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Design and Implementation of a CANBus-Based Eco-Driving System for Public Transport Bus Services

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ABSTRACT Driving vehicles according to eco-driving principles and techniques have significant impact on decreasing both fuel consumption and carbon dioxide (CO_2) emissions. In addition to some kind of technical and/or mechanical features brought by today's new generation vehicles, driver behavior is also one of the greatest factors affecting the fuel consumption. Many studies show that the effect of eco-driving education on the drivers loses its impact in long term and there needs some sort of continuous monitoring and/or feedback mechanisms. This kind of driver monitoring becomes very critical especially in fleets composed of heavy-duty vehicles, such as municipality buses, truck fleets, etc. Moreover, in order to adapt behavior to drive more economically, information about instant fuel consumption has to be provided to the driver. Hence, in this paper, we introduce an eco-driving system in which data gathered from the controller area network (CANBus) of public transport vehicles are processed for both comparative and fair evaluation of bus drivers' eco-driving performance. Moreover, in-vehicle components of the system guide the drivers during their trips; provide feedbacks and real-time warnings considering the fuel consumption. Developed system was successfully deployed and evaluated in one of the public metrobus systems used by approximately 250000 passengers every day. Based on the 15-months evaluation period, the results are very promising in the sense that both drivers and operators found the system useful and the system provided fuel saving up to approximately 5% even in the short term of monthly comparisons.

INDEX TERMS Controller area network (CANBus), eco-driving, eco-driving software, public transportation.

I. INTRODUCTION

Eco-driving aims at economical, ecological and safe driving [1]. Driving vehicles according to eco-driving principles and techniques have an important impact on decreasing both fuel consumption and carbon dioxide (CO_2) emissions [2]–[5]. In addition to some kind of technical and/or mechanical features brought by today's new generation vehicles, driver behavior is also one of the greatest factors affecting the fuel consumption [6]. Hence, training drivers by taking into consideration eco-driving principles and techniques has merit. However, many studies (e.g. [7]–[10]) show that the effect of eco-driving education loses its impact in long term (e.g. after 2-3 months) and there needs some sort of continuous monitoring and/or feedback mechanisms in order to maintain the effects of eco-driving training. This kind of driver monitoring becomes very critical especially in fleets composed of heavy-duty vehicles, such as municipality buses, local bus companies, cargo companies, truck fleets etc. Within this context, various studies (e.g. [6], [11]–[14]) investigate the ways of monitoring eco-driving performance and propose system architectures for reporting eco-driving performance based on the trip data. However, in order to adapt behavior to drive more economically, information about instant fuel waste should also be provided to the driver. New vehicles provide this information via systems based on eco-displays, but in many situations the capabilities of those systems need to be improved since the driver cannot be aware of his/her current level of driving economy while performing the visual stressful task of vehicle driving.

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Hence, in this paper, we introduce an eco-driving system in which data gathered from the controller area network (CANBus) [15] of public transport vehicles are processed for both comparative and fair evaluation of bus drivers' eco-driving performances. Comparison groups are determined according to some criteria (such as route, vehicle type and trip time) and instant trip data gathered for a specific driver are transmitted from vehicles to the main system to provide fair evaluation of the drivers. Moreover, in-vehicle components of the system guide the drivers during their trips, provide feedbacks and real-time warnings about their current eco-driving performance, again by considering the comparative evaluation of other drivers' performances. Differentiating from similar efforts (e.g. [6], [12], [13], [16]–[18]), our system does not only provide online eco-driving reporting and performance comparison in remote applications out of the vehicles, it also guides the drivers in the vehicles continuously during their trip and helps to control their eco-driving performance instantly within the same comparison group. Developed system was successfully deployed and assessed during 15 months in one of the public metrobus systems, shortly called PMS, a kind of bus rapid transit system. The in-vehicle components of our system were installed into 64 buses in the related fleet and results achieved from this implementation are also discussed in the paper.

The rest of the paper is organized as follows: Related work is given in Section 2. Software design and architecture of the eco-driving system are discussed in Section 3. Section 4 covers the methodology applied for the comparative evaluation of eco-driving performance of the drivers. Section 5 discusses the implementation of the proposed system. Section 6 includes the evaluation of the results achieved from this implementation. Section 7 concludes the paper.

II. RELATED WORK

Benefiting from eco-driving and hence providing less fuel consumption as well as less CO_2 emission are directly related to driving techniques of drivers and how they drive vehicles. Based on the study [19] carried out by USA Federal Government, it was observed that if drivers apply correct techniques while they drive vehicles, significant amount of fuel saving is possible. Within this context, there exist studies intended to evaluate driver performances ([6], [13], [16], [20]–[24]) or propose the development of systems that assist drivers while they drive ([14], [25]–[28]).

For the purpose of revealing the best driving techniques to increase fuel saving, preliminary studies were presented in [29] and [30]. Ross [30], specifically investigated the impacts of driving styles and vehicle characteristics on fuel consumption. Since the beginning of the 2000s, increasing susceptibility on environmental protection and air pollution due to CO_2 emission also affects the related research field. For example, in [31], impacts of driving techniques and driver behaviours on fuel consumption are discussed. Ahn et al. [25] recommended a method to estimate driver oriented fuel consumption such as instant acceleration. Driver behaviors and its impact on fuel saving were also examined via special driving routes in [20]. In that study, firstly, drivers were told about clues reducing fuel consumption and then application of these clues and related driving methods were evaluated. Dam [21] showed that even little improvements in driving may contribute to fuel saving. In [11] and [12], a system was proposed to provide social consciousness about the increment of eco-driving. The system aims at incrementing both fuel saving and secure driving by using mobile information and communication technologies. The web-based driving information, taken from a group of users, was used to determine driver behaviours.

Manzoni et al. [22] showed that fuel consumption of current vehicles and CO_2 emission can be decreased by the changes made in driving styles and training. Berry [32] indicated that eco-driving training given to drivers can reduce fuel consumption in long term without feedbacking drivers about their driving styles. A theoretical frame and its supporting algorithm given in [33] provide engines in vehicles to work like an autonomous intelligent system that learns the most convenient calibration according to the real time driving styles of drivers. On the other hand, Kamal et al. [34] presented a system providing driving ecologically on the roads that have especially various slope variations.

Liimatainen [6] evaluated eco-driving performances of drivers who drive public transportation vehicles of a local bus corporation in Finland. The evaluation system used the data obtained via network inside the vehicles. First, impacts of the factors independent of the drivers such as road geometry, road type, bus type, passenger capacity and traffic on fuel consumption were exposed. Then, a method was declared in which eco-driving performances are evaluated by isolating those factors. The results achieved by using this method were also discussed in [6]. As being the sequel of this study, the results of intragroup eco-driving evaluation of drivers in transportation companies were given in [35]. Similar to [6], the study also showed that the intragroup assessment of driver eco-driving performances supports the evaluation and increases the energy efficiency.

Riener [26] proposed a method based on subliminal persuasion to change the behaviours of drivers for supporting eco-driving. In the study, it was detected that visual screens showing instant fuel consumption is inadequate to provide eco-driving. Instead, drivers were given warnings about fuel consumption by the proposed system which employs tactiles placed at seatbelt and vibrotactiles placed at driver's seat. In [36], an expert system, defining traffic signals on the roads and determining the best deceleration pattern and the least breaking by using cell phones in vehicles, was given. An adaptation of the algorithm originally used for human face recognition in real time was provided. Benefiting from this adapted algorithm, the expert system warns the driver on decreasing the speed when needed and hence helps drivers to provide eco-driving.

An optimization framework for fuel economy was described in [27] by taking into account drivers' needs and priorities. Proposed framework was used in the development of a feedback system which enables the execution of visual commands in order to change the driver's behaviours instantly for decreasing the fuel consumption. On the other hand, eco-driving analysis based on a set of GPS/CANBus data achieved from four vehicles was performed in [37]. According to this analysis, the authors concluded that factors such as high accelerations at high speeds or driving in areas with many traffic lights cause higher fuel consumption. They also indicated that there is no any single set of these factors which may lead to a good fuel economy on its own, but several factors were found where the least fuel-efficient vehicle can improve. In [13], the relation between speed and fuel consumption was utilized for an eco-driving rating. A driving simulator was used to provide consistency regardless of traffic conditions and to make an eco-rating chart. Collected data was divided into trips and for each trip, fuel consumption was evaluated and scored. Rating was given as the average of the trip scores.

