How Much Money Can Be Saved? Impact of Driving Style on Bus Fuel Consumption

M. Rohani and R. Buhari

Abstract This paper presents the influences of driving style on bus fuel consumption. The study conducted was based on real data collected in Southampton UK using two research buses. This study has confirmed that the aggressive driving consumed significantly higher fuel consumption than economic and normal driving. It was estimated that, driving shifting from aggressive toward economic style can reduce approximately 16.86 l diesel fuel consumption and save about GBP 25.46 daily for a single bus.

Keywords Component · Formatting · Style · Styling

1 Introduction

There is no standard definition of eco-driving that existed in the literature. Available definitions of eco-driving suggested by a previous researchers tend to relate the driving behaviour with fuel economical. For example, ECOWILL [1] describes eco-driving as a smarter and fuel-efficient driving that represents a new driving culture. Eco-driving makes the best use of advanced vehicle technologies and improves road safety. Other researchers, Baltuti [2] describes the 'eco' in eco-driving as a driving style which takes ecologic and economic benefit considerations. The ecological and economical benefits are significantly reduced fuel consumption and green house effect.

Boriboonsomsin et al. [3] suggested the eco-driving as one of the conservation programs that can be very cost effective. Various advice such as shifting to a higher gear as soon possible, maintaining steady speeds, anticipating traffic flow,

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accelerating and decelerating smoothly, keeping the vehicle and keeping the vehicle in good maintenance through the eco-driving tips are aimed to minimise fuel consumption while driving [3].

Many eco-driving projects conducted to date concentrate on providing eco-driving advice, by mean of training to drivers. For example, CIVITAS [4], a bus company in Tallinn, provides eco-driving training for its drivers. The bus company looks an eco-driving as an element to address problems such as pollution, noise, emission and also to improve the company's passenger satisfaction in comfort and safety. In Australia, a pilot study conducted by Rose and Symmons [5] suggested that heavy duty bus driver who attended the full eco-driving training significantly use lower fuel consumption than the driver who did not attend the training.

Other methods applied for eco-driving monitoring is by the application of a special device. For example, Boriboonsomsin et al. [3] found that an on-board eco-driving device has made an improvement in driver behaviour. The use of the device is to make real-time instantaneous fuel consumption as a result from driving behaviour available to be seen by the driver. The fuel data guides the driver to a more economical driving. As a result average fuel economy improves 6 % on city streets and 1 % on highway.

Stagecoach is a bus company in the UK that invested multi-million pound sterling on eco-driving technology [6]. The investment includes the installation of GreenRoad system in 6,500 buses in Scotland, England and Wales. The scheme is targeted to reduce 4 % fuel consumption and accident rate. GreenRoad system used is an on-board system that provides driver with real-time feedback on their driving style. The information provided includes speed, braking, acceleration, lane-handling and turning. Further to the system, the Stagecoach also is one of the first UK bus companies that applies a new GreenRoad's new engine idling solution. This new system is able to monitor specific trips by identifying unnecessary idling based on agreed thresholds.

Foot-LITE is an ongoing UK-based project on eco-driving that provide both online and offline feedback for driver. The project is aimed to address an important parameter in vehicle driving such as engine speed, gear choice and throttle position [7]. In the system proposed, driving feedback will be delivered to the driver in order to promote the take up and retention of eco-driving efficient and safe driver behaviour. The system is also able to monitor driver's behaviour, road network conditions and vehicle metrics [7]. The advance system in Foot-LITE project analyse all gathered data via an on-board device. From the analysis driver will be provided all related information, advice and useful reminders.

