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Bus Following Model: A Case Study in Edinburgh

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Abstract

A number of car following models have been developed and calibrated for the purpose of understanding and simulating the behaviour of driving under various traffic and transportation management systems. Such studies are useful for safety impact studies, network analysis and capacity analysis. However bus following is a special behaviour, which impacts on other traffic especially in the absence of dedicated bus lanes. This paper reports on a study in the City of Edinburgh which was undertaken to investigate and understand the behaviour of buses in the city. A commuter bus equipped with a data logging device was followed by an instrumented vehicle to collect data to study bus following behaviour. A model of distance difference as a function of the acceleration/deceleration, speed and speed difference has been developed for bus following behaviour. The GHR model was used to investigate and calibrate the parameters of the model of the car following a bus. The study findings show that the speed and acceleration of the following vehicle are influenced by the leading commuter bus in both acceleration and deceleration regimes. The results also show that a car following a bus behaves differently to a car following a car. This is because of the limited visibility, huge delays for buses on the corridor and the different driving characteristics of the bus with respect to the car.

Keywords: *Bus-following, Commuter bus, Instrumented vehicle, Distance difference, Relative speed*

1. Introduction

Vehicular traffic volumes have been increasing rapidly for the past several years and have outstripped the capacities of main roads in many cities across the world especially cities in developed countries such as the City of Edinburgh in the United Kingdom. This trend has made it essential for traffic engineers to understand traffic flow dynamics and to develop mathematical descriptions of traffic flow processes. In cities where there is heavy flow of traffic, we expect the main roads to perform at their peak and in so doing it makes the understanding of the mathematical process particularly relevant in dealing with such situations. There have been numerous theories attempting to describe the vehicular traffic following process. The most common theories that attempt to describe traffic flow are derived from statistical studies of the flow (Greenberg, 1959). Car-following theory is one of these, which is based on a follow-the-leader concept, which describes how the driver of a vehicle follows another vehicle in the same single lane of a traffic stream. The rules governing how the driver follows the vehicle ahead of him/her are established based on both experimental observations and theoretical considerations, see for example (Zhang and Kim, 2002).

Sometimes the rapid growth of vehicular traffic in major cities and town centres across the United Kingdom, such as in Edinburgh, has often forced city transport authorities to take drastic measures such as bus only lanes to discourage the use of cars during certain times of the day or to provide free park and ride sites in the outskirts of the city to encourage motorists to park their vehicles and use public

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buses to reach the centre of towns. All these measures attempt to reduce traffic volumes and congestion during the peak (*i.e.*, rush hour) periods. To further encourage fewer cars during rush hour periods in order to reduce congestion on the road, more public buses are often introduced with an increase in bus frequencies and bus only lane restrictions enforced. There are a number of travel demand management polices which can be appropriately implemented to encourage greater use of public transport and less use of the private cars. It is very important however to have a good understanding of bus driving behaviour in order to implement the right polices efficiently.

This study investigates the behaviour of a vehicle following a commuter bus for a period of time without the possibility of passing the commuter bus in a mixed traffic lane where all vehicle types share the same road space *i.e.*, there is no dedicated bus lane. In order to carry out the investigation, we instrumented a private vehicle with GPS data logging devices with high resolution cameras and followed a commuter bus equipped with a GPS data logging device on a public road with no lane restriction in place (*i.e.*, no dedicated bus lane). For this study we used the bus following data set (which we collected) to calibrate an existing basic car-following model which is reported in the literature. This paper is divided into the following sections: section 1 is the introduction, Section 2 discusses the review of literature on car-following, the data collection processes and case study area is presented in Section 3 while the general statistics of the study are presented in section 4. Section 5 discusses bus following model and Section 6 presents analysis of the results and discussions of the study. Section 7 concludes the study.

2. Car following Models

Car-following theories have been studied since the mid-fifties. Since then numerous mathematical equations to describe the process of the behaviour of drivers following one another have been developed. Several of these are car-following models and the most commonly known models proposed in literature have been categorised and grouped into different classifications such as Gazis-Herman-Rothery (GHR) model, linear models, safety distance or collision-avoidance (CA) models, psychophysical models, fuzzy logic-based models and optimal velocity model (OVM) (Brackstone and Mcdonald, 1999; Ranjitkar *et al.*, 2005; Chang and Chong, 2005; Panwai and Dia, 2005; Li and Sun, 2012). These car-following models were developed based on different assumptions and are intended to describe the car following situations in which one vehicle passing the other is impossible and they could be used to study certain features of traffic flow (Newell, 1959). It is the intent of this study to focus on the primary car-following model known as the GHR model. It should be noted here that it is beyond the scope of this study to present a general overview of all the previously developed models.