Magana and Munoz-Organero [28] proposed the use of a system assisting to learn eco-driving techniques. In the system, first of all, the information such as acceleration, deceleration, vehicle speed, engine load is taken and the profile of the driver is formed. After the driving data are collected under the same road type and under similar traffic conditions, the average threshold value is calculated for each driver taking into account the driver profile, road condition and vehicle characteristics. The assistant system makes real-time recommendations to the drivers via the smartphone interface using these calculated thresholds.

Díaz-Ramirez *et al.* [16] introduced a statistical methodology to identify variables affecting fuel consumption and to evaluate the effects of eco-driving training. Data such as driving errors, driving conditions, driver behavior and driver profiles were collected, evaluated and discussed before and after the training. The study showed that fuel consumption decreased after eco-driving training and driver errors such as overspeed, acceleration and braking, and factors such as average speed were directly related to fuel consumption.

Numerical and symbolic eco-driving feedbacks were provided according to various driving parameters using the smartphone applications given in Dahlinger et al.'s studies [14], [38], and it was found that symbolic feedback provides more fuel savings than numerical feedback. Xiong *et al.* [17] introduced an eco-driving support system with various warnings, such as gear shifting and accelerator pedal operation. Four drivers with different driving experiences were asked to drive with and without the eco-driving support system and it was seen that the eco-driving support system changes the behavior of the drivers positively. In [39], a model was created by using variables such as acceleration, speed, distance (to other vehicles) and cornering speed and hence an eco-driving support system was proposed according to this model. Zhai *et al.* [40] investigated how the fuel efficiency of vehicle platoons can be increased and proposed a control strategy for vehicle platoon travelling on roads with varying slopes. Similarly, an optimization model is derived in [41] for ensuring the shortest transit time in the traffic and hence reducing the energy consumption at the signalized intersections considering the electric platoons.

In the study of Goes *et al.* [18], steps such as eco-driving training, sample collection and data analysis, economic evaluation and environmental evaluation were realized to measure the effects of eco-driving techniques and it was observed that both fuel saving and CO_2 emission were reduced. A simulator system was established in [24] to investigate the eco-driving efficiency of the incentive, the competition with other drivers and the feedback mechanism. In order to maximize the realism of the driving experience and the familiarity of drivers on the road, areas similar to a city and its surroundings were created and various traffic incidents were simulated. While driving, data such as speed, acceleration and deceleration were collected by the simulator. In addition, drivers were subjected to messages left to the driver's choice, including feedback and / or advice and encouragement based on driving conditions. As a result of the study, it was found that the feedback mechanism helps eco-driving and fuel saving more than the incentive and the competition with other drivers.

When we take into account the above discussed noteworthy efforts in the related field, we can see that the big majority of the studies just concentrate on providing and/or assisting eco-driving by warning the drivers instantly during their trips and hence those studies do not consider the comparative evaluation of the eco-driving performances. Such instant or real time measurement on its own may cause improper assessment of the driver performances inside huge driver groups of the same public transportation or any other transportation fleets regarding the conditions that are out of the driver's control. In fact, many of those studies (e.g. [14], [16], [17], [25]–[27], [36], [39]) do not aim at comparing eco-driving performances of different drivers. Further, neither reporting the comparison between performances nor the usage of the previous trips' data retrieved over CANBus for assisting the drivers are considered in those studies. On the other hand, systems proposed in [6], [12], [13] and [37] have similarities with our system in the way of collecting CANBus data, transferring those data from the vehicles to the servers over wireless networks and reporting the eco-driving performances for both single drivers and a group of drivers. Specifically, the system given in [6] and our system use almost the same principle in fair evaluation and reporting of the driver's eco-driving performances. In addition to trip distance and speed, both systems create the comparison groups according to some criteria such as vehicle's route, vehicle's type, trip season and trip time and they report on the performance over the calculations specific for each comparison group. However, our system does not only provide eco-driving reporting and performance comparison out of the vehicles. It also guides the drivers continuously during their trip and helps to control their eco-driving performance instantly within the same comparison group. Real time monitoring and giving feedback on the instant eco-driving performance by comparing with the previous performances of the drivers of the same group are two major contributions of the proposed system in this paper when we take into account the above given eco-driving performance assessment studies. Moreover, we also believe that our system can also help to bridge the gap between the systems solely assists drivers during driving and the other systems just consider the off-line eco-driving benchmarking since it combines the features of these systems and in addition; it brings the benefit of fair evaluation of driver performances with the help of constructing comparison groups.

III. ARCHITECTURE OF THE ECO-DRIVING SYSTEM

The proposed system consists of both hardware and software components deployed on public transport buses and operation maintenance centers of the related transportation companies. The architecture of the system is depicted in Fig. 1. Hardware component in every bus is mainly a validator unit, designed and manufactured by Kentkart Automatic Fare Collection & Vehicle Tracking Systems Company (shortly Kentkart) [42]. The validator is an On-board Unit (OBU) which is originally used for the authentication of both driver and passenger smart cards. In our architecture, it is also connected to the CANBus of the vehicle to achieve instant data (e.g. fuel level, speed) according to Society of Automotive Engineers (SAE) J1939 standard [43]. Achieved CANBus data are combined with the GPRS data and sent over the wireless network to the two remote server computers residing on the bus operation center. One of the servers is an application server and provides evaluation and reporting of eco-driving performances of the drivers while the other server is the database on which CANBus and GPRS data received from the buses are stored.

For the design of the system software, we applied one of the well-known and widely-used software architecture patterns, called Model-View-Controller (MVC) [44]. In MVC pattern, the model simply corresponds to the collection of data used for any process. The model also covers the new data gained after processing the former data. The view can be thought as the user interface which can be used for the exhibition of the model in various formats (such as windows, forms or textual outputs). The model can update the view in case of an alteration on the stored data. Finally, the controller manipulates the model and in many situations it also establishes the relation between the model and many different views. That software architecture provides the abstraction of the model from the user and it enables a user to see the model just via the given interface (view) and use the model over the controller.

In our MVC design (see Fig. 1), the Database on the operation center is the model part. It stores trip data achieved from the buses and other driver records which are all used during the evaluation. Software on the Application Server and the OBU conforms to the controller part. Each OBU transmits data pertaining to route, trip, direction (half progress type (Hpt)), bus id, GPS, etc. to the application server. Eco-driving calculation is performed on the application server by using the retrieved data and the former data stored on the Database. Results are also stored into the database for future usage. OBUs download monthly fuel consumption average data from the application server in order to use them during instant warning of the drivers on their trips.

Finally, user interfaces prepared for the trip operation managers (shortly operators) and drivers constitute the view part. Graphical interface on the server side is web-based and provides displaying the eco-driving performance of the drivers. Operators can use this interface to get following reports on: 1) comparative evaluation both for a single driver and a group of drivers, 2) daily / monthly / yearly driver performance, 3) company-wide consumed fuel per mileage, 4) fuel consumption distribution of the drivers.