Bus driver eco-driving substantially benefit to bus operational cost, environment and safety. Specifically, Vogel [8] list the advantages of eco-driving as follows;

- More cost-effective driving
- Less pollution
- Quicker journeys
- Greater road safety

- Less wear and tear on vehicle parts
- Longer life-span of tires
- More driving comfort

In Europe, eco-driving program has started to establish more seriously in 2001 [9]. The program is partly financed by the former European Energy Efficiency Programme (EEEP). It is co-ordinated by the Austrian Energy Agency (AEA). The project was targeted at specific groups of driver and successfully reduced 5–20 % fuel consumption in various countries such as German, and Switzerland.

2 Research Setting and Approach

2.1 Research Aim

The objective of this research is to compare the bus fuel consumption between different driving styles (economic, normal and aggressive). It is also estimate how much saving can be attained from driving style changes.

2.2 Research Approach

This study was conducted in urban driving environment in Southampton, UK areas. During the period of data collection, 54 UniLink bus drivers driving styles were monitored within the same route continuously during bus service operation hours. However, for the analysis purposes, the focus has been given only on instantaneous driving style 10 s after the driver leaving from stationary at selected bus stops, signalized intersections and roundabout. The selection of these 10 s data is based on the highest rate of acceleration and fuel consumption observed from the real data that strongly considered for research analysis.

2.3 Research Equipment and Data

Data used in this study was collected on-board using 2 research buses; a Mercedes-Benz Citaro and Scania Omnicity which were equipped with an automatic transmission of 6 and 5 gears respectively. The engines of the buses are also different. The Mercedes Citaro complies with Euro 4 emission standard while Scania Omnicity complies Euro 5 and EEV. Both buses were operated by UniLink, a bus company from Southampton, UK.

On-board device, a Portable Vehicle CANBus Systems (PVCS) was installed on research buses to collect real time data. The PVCS iLogCAN data logger developed by Squarell technology is designed with a Fleet Management System (FMS) interface to monitor a CANbus activity under actual on-road driving. This special device was used to capture bus location, speed, and the behaviour of the driver who controls the accelerator pedal as well as the instantaneous fuel consumption.

Seven study sites selected in this study are 3 bus stops, 3 signalised intersections and 1 roundabout. For all study sites the general characteristics of the site and data collected are summarised as follow:

- On each site, the road segment has one lane for both directions and is fairly flat with a minor grade.
- The traffic condition between sites in the same group is fairly similar.
- The bus stop type for each study site is ‘bus stop marking on the carriageway’, which is referred as ‘bus cage’.
- Only behaviour from passing straight ahead at signalised intersection is included in the data analysis at such intersections (no right or left turn is counted).
- Only behaviour from passing through is included in the data analysis at such roundabout.

2.4 Clustering driving Style

Bus driver driving behaviours data were clustered into three driving styles; aggressive, normal and economic. In this study, the cluster analysis applied involved 4 steps of analysis

- Selection of variables,
- Determination of cluster hierarchy in the variables using hierarchical analysis
- Cluster analysis using K-mean method and
- Cluster validation using discriminant analysis

Further explanation of cluster analysis in this study is available from [10].

3 Results and Discussion

In this study, the correlation between fuel consumption and clustered driving style was assessed. Spearman Rho correlation analysis was conducted aim to explore the relationship between clustered driving style with average fuel consumption. Result from analysis for both Mercedes and Scania buses is shown in Table 1. The finding from this result indicated that, the driving style has a significant correlation with

Table 1 Spearman Rho correlation between average fuel consumption with clustered driving style

Bus		Clustered driving style
Mercedes Citaro	Average fuel consumption	0.472[a]
	Clustered driving style	1.000
Scania OmniCity	Average fuel consumption	0.300
	Clustered driving style	1.000

[a] Correlation is significant at 0.05 level (2-tailed)