The GHR model is a stimulus-response model first developed by Chandler *et al.*, (1958) as a linear model. The model suffered some limitations which were later addressed by Gazis *et al.*, (1961). Gazis *et al.*, introduced a new calibration parameters m and l into the model in which the sensitivity, namely the gain factor was considered proportional to the speed of the following vehicle raised to the power, m, and inversely proportional to the relative distance (*i.e.*, space headway) raised to the power, l. The new nonlinear model became known as the General Motors (GM) model. The model is formulated as follows:

$$a_n(t) = cv_n^m(t)\frac{\Delta v(t)}{\Delta x^l(t)} \tag{1}$$

where a_n is the acceleration/deceleration of the following vehicle n, Δx is the relative distance between the following vehicle, n and the vehicle immediately in front, $(n-1)$, Δv is the relative speed of the following vehicle, n and the vehicle immediately in front, $(n-1)$ and c, m, l are calibration parameters.

Several researchers have performed various empirical studies (Herman and Potts, 1959; Edie, 1961; May and Keller, 1967; Bevrani *et al.*, 2012) to determine the values of the calibration parameters. Different data sets such as Next Generation Simulation (NGSIM) (Bevrani *et al.*, 2012) have been used to evaluate the GHR model and to determine the correct sets of calibration parameters m and l. However, using real time series data sets from cars following large vehicles to determine the calibration parameters has not been given much attention in the literature.

The motivation to develop a reliable car-following model comes from the necessity to evaluate the effects on the flow of traffic on any particular road network as a result of any planned changes to the network. It is important to assess what the impact of the potential changes to the driving surroundings will have on the flow of traffic when predicting the reaction of a following vehicle in relation to the behaviour of the vehicle in front. It was recognised by Gipps that models that have been proposed to describe these behaviours have different strengths and weaknesses (Gipps, 1981). Car-following models often describe the interaction process between two successive vehicles with no passing and travelling in the same direction. Ranney (1999) asserts that car-following is characterised by the headway between the vehicles and the extent to which the vehicle following traces the speed variations of the vehicle immediately in front.

Most of the car-following studies carried out for the past several years consider the car-to-car following situations, for example Chandler *et al.*, (1958), and other studies on extended car-following models usually use two-car following models, for example Hoogendoorn and Ossen (2006). Mehmood and Easa (2010) in their studies involving both the back and front vehicles using the NGSIM database excluded the motorcycles and trucks from their data set. The few studies on car-following models that consider large vehicles and trucks often consider them as part of random following vehicles. For instance, Hoogendoorn and Ossen (2006) used an air-born observation platform (a helicopter) mounted with a high frequency digital camera and frame grabber to collect car-following data. They considered two following situations, firstly, the driver behaviour of private cars and trucks and secondly, the driver behaviour in the case where the first leader is either a person-car or a truck. This was to enable them gain an insight into the inter-driver differences in car-following parameters. The study captured vehicle trajectory of approximately 500 m of roadway stretch. The study focused more on the ability for the vehicle following the trucks to be able to react to the vehicle immediately in front of the trucks but less on the vehicle following behind the trucks. Moreover, in the case of the vehicle following the trucks, it could be considered that they were not following for a longer period (*i.e.*, 500 m stretch of road) to able to assess the variability in driving behaviour of the vehicles following the trucks.

Other studies often use a “passive” mode of collection (Brackstone *et al.*, 2002) where the data logging device (*i.e.*, the radar sensor) is facing backwards and which observe the following vehicles including large vehicles and trucks. For example, Kim (2005) conducted an experiment using an instrumented vehicle as the leading vehicle to collect time series traffic data on the I-495 and I-295 in the USA. He mounted the radar sensor at the back of the instrumented vehicle (*i.e.*, “passive” mode) to collect random data of the following vehicles including large vehicles and trucks. Kim grouped the data into different classification including autos (car) and autos, autos and trucks and analyzed their behaviour. Kim suggested that truck drivers tend to have a longer time gap than auto (car) but the study did not consider the behaviour of the vehicle (auto) following the trucks or large vehicles since the instrumented vehicle was the leading vehicle. Such situations, where the vehicle (*i.e.*, instrumented vehicle) follows a large vehicle (especially a commuter bus) for a period of time has not been given much consideration in the current literature.