User interface inside the buses can be used by the drivers during their trips for checking their instant eco-driving performance. Performance calculation is made according to the average fuel consumption of the previous trips of the

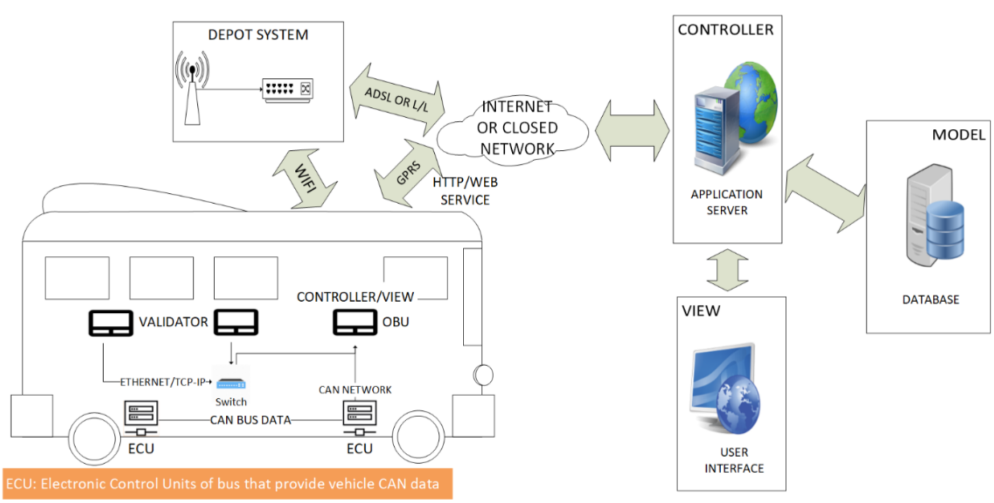


FIGURE 1. Architecture of the system.

same comparison group. The driver is warned as the fuel consumption closes to the average, and the warning is changed when the consumption passes the average. The interface is kept as simple as possible to prevent distraction of the drivers while driving the bus. Instant performance is symbolized with colored figures and the application gives alert in case of low eco-driving performance. Moreover, when the trip ends, the information on traveled distance, fuel consumption and the average fuel consumption are shown on the screen.

IV. METHODOLOGY FOR THE COMPARATIVE EVALUATION OF ECO-DRIVING PERFORMANCE

As indicated in [6], driver independent factors such as vehicle type, vehicle specifications, route direction, and traffic density have a significant effect on the fuel consumption of buses and hence the effect of these factors can be isolated to enable fair comparison of drivers on the basis of fuel consumption. We followed the same principle while constructing our system and created comparison groups in which similar driving conditions are provided for fair evaluation of the drivers' eco-driving performance. By isolating driver independent factors, now fuel consumption can be utilized as a performance indicator in an eco-driving incentive system.

While calculating the eco-driving performance and using achieved value in further interpretation, information collected from both CANBus and OBU of each vehicle are utilized. Fuel consumption, engine speed, vehicle speed and travelled distance constitute the information collected from CANBus. On the other hand, OBU provides vehicle identification number, driver identification number, route code, trip code, direction of route and Global Positioning System (GPS) information.

It is worth indicating that a comparison group does not denote a group of drivers; instead, each group represents a set of driving conditions. When generating the comparison groups for drivers, following items are taken into consideration:

- Route
- Direction
- Bus type (brand / model, specifications such as air conditioned, two axle / tandem axle)
- Season period (summer / winter)
- Weekdays / weekends
- Rush hours of the traffic

Hence, a comparison group is the combination of the same route, same direction, same bus type, same season and same time of day. Driving in one direction of a route is called a "trip" and fuel consumption data gathered for each driver's trip pertaining to a comparison group is evaluated by taking into consideration of other trips in the same comparison group. It can be expected that one driver has more than one trip within the same comparison group, i.e. he drove more than once in the same route with the same bus in the same hour interval of the same day of the week.

Construction of comparison groups enables us to calculate two weighted averages for each driver and utilize those averages for the determination of eco-driving level of each driver. Formulation of the weighted averages given here is introduced in [6] and they are adapted in our work according to the newly created types of the comparison groups discussed above. Let;

d_i: average fuel consumption of a driver in the comparison group i

c_i: average fuel consumption of all drivers' all trips in the same comparison group i

k_i: total mileage (distance) took by this driver in the comparison group i

Using Equation (1), index D, which is the weighted average of one driver's fuel consumption within each comparison group, can be calculated. Using Equation (2), fuel consumption of an average driver can be calculated if the average driver would have driven the same amount of kilometers within the same comparison groups but with all drivers' average fuel consumption. In other words, index C will represent the reference consumption.

$$D = \frac{\sum_{i=1}^{n} k_i d_i}{\sum_{i=1}^{n} k_i} \tag{1}$$

$$C = \frac{\sum_{i=1}^{n} k_i c_i}{\sum_{i=1}^{n} k_i} \tag{2}$$

Reference consumption (C) and every driver's unique consumption (D) are used in the calculation of the economy percentage (E) which in fact represents the level of eco-driving for each driver (see Equation 3). That makes fair comparison of the driver performances possible.

$$E = 100\% - \left(\frac{D}{C}\right) * 100\% \tag{3}$$

Positive E value indicates that the related driver consumed less fuel and drove more economically on average than other drivers inside the same comparison group.

Let us consider the following example which demonstrates the use of the following operations. In this example, we use the data listed in Table 1 which include fuel consumptions and travelled distances calculated / measured both for a specific driver (let us give an id: 70232) and all drivers having trips in the same comparison group. All measured data given here are within a 25-days period and they are taken from the real implementation of the proposed system in the metrobus line of PMS during February 2019. In this example, weekdays and weekends are handled together.

In Table 1, fuel consumptions and travelled distances, which are measured and recorded for our specific driver (70232) inside each comparison group, are shown in the columns "Fuel Consumption – L (Driver)" and "Distance Travelled – km (Driver)" respectively. Likewise, total fuel consumptions and total travelled distances measured from all trips of all drivers according to the same comparison groups are listed in the columns "Fuel Consumption - L (Total)" and "Distance Travelled – km (Total)" as expected. Since the driver 70232 does not have a trip in the comparison groups, namely

TABLE 1. Sample measured / calculated fuel consumptions and travelled distances both for A specific driver and all drivers having trips in the same comparison group.

Comparison Group	Fuel Consumption – L (Driver)	Distance Travelled – km (Driver)	d_i - L/100 km (Driver)	Fuel Consumption - L (Total)	Distance Travelled – km (Total)	c_i - L/100 km (Total)
07:00 – 09:00	0	0	0	2362.5	5107.59	46.26
09:00 – 11:00	0	0	0	2060.5	4488.65	45.90
11:00 – 13:00	0	0	0	1685	3543.87	47.55
13:00 – 15:00	0	0	0	1858.5	3954.91	47
15:00 – 17:00	36.5	77.34	47.19	2105.5	4502.9	46.76
17:00 – 19:00	25	52.62	47.5	2059	4426.09	46.52
19:00 – 21:00	12.5	25.79	48.47	1367	2848.66	47.99

07:00-09:00, 09:00-11:00, 11:00-13:00 and 13:00-15:00, during this 25-days period, related consumption and distance values are all listed as zero in the table.

d_i and c_i values (where i refers to the related comparison group) are calculated by using the following formulas:

$$d_i = \frac{fuel\ consumption\ (driver)}{distance\ travelled\ (driver)} * 100 \tag{4}$$

$$c_i = \frac{fuel\ consumption\ (total)}{distance\ travelled\ (total)} * 100 \tag{5}$$

In order to exemplify these calculations, let us consider the comparison group "15:00-17:00". For this comparison group, we can see from Table 1 that the fuel consumption for our driver is 36.5L while the travelled distance is 77.34 km. Total fuel consumption and travelled distance for all drivers in the same group are 2105.5L and 4502.9 km. Hence, using Equation (4) and Equation (5), d_i and c_i are calculated as follows:

$$d_i = \frac{36.5L}{77.34km} * 100 = 47.19\ L/km$$

$$c_i = \frac{2105.5L}{4502.9km} * 100 = 46.76\ L/km$$

Similar to this comparison group, these calculations should be performed for all remaining comparison groups. These calculated d_i and c_i values are also shown in Table 1 inside the columns entitled "d_i- L/100 km (Driver)" and "c_i - L/100 km (Total)" for each comparison groups (e.g. see the line for "15:00 – 17:00")

Now, it is the time for calculating the economy percentage. First, D and C values are calculated by using the equations (1) and (2):

$$D = \frac{77.34 * 47.19 + 52.62 * 47.5 + 25.79 * 48.47}{77.34 + 52.62 + 25.79} = 47.51\ L/100\ km$$

$$C = \frac{77.34 * 46.76 + 52.62 * 46.52 + 25.79 * 47.99}{77.34 + 52.62 + 25.79} = 46.88\ L/100\ km$$

Finally, the economy percentage is calculated for our driver by using Equation (3):

$$E = 100\% - \left(\frac{47.51}{46.88}\right) * 100\% = -1.35\%$$

As previously mentioned, the economy percentage represents the level of eco-driving for each driver. In this example, our driver‘s economy percentage is −1.35%. It means that the related driver consumed more fuel and drove less economically on average than other drivers within this group. Since the calculations are made within a comparison group, some drivers may have a good performance while some may have a bad performance. The performance of a specific driver is determined in relative with the whole group. Hence, if the performance of all drivers is equal in a comparison group (e.g. all have good or bad performances), the calculated economy percentage will be zero.