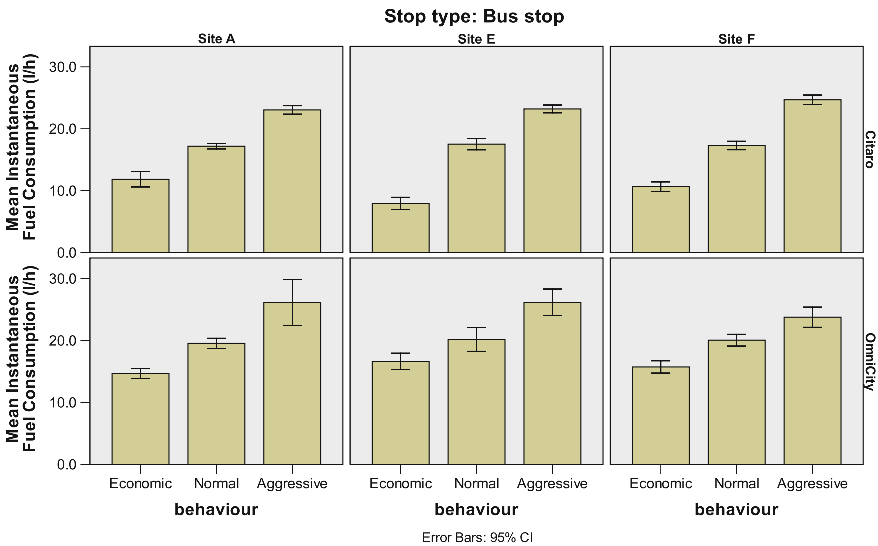

Fig. 1 Comparison of bus fuel consumption between economic, normal and aggressive driving at difference study sites (bus stop)

average fuel consumption. This also can be seen graphically from Figs. 1, 2 and 3 which demonstrated that the fuel consumption increase as the driving behavior change from economic to normal and aggressive respectively.

Further analysis for the research data was also conducted to test the significant different in fuel consumption from one behavior to another. To conduct this, a Mann–Whitney test was used. The result from Table 2 shows that, for both research buses, the aggressive bus driving at most of study sites consumed significant higher fuel consumption than that of normal and economic bus driving ($p < 0.016$). However, this result is not significant at Site D for Scania bus. Nevertheless the higher mean found in aggressive driving (see Fig. 3) indicated that the driver used slightly higher fuel consumption than the normal driver.

Regarding the how much the fuel cost can be saved from driving style change when leaving from bus stop, signalized intersection and roundabout, Table 3

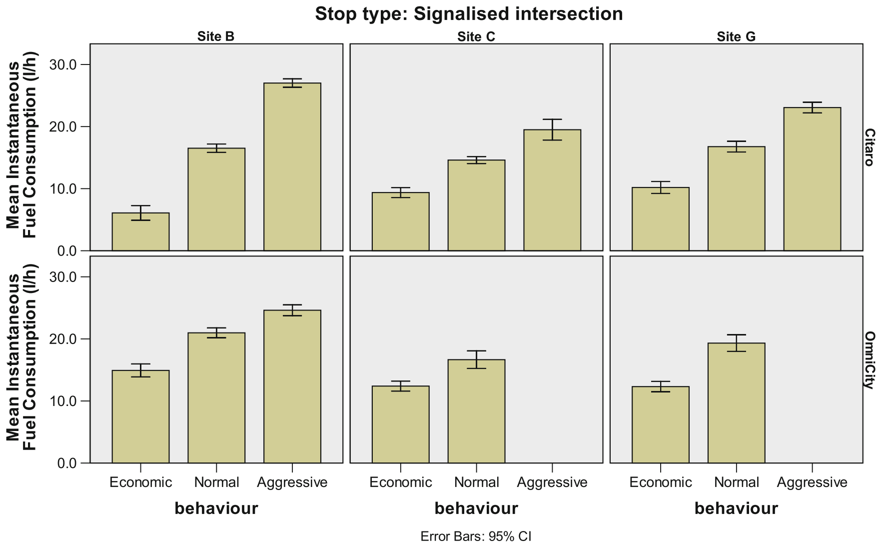

Fig. 2 Comparison of bus fuel consumption between economic, normal and aggressive driving style at different study sites (signalised intersection)