3. Data Collection and Case Study Area Description

This study was carried out in Edinburgh, the capital city of Scotland in the United Kingdom. The City of Edinburgh is the seat of the Scottish Government and the Scottish Parliament. The city is located between the Pentland Hills and the southern shore of the Firth of Forth with a total residential population of 476,626 (Scotland 2011 Census, 2013). Edinburgh is well known for its ancient and historic listed architectural buildings, the Edinburgh International Arts Festival and the Fringe Festival. Edinburgh serves as one of Europe's cultural and historical centres with the city's Old Town and New Town dating back to the 18th century and is recognised as World Heritage Site by UNESCO. The City of Edinburgh serves as the financial hub of Scotland and one of the fastest growing economies in the UK.

This study was carried out on one of the busy arterial roads in the southeast of Edinburgh that connects to the nearby towns of Lasswade, Bonnyrigg and Polton in the Midlothian local authority area and beyond. The corridor is a single lane mixed traffic road that starts from the junction with Liberton Brae (A701) through the suburbs of Liberton, Gracemount where it meets with the B701 (Captain's Road – Gilmerton Dykes Street) at a major signalised junction. Most drivers use this corridor to connect to the Edinburgh City Bypass (A720). The corridor (Kirk Brae – Lasswade Road – Hillhead/High Street (B704)) passes under the A720 and continues through a rural road where vehicular passing (*i.e.*, overtaking) is minimal (or impossible due to the oncoming traffic) to Bonnyrigg town centre and to the last stop of the commuter bus at Polton town centre. It has a speed limit ranging from 30 mph to 40 mph. The study corridor has a mixed traffic lane with no dedicated bus lanes.

The selection of the corridor enabled us to follow the commuter bus with the instrumented car continuously without any interruption due to lane restrictions. The corridor running through a rural road enabled continuous following of the commuter bus without the commuter bus stopping since there were few or at times no bus stops for at least 2 miles on some sections of the corridor. The research was carried out during the late part of the afternoon peak hour, the time that we would expect some heavy traffic and the likelihood of traffic congestion on the road. The heavy traffic ensured that the following vehicle had no space available or the choice to pass the commuter bus when it stops at the dedicated bus stops but had to wait till the bus begins to move again.

3.1. Instruments used in Data Collection

The equipment that was used for this experiment included a private car provided and driven by the researcher, a Lothian double decker bus, two PerformanceBox and a Video VBOX supplied by the university.

The Car and the Bus

The car used for the experiment was a standard Ford Mondeo 2002 model with a 1.8 litre engine capacity. The car dimensions enabled enough room for installation of the devices and cables, and also for the bus driver to be able to possibly see the car in his driving mirrors. The bus which was followed in this study was operated and owned by the

Lothian Buses, a publicly owned local bus company – the major shareholder being The Edinburgh City Council. The double decker bus (i.e. route 31 bus) which runs on this corridor was used for the study. The double decker bus provided space to enable us to place our GPS based data logging device on the deck dashboard directly over the bus driver at the same position that we would expect the bus onboard speedometer to be mounted.

The PerformanceBox

PerformanceBox is a Global Position System (GPS) based data logger and performance meter making it easy to measure the acceleration, speed, time and distance travelled by the vehicle. It has data logging frequency of 10Hz coupled with fully calibrated GPS engine used to provide accuracy and precision. The PerformanceBox when used in combination with a Micro Input Module can record the data of the vehicle (such as RPM and throttle angle) alongside the GPS logging parameters. The data starts to log when the velocity is above 0.5 km/h.

The Video VBOX Lite

Video VBOX Lite is a powerful Racelogic GPS data logger that combines with a high quality solid-state video-audio recorder, which takes multiple cameras inputs simultaneously and combines them with a graphical overlay. The data logged and the resulting video-audio streamed onto a removable SD card. The Video VBOX Lite records the following parameters as part of the standard along with the video file: time, velocity, acceleration and distance travelled (Video VBOX Manual, 2009).

3.2. Data Collection

The data were collected using the instrumented vehicle and a double decker commuter bus equipped with one speed data logging device. The vehicle was fitted with a Performance Box and Video VBOX. The GPS antenna of both the Performance Box and the Video VBOX were mounted at the centre of the vehicle's roof away from each other and away from the radio aerial to prevent interference. The Performance Box was mounted at the centre of the windscreen of the instrumented vehicle. The Performance Box was use to record the speed, acceleration, time and distance travelled by the instrumented vehicle. The video recordings were useful in clarifying and checking any possible confusing data from the Performance Box and the Video VBOX such as data from other vehicles that cut in and stay in lane between the bus and the instrumented vehicle. It also permanently recorded the experiment such as the road and whether conditions as well as vehicles following the instrumented vehicle. In this study the main focus was with the front camera as our main aim was to follow the bus and not the vehicles following behind. The Video VBOX in addition to the video recordings also recorded the speed, acceleration, distance and time data of the instrumented vehicle which were used to compare and verify the accuracy of the data from the Performance Box.