Economy percentage reports are automatically generated in our proposed system daily, monthly and yearly for each driver by using the method given above.

V. IMPLEMENTATION

After the system architecture was constructed and CANBus data from the field (from daily working buses) were successfully collected, the data were started to be interpreted for the eco-driving performances.

The equipments previously introduced in Section 3 were installed into 64 public buses working in PMS to measure drivers' performance. This metrobus system is used by approximately 250000 passengers every day. The following subsections discuss how the system is implemented and used via provided interfaces. The same measurement period (01 - 31 January 2019), the same driver (with id: 70232) and the same line / direction are considered to enable traceability and consistency during demonstrations. Bus type (brand and model) is also same for the whole implementation. In some of the following example reports, the number of buses may differ. However, this does not affect the related eco-driving group since comparison groups are abstract from the number of buses.

A. COLLECTING DATA AND CALCULATING ECO-DRIVING PERFORMANCE

The software inside the OBU of each bus enabled the collection of data such as fuel consumption, travelled distance, and vehicle speed. Every 10 seconds, data collected from CANBus were recorded on the local disk of OBU, and every 30 minutes, these data were sent to main database server by calling the web server via GPRS. The time interval between each OBU recording was defined as 10 seconds since we examined that CANBus value changes in odometer and fuel consumption do not have an effect on the precision of the calculations made when this interval is below 10 seconds. So, the collection period was chosen 10 seconds both to reduce the size of the recorded data and to retrieve sufficient data needed for the calculations. It is worth indicating that when a trip is over, a metrobus driver terminates the trip operation and any remaining CANBus data, which were not transferred yet, are immediately sent to the main database. This is the case when the total trip duration is more than the multiples of 30 minutes. The trip information received from the automatic toll collection system was transferred to the database via another service. Listing 1 shows the algorithm for this process.

Algorithm Collecting CANBus data

```
1:  procedure GETCANBUSDATA
2:      connect to CANBus
3:      set elapsed time to 0
4:      while true do
5:          if elapsed time is equal or greater than 30 min. then
6:              send saved CANBUS data to the main database
                server via GPRS
7:              set elapsed time to 0
8:          end if
9:          get CANBus data from CAN Network and save
10:         sleep 10 sec.
11:         add 10 sec. to the elapsed time
12:     end while
13: end procedure
```

LISTING 1. The algorithm of data collection.

In line 2 of the algorithm, the application connects to the CANBus. Collected data are sent to the database server via GPRS if more than 30 minutes elapsed and then timer resets (lines 5-8). Data are received form CANBus and saved into OBU in line 9. To receive the next data and save them again, the application needs to wait (lines 10-11).

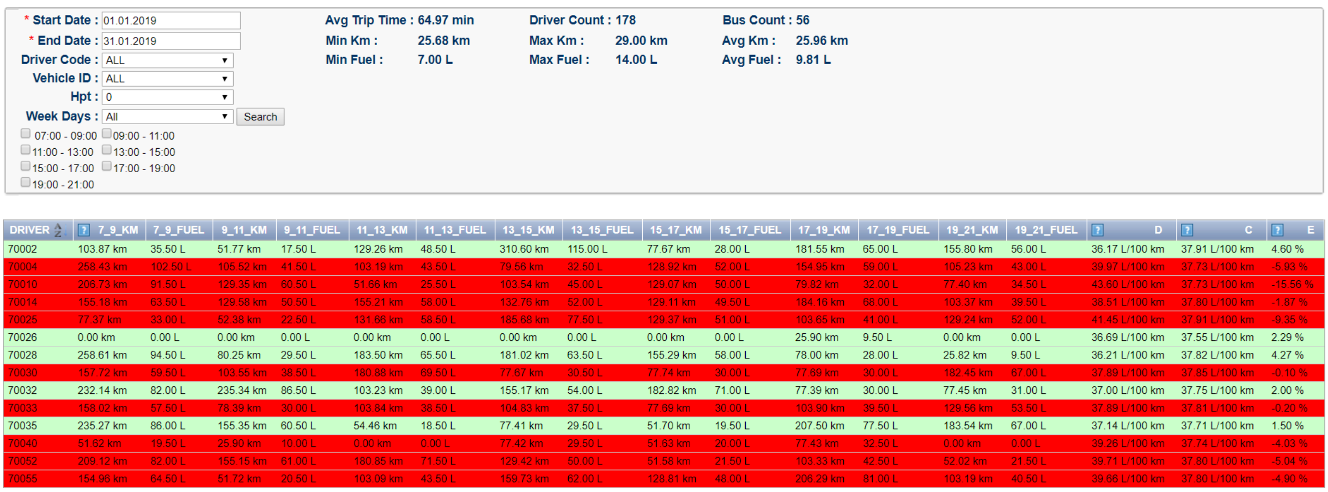
On the application server (see the architecture given in Section 3), the data received from each bus and the trip information were used to automatically calculate the eco-driving performances of all drivers by applying the methodology discussed in Section 4. Several reports were created to show the results of the calculations. In these reports, information of fuel consumption, distance coverage and driving performance of a specific driver or the whole metrobus system can be seen. In the following subsections, these reports are described.

B. ACTION REPORT

Action report is the main and perhaps the most important report since it provides the eco-driving performance analysis of the drivers. Fig. 2 shows a screenshot taken from the application where an action report is displayed for the calculated eco-driving performance of the bus drivers with including their travelled distance and fuel consumptions.

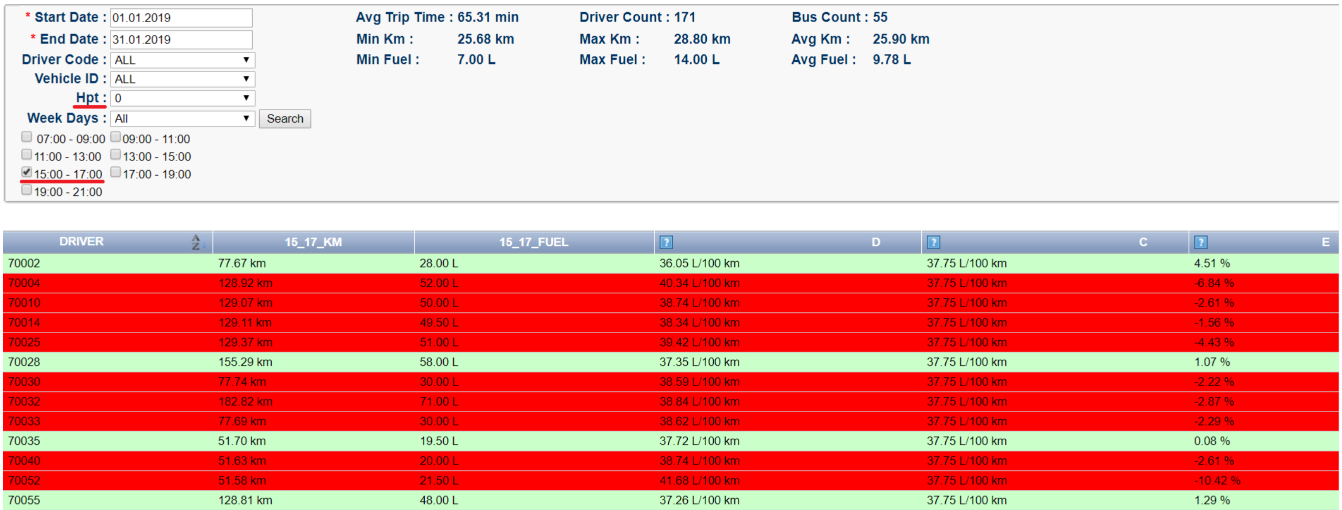
Taking into consideration C, D, E values described in Section 4, the rightmost columns in the given table show these values for each driver's eco-driving performance. Remaining columns show the fuel consumptions and the travelled distances within two-hour periods for the given start and end dates.