Fig. 3 Comparison of bus fuel consumption between economic, normal and aggressive driving style at roundabout

Table 2 Comparison test for instantaneous fuel consumption between aggressive, economic and normal driving

Clustered driving style	Stop type	Site	Bus	Sig. (2-tailed)
Economic versus normal driving	Bus stop	Site A	Citaro	0.0000001
			OmniCity	0.0000001
		Site E	Citaro	0.0000001
			OmniCity	0.002
		Site F	Citaro	0.0000001
			OmniCity	0.0000001
	Signalised intersection	Site B	Citaro	0.0000001
			OmniCity	0.0000003
		Site G	Citaro	0.0000001
			OmniCity	0.000004
		Site C	Citaro	0.000001
			OmniCity	0.000001
	Roundabout	Site D	Citaro	0.0000001
			OmniCity	0.078
Normal versus aggressive driving	Bus stop	Site A	Citaro	0.00000003
			OmniCity	0.0000001
		Site E	Citaro	0.00000001
			OmniCity	0.00004
		Site F	Citaro	0.000001
			OmniCity	0.001
	Signalised intersection	Site B	Citaro	0.000002
			OmniCity	0.00001
		Site G	Citaro	0.000005
			OmniCity	0.000001
		Site C	Citaro	0.0000001
			OmniCity	–
	Roundabout	Site D	Citaro	0.0000003
			OmniCity	0.000001
Aggressive versus economic driving	Bus stop	Site A	Citaro	0.0000001
			OmniCity	0.0000001
		Site E	Citaro	0.0000001
			OmniCity	0.0000001
		Site F	Citaro	0.0000003
			OmniCity	0.0000001
	Signalised intersection	Site B	Citaro	0.0000001
			OmniCity	0.0000001
		Site G	Citaro	0.0000001
			OmniCity	0.0000002
		Site C	Citaro	0.0000005
			OmniCity	–
	Roundabout	Site D	Citaro	0.0000001
			OmniCity	0.0000001

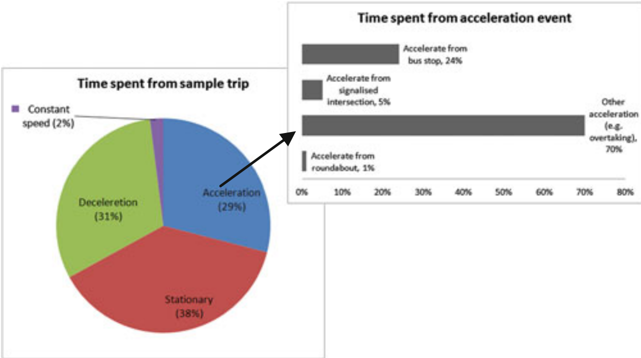

Fig. 4 Percentage of time spent on stationary, acceleration, deceleration and constant speed observed from normal driving and specific acceleration events behaviour

presents the calculation of the mean of instantaneous and percentage of fuel saving from driving style shifting from normal to economic, aggressive to normal and aggressive to economic. The estimation within all the study sites and research buses indicated that, the percentage of fuel saving from driving style shifting varied between 17 and 77 %. The analysis conducted also shows that driving shifting from normal to economic and aggressive to normal can promote fuel saving of up to 37 and 24 % respectively. The greatest fuel saving was observed to be from aggressive to economic (52 %) driving shift. This result is considerably accepted since fuel consumption is dependent on various factors such as road geometry, traffic condition and bus technology.

Saving benefit from driving style shift can be further estimated based on a daily and monthly trip basis. To estimate the bus fuel cost, a real driving profile from sampled data was taken (data was collected in Southampton, UK). The driver took 2 h 30 min to complete the journey from Southampton General Hospital (SGH) to Dock Gate 4 at Southampton city centre and getting back to SGH. Within the journey, the driver stopped 60 times at bus stops, 12 times at signalised intersections and 2 times at roundabouts. Assumption was made that the driver always adopted normal driving style at all stop types.

