number of seconds until lights change. In fig. 13, for example, such system, in operation at an intersection in city of Osijek, Croatia, has been shown.

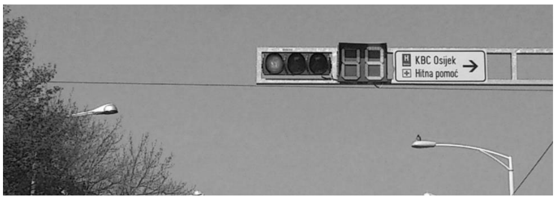

Figure 13. A traffic light timer display installed at an intersection in Osijek, Croatia

Placing this counter at intersections allows the public transport drivers to read the numbers from a significant distance,

Table 4. Driver ranking based on driving efficiency – an example

Driver	Distance travelled [km]	Route duration	Number of mistakes	Type of mistakes					
				Excessive idling	Harsh braking	Harsh acceler.	Over revving	Over speeding	Results
				(+1)	(+1)	(+1)	(+1)	(+1)	
Driver 1	58.4	2:17:30	5	0	0	0	5	0	0.086
Driver 2	86.1	3:39:51	32	2	0	0	30	0	0.371
Driver 3	88.7	3:53:07	42	0	3	0	39	0	0.473
Driver 4	156.7	5:59:54	82	0	0	0	80	2	0.523
Driver 5	147.3	6:23:53	86	1	7	13	65	0	0.583
Driver 6	89.0	4:16:24	57	0	2	0	53	2	0.640
Driver 7	155.3	5:54:52	158	0	0	2	156	0	1.017
Driver 8	96.3	4:00:21	108	0	1	0	103	4	1.121
Driver 9	156.9	5:11:05	279	3	5	0	192	79	1.778
Driver 10	153.9	5:59:21	275	0	3	30	240	2	1.787
Driver 11	148.1	5:49:14	313	1	9	38	250	15	2.113
Driver 12	97.9	5:01:48	214	0	1	5	204	4	2.186
Driver 13	154.7	5:37:43	355	7	5	39	255	49	2.295

allowing them to react accordingly. Owing to the years of experience and the eco-driving training received, most drivers would be able to estimate braking and stopping times, as well as maximize the usage of inertia. This, along with other aforementioned parameters, would result in improved fuel consumption and reduced environmental pollution. These direct effects would also be accompanied by indirect savings in, for example, component wear and vehicle maintenance. Finally, traffic safety and comfort would also be improved, further confirming the utility of this system.

Conclusions

Different types of interventions can be put in place in order to promote eco-driving. Currently utilized eco-driving interventions are generally aimed at changing driver behavior and increasing motivation (interventions such as informing drivers of the techniques, improving their skill levels, providing them with in-vehicle feedback through support systems, employing a combination of different incentives, *etc.*).

Experiences gained in Europe indicate that the driver education can lead to significant fuel savings and reductions in GHG emissions. The results reported here show that eco-driving brings many benefits and savings for the community as a whole.

This study of the effects of eco-driving, carried out in Novi Sad, yielded findings that are in line with those reported in many eco-driving projects in the world, thus confirming that investing into eco-driving is justified. In order to improve environmental conditions, it is necessary to change human behavior and perceptions towards a more eco-friendly driving behavior.

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Paper submitted: February 19, 2015
Paper revised: April 18, 2016
Paper accepted: June 28, 2016