The information in column D shows the eco-driving performance of a driver in the comparison group while column C shows the average performance of that comparison group. If no comparison group is defined while searching, then comparison groups of the drivers are determined for each driver individually and values are calculated for that comparison group. In column E, the performance value of a driver in that



DRIVER	7_9_KM	7_9_FUEL	9_11_KM	9_11_FUEL	11_13_KM	11_13_FUEL	13_15_KM	13_15_FUEL	15_17_KM	15_17_FUEL	17_19_KM	17_19_FUEL	19_21_KM	19_21_FUEL	D	C	E
70002	103.87 km	35.50 L	51.77 km	17.50 L	129.26 km	48.50 L	310.60 km	115.00 L	77.67 km	28.00 L	181.55 km	65.00 L	155.80 km	56.00 L	36.17 L/100 km	37.91 L/100 km	4.60 %
70004	258.43 km	102.50 L	105.52 km	41.50 L	103.19 km	43.50 L	79.56 km	32.50 L	128.92 km	52.00 L	154.95 km	59.00 L	105.23 km	43.00 L	39.97 L/100 km	37.73 L/100 km	-5.93 %
70010	206.73 km	91.50 L	129.35 km	60.50 L	51.66 km	25.50 L	103.54 km	45.00 L	129.07 km	50.00 L	79.82 km	32.00 L	77.40 km	34.50 L	43.60 L/100 km	37.73 L/100 km	-15.56 %
70014	155.18 km	63.50 L	129.58 km	50.50 L	155.21 km	58.00 L	132.76 km	52.00 L	129.11 km	49.50 L	184.16 km	68.00 L	103.37 km	39.50 L	38.51 L/100 km	37.80 L/100 km	-1.87 %
70025	77.37 km	33.00 L	52.38 km	22.50 L	131.66 km	58.50 L	185.68 km	77.50 L	129.37 km	51.00 L	103.65 km	41.00 L	129.24 km	52.00 L	41.45 L/100 km	37.91 L/100 km	-9.35 %
70026	0.00 km	0.00 L	0.00 km	0.00 L	0.00 km	0.00 L	0.00 km	0.00 L	0.00 km	0.00 L	25.90 km	9.50 L	0.00 km	0.00 L	36.69 L/100 km	37.55 L/100 km	2.29 %
70028	258.61 km	94.50 L	80.25 km	29.50 L	183.50 km	65.50 L	181.02 km	63.50 L	155.29 km	58.00 L	78.00 km	28.00 L	25.82 km	9.50 L	36.21 L/100 km	37.82 L/100 km	4.27 %
70030	157.72 km	59.50 L	103.55 km	38.50 L	180.88 km	69.50 L	77.67 km	30.50 L	77.74 km	30.00 L	77.69 km	30.00 L	182.45 km	67.00 L	37.89 L/100 km	37.85 L/100 km	-0.10 %
70032	232.14 km	82.00 L	235.34 km	86.50 L	103.23 km	39.00 L	155.17 km	54.00 L	182.82 km	71.00 L	77.39 km	30.00 L	77.45 km	31.00 L	37.00 L/100 km	37.75 L/100 km	2.00 %
70033	158.02 km	57.50 L	78.39 km	30.00 L	103.84 km	38.50 L	104.83 km	37.50 L	77.69 km	30.00 L	103.90 km	39.50 L	129.56 km	53.50 L	37.89 L/100 km	37.81 L/100 km	-0.20 %
70035	235.27 km	86.00 L	155.35 km	60.50 L	54.46 km	18.50 L	77.41 km	29.50 L	51.70 km	19.50 L	207.50 km	77.50 L	183.54 km	67.00 L	37.14 L/100 km	37.71 L/100 km	1.50 %
70040	51.62 km	19.50 L	25.90 km	10.00 L	0.00 km	0.00 L	77.42 km	29.50 L	51.63 km	20.00 L	77.43 km	32.50 L	0.00 km	0.00 L	39.26 L/100 km	37.74 L/100 km	-4.03 %
70052	209.12 km	82.00 L	155.15 km	61.00 L	180.85 km	71.50 L	129.42 km	50.00 L	51.58 km	21.50 L	103.33 km	42.50 L	52.02 km	21.50 L	39.71 L/100 km	37.80 L/100 km	-5.04 %
70055	154.96 km	64.50 L	51.72 km	20.50 L	103.09 km	43.50 L	159.73 km	62.00 L	128.81 km	48.00 L	206.29 km	81.00 L	103.19 km	40.50 L	39.66 L/100 km	37.80 L/100 km	-4.90 %

FIGURE 2. Action report.



DRIVER	15_17_KM	15_17_FUEL	D	C	E
70002	77.67 km	28.00 L	36.05 L/100 km	37.75 L/100 km	4.51 %
70004	128.92 km	52.00 L	40.34 L/100 km	37.75 L/100 km	-6.84 %
70010	129.07 km	50.00 L	38.74 L/100 km	37.75 L/100 km	-2.61 %
70014	129.11 km	49.50 L	38.34 L/100 km	37.75 L/100 km	-1.56 %
70025	129.37 km	51.00 L	39.42 L/100 km	37.75 L/100 km	-4.43 %
70028	155.29 km	58.00 L	37.35 L/100 km	37.75 L/100 km	1.07 %
70030	77.74 km	30.00 L	38.59 L/100 km	37.75 L/100 km	-2.22 %
70032	182.82 km	71.00 L	38.84 L/100 km	37.75 L/100 km	-2.87 %
70033	77.69 km	30.00 L	38.62 L/100 km	37.75 L/100 km	-2.29 %
70035	51.70 km	19.50 L	37.72 L/100 km	37.75 L/100 km	0.08 %
70040	51.63 km	20.00 L	38.74 L/100 km	37.75 L/100 km	-2.61 %
70052	51.58 km	21.50 L	41.68 L/100 km	37.75 L/100 km	-10.42 %
70055	128.81 km	48.00 L	37.26 L/100 km	37.75 L/100 km	1.29 %

FIGURE 3. Action report taken after selecting the comparison group criteria.

Driver Code	Bus ID	Model	Type	Trip Start	Trip End	Route Code	Odometer Diff	Fuel Diff
70232	20002	Volvo 1 2012	Passenger Bus Metro	01.01.2019 12:16:19	01.01.2019 13:20:57	90001	25.991 km	9 L
70232	20004	Volvo 1 2012	Passenger Bus Metro	01.01.2019 09:44:13	01.01.2019 10:48:21	90001	28.361 km	9 L
70232	20001	Volvo 1 2012	Passenger Bus Metro	01.01.2019 07:22:03	01.01.2019 08:26:38	90001	25.939 km	9.5 L
70232	20038	Volvo 1 2012	Passenger Bus Metro	02.01.2019 07:59:15	02.01.2019 09:02:28	90001	25.865 km	8 L
70232	20025	Volvo 1 2012	Passenger Bus Metro	02.01.2019 13:09:55	02.01.2019 14:14:31	90001	25.77 km	10 L
70232	20025	Volvo 1 2012	Passenger Bus Metro	03.01.2019 10:29:20	03.01.2019 11:34:33	90001	25.902 km	8.5 L
70232	20025	Volvo 1 2012	Passenger Bus Metro	03.01.2019 12:59:28	03.01.2019 14:04:47	90001	25.808 km	9.5 L
70232	20013	Volvo 1 2012	Passenger Bus Metro	05.01.2019 17:32:38	05.01.2019 18:38:28	90001	25.842 km	10.5 L
70232	20013	Volvo 1 2012	Passenger Bus Metro	05.01.2019 19:54:23	05.01.2019 21:00:42	90001	25.879 km	9.5 L
70232	20018	Volvo 1 2012	Passenger Bus Metro	06.01.2019 20:04:17	06.01.2019 21:10:56	90001	25.816 km	10.5 L

FIGURE 4. Summarized trip information of a driver.

comparison group is shown. According to the column E, eco-driving performance of the drivers are colored as green or red meaning good or bad performance respectively.