The bus-following data collection was carried out in the afternoon of 2 June 2014 at 14:15 pm UTC. It was a dry sunny summer day. A total of 20.4 km or 12.6 miles was covered for the entire bus following experiment. From Point A to Point B of the corridor (see Figure 2), the instrumented vehicle followed the commuter bus continuously without stopping in both directions of travel. This may be due to the rural nature of the road and also as the bus driver did not have any passengers to drop off or pick up at the few designated bus stops along that section of the corridor. Figure 3 shows the instrumented vehicle following the route 31 commuter bus with the Performance Box data logging device to log the speed, distance travelled, acceleration and time of the bus.

Figure 1. PerformanceBox Mounted on the Top Deck Dashboard of the Double Decker Bus

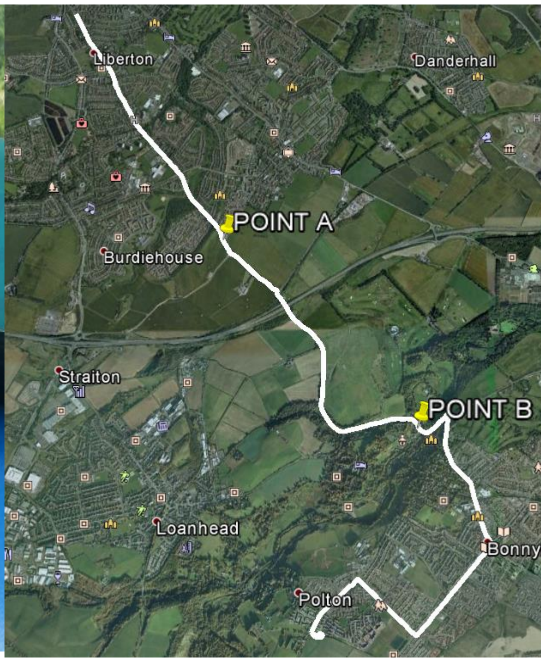

Figure 2. Corridor Route Map (GPS Tracker on Google Earth) showing Point A and B

Figure 3. The Instrumented Vehicle following the Commuter Bus with the PerformanceBox

4. General Statistics

Throughout the experiment we ensured that whenever the bus stopped we also stopped and all data logging equipment recorded the speed, distance travelled and acceleration as zero. We also ensured that no other vehicle came between the instrumented vehicle and the route 31 double decker bus. The instrumented vehicle followed the double decker commuter bus to and from the last stop to the start of the experiment in a total time of 3554 seconds.

Using the available software such as VBOX Tools, Circuit Tools and Performance Box Tools, the data from both the commuter bus and the instrumented vehicle's Performance Box and Video VBOX were downloaded. The data downloaded included: UTC time, speed (mph), distance (m), acceleration/deceleration (m/s^2) and time (s). For checking the accuracy of the data from the instrumented vehicle's Performance Box, we compared the data with the data from the instrumented car's Video VBOX data. We found that the differences in the data were insignificant and therefore, we were confident that the data from the Performance Box from both the instrumented vehicle and the commuter bus were accurate.

The data from the instrumented vehicle's Performance Box and the commuter bus' Performance Box were synchronized using the UTC time. This is because both devices use UTC time as the default time for tracking and receiving satellite signals. After matching the data from the instrumented vehicle and the bus, the raw data was refined by removing all instances where there was no bus following behaviour occurring. Instances where the acceleration, speed and distance travelled recorded zero were removed from the data set. This means the bus was stationary at the designated bus stop or in a traffic queue due to congestion on the corridor. We had a total of 1692 seconds out of 3554 seconds of data where the instrumented vehicle continuously followed the bus. The final data was used to obtain the relative speed (mph), distance difference (*i.e.*, separation distance) (m), and time (s). The data was grouped according to the direction of travel, for instance, when following the bus from the City of Edinburgh to Polton Town Centre including the neighbouring towns outside of the city and when following the commuter bus from Polton Town Centre to Edinburgh City Centre. The data was further grouped into acceleration and deceleration for analysis. Figures 4, 5 and 6 show the differences in time – relative speed - speed, distance difference – relative speed and time – distance difference relationships for the data collected when the instrumented vehicle followed the route 31 commuter bus to Polton Town Centre (left) and to the City of Edinburgh (right).

The speed and the speed difference were converted from miles per hour (mph) as presented in Table 1 below. Table 1 shows the general average statistics of the bus following experiment for the acceleration and deceleration regimes in both direction of travel.