Figure 4 shows the percentage of each driving phase (acceleration, deceleration, stationary, and constant speed) observed from the data. Time spent within the bus trip at stationary, acceleration, deceleration and constant speed were 38, 29, 31 and 2 % respectively. Within the acceleration phase, 30 % of the times were spent to accelerate the bus away from bus stop, signalised intersection and roundabout (percentage was considered only the 10 s strong acceleration). The proportion of fuel consumption within the trip is shown in Fig. 5. The calculation of fuel consumption of the driving profile showed that, driver spent 74 % of the fuel consumption on acceleration, 13 % on deceleration, and 13 % on stationary and constant speed. It was also observed from the data that, driver used 16.99 l diesel

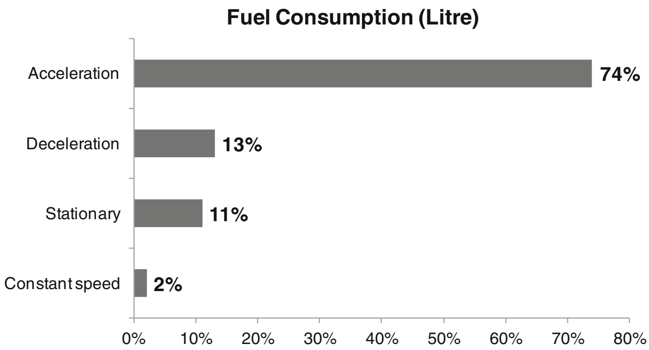

Fig. 5 Proportion of fuel Consumption of normal driving

to complete 1 trip duty. From this figure, percentage fuel spent on acceleration was calculated as 12.63 l (refer Fig. 5 and Table 3).

Tables 4, 5, 6, 7, 8 presents daily fuel consumption from sample data and the calculation of estimated fuel consumption and fuel cost for economic, normal and aggressive driving. For economic driving, it was estimated that fuel consumed from acceleration phase leaving bus stops, roundabouts and signalised intersections were 1.69, 0.04 and 0.29 l respectively. By assuming that the fuel consumption from other driving events were at the same rate, the result of total fuel consumption for the entire trip was observed to be lower than normal driving (19.85 L). Similarly, aggressive driving was estimated to consume 22.66 l diesels for the whole trip.

From the estimation of fuel consumption, the daily fuel usage can be calculated. Assume that the bus operated 6 trips daily; therefore the total fuel consumption for economic, normal and aggressive are 119.1, 128.04 and 135.96 l respectively.

The analysis conducted show that, fuel saving from driving shift benefit to reduce bus operational costs. For example, driving shift from aggressive towards economic, save 16.86 l diesel daily. If the diesel price is GBP 1.51 per litre, the bus company can save GBP 25.46. Across the fleet, if the company owned 10 buses, this can save GBP 256.6 daily or GBP 7,637.58 monthly.

Table 3 Mean of instantaneous fuel consumption and percentage of fuel consumption saving from driving style shifting at bus stop, signalised intersection and roundabout

				Driving style			Percentage saving from driving style shifting		
				Economic Mean instantaneous fuel consumption (l/h)	Normal Mean instantaneous fuel consumption (l/h)	Aggressive Mean instantaneous fuel consumption (l/h)	Normal to economic	Aggressive to normal	Aggressive to economic
Citaro	Stop type	Bus stop	Site A	11.852	17.191	23.045	31.06	25.40	48.57
			Site E	7.949	17.522	23.203	54.63	24.48	65.74
			Site F	10.660	17.303	24.681	38.39	29.89	56.81
		Signalised intersection	Site B	6.091	16.516	27.011	63.12	38.86	77.45
			Site C	9.373	14.604	19.494	35.82	25.09	51.92
			Site G	10.188	16.768	23.065	39.24	27.30	55.83
		Roundabout	Site D	7.998	17.123	23.025	53.29	25.64	65.26
OmniCity	Stop type	Bus stop	Site A	14.683	19.564	26.140	24.95	25.16	43.83
			Site E	16.652	20.178	26.166	17.47	22.88	36.36
			Site F	15.735	20.065	23.777	21.58	15.61	33.82
		Signalised intersection	Site B	14.919	20.977	24.614	28.88	14.78	39.39
			Site C	12.399	16.653		25.54	–	–
			Site G	12.314	19.321		36.26	–	–
		Roundabout	Site D	11.233	21.405	24.261	47.52	11.77	53.70
						Average	36.983	23.90	52.39