Comparison group criteria can be changed by using the filters placed at top of the report. For instance, to see the performances of drivers who work between 15:00 – 17:00 and "on forward direction", appropriate filters can be selected. Hence, the action report now shows the performances of the drivers who only work under these conditions. Fig. 3 shows the selection example (see underlined Hpt and hour intervals). Zero value for Hpt means "on forward direction"). It is worth indicating that all the values in column C (Fig. 3) are same since a comparison group is now defined.

In addition, summarized trip information of a specific driver for a date range can be listed by only selecting this driver's code. The result shows the trip information like trip start/end time, traveled distance (odometer diff.), fuel consumption (fuel diff.) etc. between the given dates. An example for such a report can be seen in the screenshot given in Fig. 4. Moreover, eco-driving performance information for the selected comparison group and any remaining summarized information are also shown at the right top of this report.

In Fig. 4, the report for the driver with code 70232 is shown. According to this report, index D value calculated for this driver (37.92 L/100 km) is more than the reference consumption value of the comparison group, represented with index C (37.86 L/100 km). Hence, the economy percentage (E) is calculated as −0.17% for the driver 70232, which means the selected driver consumed more fuel and drove less economically on average than the other drivers in the same group.

C. DRIVER REPORT

Driver report (Fig. 5) is the graphical representation of the monthly driving performance of a specific driver. Graphics in the report show the number of drivers according to the performance values.

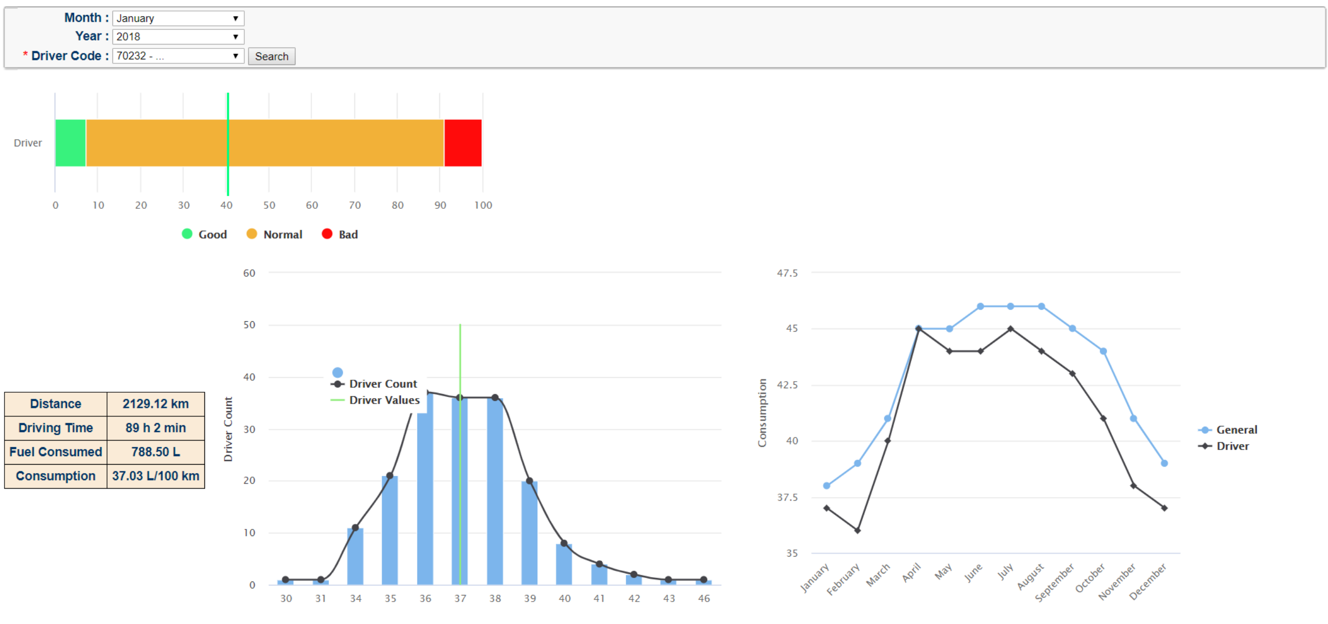


FIGURE 5. Driver report.

The graphic placed at the bottom middle shows the performance values for the chosen month. Horizontal axis shows average fuel consumption while vertical axis shows the number of drivers. The vertical green line indicates the range in which the selected driver's performance value falls. Based on this graphic, it is clearly seen that the driving of the selected driver (70232) is more economical than approximately 60% of the drivers for the selected period.

The graph on the rightmost side of Fig. 5 shows the eco-driving performance comparison of the selected driver (depicted with the black color) with the average of other drivers (given in the blue color) for all months. According to the graph, we can see that the selected driver consumed less fuel and drove more economical in comparison with the others throughout the year since the black curve is generally under the blue curve. For instance, the selected driver's average fuel consumption is 44 L/100 km in June while the group's average is 46 L/100 km in the same month.

Colorful horizontal bar shows the percentage distribution of the eco-driving performance. The standard deviation value, calculated via Gaussian distribution, is applied to the average fuel consumption data and the upper and lower limits of the average performance are determined. According to upper and lower limits, driver count is calculated and represented in the percentage distribution chart. These performances are classified as good, average and bad. The red part represents the percentage of the drivers with bad performance, orange for the percentage of the average performances and the green for the percentage of the good performances. The vertical green line indicates where the selected driver (70232) resides on the percentage distribution. The selected driver's percentage is approximately at 40%. It means that the driver 70232 drove more economically than the remaining 60% of all drivers.

Finally, the selected driver's total fuel consumption, total driving time, total distance travelled, and average fuel consumption are all listed on the bottom left of the report.

D. COMPARISON GRAPHICS

Graphics screen of the application displays the average fuel consumption of each driver between given dates with a bar chart (Fig. 6). On the report, the x-axis shows driver code and the y-axis shows the fuel consumption of the drivers. In fact, this report works similar to the action report and it also supports the comparison group filtering and the performance value calculation. However, it facilitates the comparison with bar charts. For instance, according to the graph in Fig. 6, the driver 70199 has the minimum fuel consumption while the driver 70238 has the maximum within the given comparison group.

When a driver is chosen from the driver list, this driver's average fuel consumption (hourly, daily or weekly) can be displayed again in bar charts (Fig. 7).

E. COMPANY REPORT

The company report visually shows the summarized monthly data for the travelled distance, fuel consumption and total travel time. The report consists of two parts. In the first part, the data for the selected month is shown in tabular form. In addition to this table, the average fuel consumption information of the company for the relevant month is added. The table is positioned above the charts. In the second part, total fuel consumption, total distance traveled, total journey time, and average fuel consumption information for all months are shown as separate line graphs (Fig. 8).

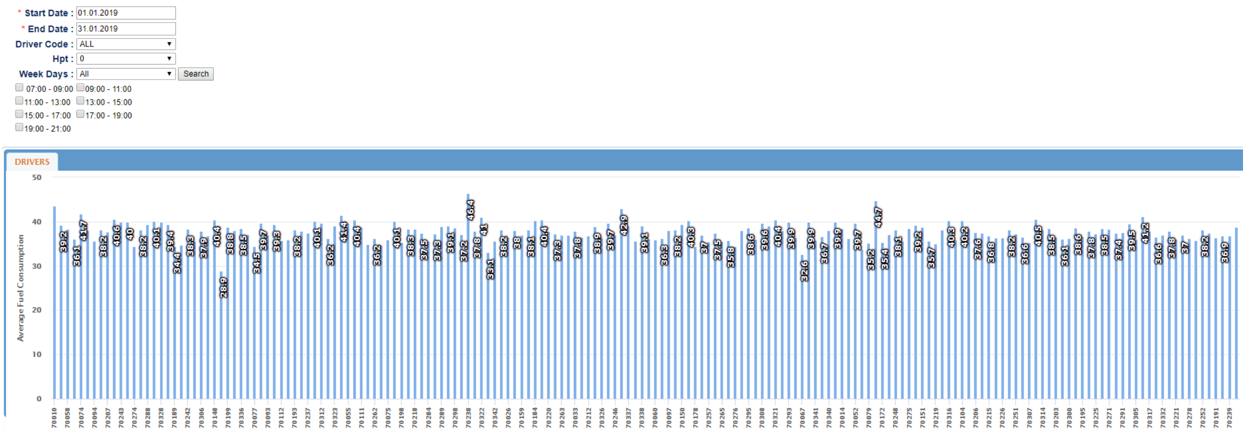


FIGURE 6. Comparison with bar charts.

FIGURE 7. The chart showing the hourly fuel consumption of a selected driver.

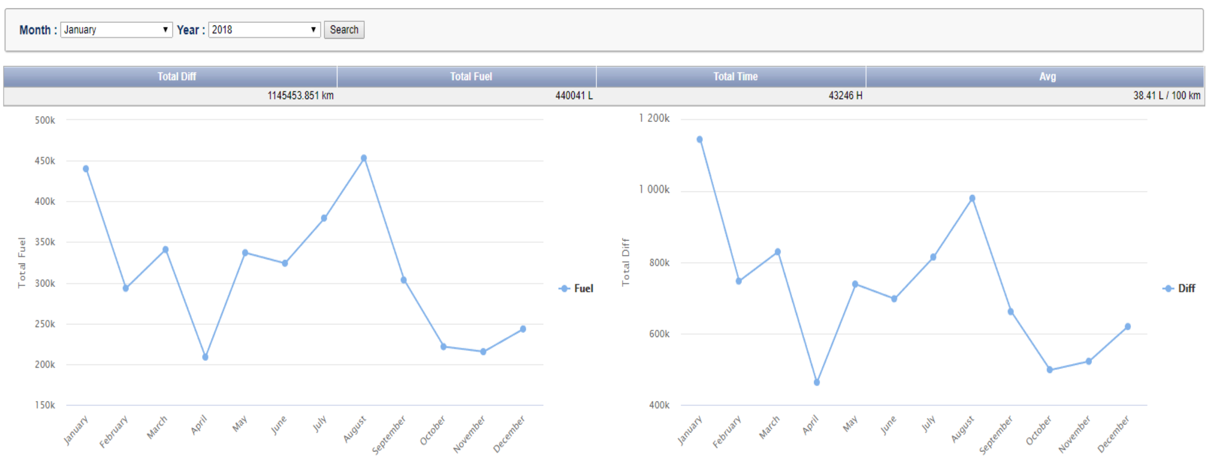


FIGURE 8. Company report.

F. PERFORMANCE DISTRIBUTION

In Fig. 9, the colored list, placed at the right side, shows the average fuel consumption of the drivers in a comparison group. Coloring is realized according to the eco-driving performance distributions. The standard deviation value, calculated via Gaussian distribution, is applied to the average fuel consumption data and the upper and lower limits of the average performance are determined. Red, orange and

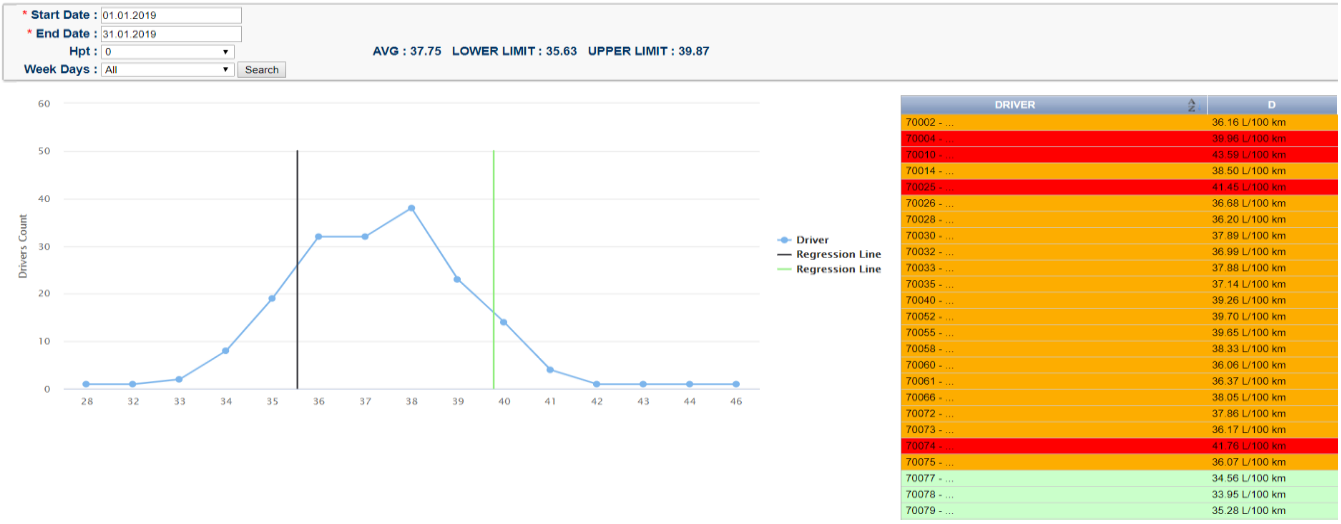


FIGURE 9. Driver performance distribution report.

green colors indicate bad, average and good performances respectively.

The list in the right is also used to create the line graph (on the left of Fig. 9) to show the distribution of average fuel consumptions over the number of drivers. Two vertical line divide the distribution into three areas on the graphic. The left side of black vertical line is the area representing the good driving performances, the area between black and green lines for average usage and the right side of the green line depicts the bad driving performances.

Comparison group can also be filtered by selecting the route or the type of days (weekdays or weekends).

G. ECO-DRIVING FEEDBACK SYSTEM

One of the novel features of our system is to assist the bus drivers during their trip and instantly warn them about their eco-driving performances in comparison with the whole assessment group. Hence, a driver can manage and change his/her driving style in real-time to have better eco-driving performance. For this purpose, a feedback interface was implemented and deployed into the vehicles of PMS.

During a trip, CANBus data is gathered and analyzed to automatically calculate the driver's eco-driving performance. The screen on the driver panel provides instant feedback on the driving performance by comparing this calculated value with the value which is received from the remote server for the eco-driving performance of the whole comparison group including its lower and upper limits according to the standard deviation.

Three different feedback symbols (Fig. 10) are available on the screen based on the calculated performance value. As expected, the color scheme is defined to be good performance in green (if the calculated performance is less than the lower limit of eco-driving performance of the related comparison group), average performance in orange (if the calculated performance is equal or greater than the lower limit and less than upper limit), and poor performance in red (if the calculated performance is equal or greater than upper limit). When the driver's performance is currently equal to the average of all drivers in the group, the driver's performance will also be the average. At this condition, the symbol with the orange color is shown to the driver. In Fig. 11, the appearance of these feedback symbols on the screen of the real driver panel can be seen.

FIGURE 10. Feedback symbols to show real-time eco-driving performances.

FIGURE 11. Eco-driving feedback symbol is shown on the right side of the driver panel.

VI. EVALUATION

The use of the proposed eco-driving system in PMS also enabled us to evaluate 1) the system's effect on reducing fuel consumption of the metrobuses and 2) the adoption of the system by the drivers and the operators.

The eco-driving system was run in 15-months period between January 2018 and April 2019. Table 2 lists some of the monthly average fuel consumptions achieved during utilization of the system.