Table 4 Daily fuel consumption from sample data

Driving profile	Time spent from sample trip (s)	Percentage	Average fuel consumption (l/h)	Fuel consumption (l)	Fuel consumption (%)
Constant speed (A|)	129.4	1.56	6.84	0.25	1.45
Acceleration	2,441.6	29.45	18.62	12.63	74.36
Deceleration (B)	2,564.8	30.93	3.17	2.26	13.30
Stationary (C)	3,155.7	38.06	2.11	1.85	10.89
Total fuel consumption				16.99	100
Total fuel consumption excluding fuel from acceleration, (A + B + C)				4.36	25.64

Table 5 Estimated fuel consumption for normal driving style

Acceleration from	Time spent from sample trip (s)	Percentage	Average fuel consumption (l/h)	Fuel consumption (l)	Total fuel consumption from trip (l)
Bus stop	600	26.53	17.34	2.89	16.98 + 4.36 = 21.34
Roundabout	20	0.88	17.12	0.10	
Signalised intersection	120	5.31	15.96	0.53	
Other points (e.g. overtaking)	1,521.6	67.28	–	9.11	

Table 6 Estimated fuel consumption for economic driving style

Acceleration from	Time spent from sample trip (s)	Percentage	Average fuel consumption (l/h)	Fuel consumption (l)	Total fuel consumption from trip
Bus stop	600	26.53	10.15	1.69	15.49 + 4.36 = 19.85
Roundabout	20	0.88	8	0.04	
Signalised intersection	120	5.31	8.6	0.29	
Other points (e.g. overtaking)	1,521.6	67.28		9.11	

Table 7 Estimated fuel consumption for aggressive driving style

Acceleration from	Time spent from sample trip (s)	Percentage	Average fuel consumption (l/h)	Fuel consumption (l)	Total fuel consumption from trip
Bus stop	600	26.53	23.64	3.94	18.30 + 4.36 = 22.66
Roundabout	20	0.88	23.03	0.13	
Signalised intersection	120	5.31	23.19	0.77	
Other points (e.g. overtaking)	1,521.6	67.28		9.11	

Table 8 Estimated daily fuel consumption and fuel cost

	Economic driving	Normal driving	Aggressive driving
Daily fuel consumption*	19.85 × 6 = 119.1	21.34 × 6 = 128.04	22.66 × 6 = 135.96
Daily fuel cost**	119.1 × 1.51 = 179.84	128.04 × 1.51 = 193.34	135.96 × 1.51 = 205.30

*Assume that, the bus operated 6 trips daily
**Assume that, 1 l diesel price is GBP 1.51

4 Conclusion

Research findings suggested that in general, driving style can affect bus fuel consumption and bus operation cost through fuel cost. Aggressive driving after leaving from bus stops, signalized intersection and roundabout were found to consumed extra 23.9 and 52.4 % fuel than the normal and economic style respectively.

The result of this study provides evidence and support previous report of benefit of eco driving on bus fuel consumption [5, 8]. By changing driving style from aggressive to economical style, bus operator can save 16.86 l daily. This amount is worth for GBP 25.46 daily or GBP 763.76 monthly for a single bus. The finding of this study is practically important to ease bus operation cost.

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