TABLE 2. Some monthly average fuel consumptions gained after using the eco-driving system.

Period Average	Fuel Consumption
2018/01	38.62 L/100 km
2019/01	37.60 L/100 km
2018/02	39.32 L/100 km
2019/02	38.33 L/100 km
2018/03	41.42 L/100 km
2019/03	39.54 L/100 km

Comparing the same monthly periods of the years 2018 and 2019, the saving in the fuel consumption is approximately 2.64%, 2.51% and 4.53% for the months January, February and March respectively. The same months of the year were evaluated considering the seasonal effects. Since the monthly fuel consumptions after April 2019 were not ready at the time of writing this paper, the comparison of the remaining months (e.g. 2018/11 vs. 2019/11) could not be performed. However, this comparison of 3-months is promising in the sense that an annual projection will result up to approximately 5% fuel saving. This fuel saving is naturally expected to increase as the system continues to operate.

In order to assess the adoption of the users, we conducted two separate surveys; one for the metrobus drivers and the other for the operators (the supervisors of these drivers) using the remote monitoring facilities of the system. Based on our previous studies (e.g. [45]–[48]) performed for the assessment of various industry-scale system implementations, we believe that such a survey-based evaluation enable us to receive the opinions of the system users and help to determine whether the drivers and the operators found the system useful. For scoring in the surveys, Likert Scale was used and the participants answered the questions by rating as Great (5), Good (4), OK (3), Bad (2) and Very Bad (1).

40 drivers and 12 operators (supervisors) were voluntarily participated into this survey. After training on the new system, the drivers were requested to drive the vehicles by paying attention to the real time feedback symbols appeared inside the driver panels of the buses (introduced in Sect. 5.7). At the end of a 12-months period system use, the drivers were asked to answer the following survey questions by scoring with the scale given above.

1) Do you think the eco-driving system is useful?
2) Do you find the feedback interface presented in the driver panel comprehensible and handy?
3) Does the feedback interface presented in the driver panel assist you and give feedbacks towards your drive correctly?
4) Do you continuously obey warnings shown by the feedback symbols inside the driver panel?
5) Does the feedback interface presented in the driver panel help you to improve yourself on eco-driving?

The distribution of the answers given by the metrobus drivers for each question is listed in Table 3.

TABLE 3. Number of scores given by the drivers for the whole survey.

	Great	Good	OK	Bad	Very Bad
Question 1	11	20	7	1	1
Question 2	9	28	3	0	0
Question 3	13	17	7	2	1
Question 4	20	12	7	1	0
Question 5	12	19	9	0	0

According to the achieved survey results, 31 out of 40 drivers (77.5%) found the eco-driving system useful when we consider the answers "Great" and "Good" as the positive responses. Based on the scores given for the second question, it seems that the vast majority of the drivers (92.5%) did not have any difficulties with both understanding and using the feedback interface of the driver panel. Moreover, 75% of the drivers confirmed that the new panel provided correct feedbacks on eco-driving and helped during trips when we take into account the scores given for the third question. These results for the questions 2 and 3 are encouraging since, in fact, they clearly revealed that the new system was adopted by most of the drivers and also the drivers approved how the system facilitated eco-driving. Again considering "Great" and "Good" responses as positive for the fourth question, 32 out of 40 drivers stated that they paid attention to the real time warnings appeared on the driver panel for eco-driving. Finally, 77.5% of the participants agreed on the new system helped improving their eco-driving performance. This result is another indicator that the drivers found the system beneficial.

The operators, managing the drivers, used the monitoring features of the eco-driving system (discussed in sections between 5.2 and 5.6) and they experienced how the eco-driving performances of the drivers inside the comparison groups are reported for their assessment. These operators were requested to complete another survey including the following questions:

1) Does the eco-driving monitoring system facilitate your assessment on the driving performances of the drivers?
2) Do the reports generated by the system correctly reflect the eco-driving performances of the drivers?

3) Do you advise the drivers based on the reports showing their driving performances?
4) Do you observe any progress in the driving performances of the drivers with the new system?
5) Do you observe any decrease in the costs with using the new eco-driving system?

Number of scores given for all questions by the fleet operators are listed in Table 4.

TABLE 4. Number of scores given by the operators for the survey.

	Great	Good	OK	Bad	Very Bad
Question 1	3	7	2	0	0
Question 2	4	7	1	0	0
Question 3	4	6	2	0	0
Question 4	3	5	4	0	0
Question 5	5	5	2	0	0

10 out of 12 operators participating the survey responded with "Great" or "Good" for the first question which means most of the operators think that the system helps them on analyzing and assessing the eco-driving performances of the metrobus drivers. Similarly, when we consider the "Great" and "Good" again as the positive responses, almost all of the participants confirmed that the reporting facilities of the system are successful in showing the eco-driving performances. Taking into account the responses for the third question, more than 80% of the operators indicated that they gave feedback to the drivers and advised based on their eco-driving performance. In addition, approximately 67% of the operators thought that their feedbacks affected the drivers in improving their eco-driving. That slight decrease in the number of positive replies for the fourth question is, in fact, expected since the monitoring features of the system are used by the operators just for giving feedbacks without any enforcements. Hence, the drivers are free to care about the feedbacks received by the operators on their eco-driving performances. Besides, the drivers are mostly confident that their eco-driving performances were improved with the new system as can be seen from their answers given to the fifth question in the drivers' survey.

Although the comparisons on the monthly average fuel consumptions (see Table 2) already showed that the system provides fuel saving, we also wanted to know whether the operators also examined a decrease in the costs (mostly originated from fuel expenses) with using the eco-driving system. Based on the scores received for the fifth question, approximately 83% of the operators agreed that the new system contributed to reduce costs in maintaining the fleet. Remaining 17% also replied to this question with "OK" which means none of the operators thought that the system did not support savings.

Finally, it is worth indicating that the monitoring features of the new eco-driving system are being used by the metrobus company only to enhance the motivation of the drivers in the way of eco-driving. Naturally, there always exist drivers showing relatively bad eco-driving performance within the comparison groups when we take into account the applied methodology (discussed in Section 4) to determine the performances. However, these drivers may show better performance in other comparison groups with changing routes, directions, work hours, etc. The evaluation results show that the fair evaluation of the drivers with the encouragement of improving their eco-driving performances provides both their satisfaction and cost saving in the implemented system.

VII. CONCLUSION

An eco-driving system has been introduced in this paper. The system supports the fair evaluation of bus drivers' eco-driving performances with constructing comparison groups each made of a set of driving conditions, calculating weighted averages for each driver and utilizing those averages for the determination of eco-driving levels. In addition to monitoring the drivers' eco-driving performances, in-vehicle components of the system guide the drivers during their trips on improving their eco-driving with real-time warnings. The proposed system contributed to the previous efforts by enabling the remote monitoring of eco-driving performances together with instantly providing feedbacks inside the driver panels during trips as the result of comparing the previous performances of the drivers in the same group.

The proposed system was successfully deployed in one of the biggest public metrobus systems. Based on the 15-months evaluation period, it has been determined that the system helped reducing the fuel consumption of the buses. Adoption of the system by both drivers and operators has been confirmed with the conducted surveys. Drivers mostly found the system useful and agreed on their eco-driving performances were improved with the real-time feedback given by the system during their trips. The operators appreciated the monitoring features of the system on analyzing and assessing the eco-driving performances of the drivers in the bus fleet.

In our future work, we plan to broaden the application area of the proposed system with other fleets (e.g. operating in logistics) to analyze the effects of new factors encountered in these domains on eco-driving. Currently, mass-transit systems of Kentkart company [42] are being used in more than 25 cities of Turkey and more than 10 worldwide locations in various countries. That provides a good chance of applying our eco-driving method on another mass-transit system if agreed with the related local transportation company. However, it is also possible to implement the system for any other company. Another future work will be diversifying the items and driving conditions during the formalization of the comparison groups. For instance, routes in the metrobus line can be separated into sub-routes according to physical structures of the roads which leads to increase the number of the comparison groups.

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