Table 1. Average Speed, Distance, Acceleration and Deceleration of Bus following Data

Following the bus to Polton Town Centre							
	Acceleration			Deceleration			Total time following (s)
	Average			Average			
	Speed (m/s)	Distance (m)	Acceleration (m/s^2)	Speed (m/s)	Distance (m)	Deceleration (m/s^2)	
Bus	8.58	324.10	0.73	8.94	474.15	-0.67	823
Instr. Car	8.11	309.82	0.65	9.11	459.43	-0.55	
Following the bus to Edinburgh							
	Acceleration			Deceleration			Total time following (s)
	Average			Average			
	Speed (m/s)	Distance (m)	Acceleration (m/s^2)	Speed (m/s)	Distance (m)	Deceleration (m/s2)	
Bus	6.93	164.97	0.73	6.54	239.25	-0.64	869
Instr. Car	6.40	157.71	0.78	6.63	231.76	-0.70	

5. Bus Following Model

In this section we consider two cases: firstly, modelling a bus following behaviour with respect to the distance difference, following vehicle's speed and the speed difference with the experimental data and secondly, we determine the GHR model calibration parameters using our experimental data.

Case 1: We consider the following dynamic equations;

$$\Delta x = x_c - x_b \;;\quad \Delta v = v_c - v_b \tag{2}$$

$$\frac{dx}{dt} = v(t)\;;\qquad \frac{dv}{dt} = a(t) \tag{3}$$

Here, x_c and x_b are the distance travelled by the instrumented vehicle and the commuter bus at time t respectively, v_c and v_b are the speed of the instrumented vehicle and the commuter bus at time t respectively, and *a(t)* is the acceleration/deceleration of the following instrumented vehicle. We modelled our bus following behaviour in the form of which the distance difference $\Delta x(t)$ is expressed as a function of the speed difference Δv between the following vehicle and the commuter bus (route number 31), the acceleration/deceleration of the following vehicle and the speed $v(t)$ of the following vehicle. This is expressed in the form:

$$\Delta x(t) = f(a, v, \Delta v) \tag{4}$$

Using a multiple regression analysis method we obtained equation 5 as follows;

$$\Delta x(t) = 0.2138\Delta v(t) - 0.435a_n(t) - 1.6377v(t)\;;\; r^2 = 0.5 \tag{5}$$

Case 2: Here we applied our bus following data set to the GHR model (Gazis *et al.*, 1961) to determine the calibration parameters *m*, *l* and *c* (the sensitivity constant) in relation to a car following a bus. We have negative acceleration, speed difference and travel distance difference in our data set so we had to change all the data set to absolute value in order to apply logarithm to our data set. The absolute value conversion was in the form such as;

$\text{abs}\left(-a_n(t)\right) = |-a_n(t)| = a_n(t), abs(-\Delta x(t)) = |-\Delta x(t)| = \Delta x(t)$ and $\text{abs}(-\Delta v(t)) = |-\Delta v(t)| = \Delta v(t)$. Re-arranging equation (1), we have:

$$\frac{a_n(t)}{\Delta v(t)} = \frac{cv_n^m(t)}{\Delta x^l(t)} \tag{6}$$

and applying logarithm to equation (6) we have:

$$log\left[\frac{a_n(t)}{\Delta v(t)}\right] = \log c + mlog[v_n(t)] - llog[\Delta x_n(t)] \tag{7}$$

where;

$$c = 10^{\text{(the intercept of eqn. (7))}} \tag{8}$$

Using multiple regression analysis to the bus following data set to equation (7) and computing for equation (8), we obtained the values for m = 0, l = 0.1, c = 1.19 and m = -0.1, l = 0, c = 1.04 for the acceleration and deceleration regimes respectively.

6. Results and Discussions

A total of 1658 time series data in a total time of 1692 seconds were obtained from the raw data and used for analysis in this study. These data sets represent the bus following data where the instrumented vehicle followed the commuter bus continuously with stopping. It can be seen from Table 1 that when the instrumented vehicle followed the bus from Edinburgh to Polton town, the average speed, average travel distance and average acceleration for the commuter bus were higher than the instrumented vehicle's average speed, travel distance and acceleration during the acceleration regime. However, during the deceleration regime the average speed and average deceleration of the instrumented vehicle were higher than the average speed and deceleration of the commuter bus. Again, when the instrumented vehicle followed the commuter bus from Polton town to Edinburgh where heavy traffic congestion was expected during the time of the experiment, the average speed and average travel distance of the commuter bus were higher than the instrumented vehicle with the exception of the average acceleration which was less than the acceleration of the instrumented vehicle during the acceleration regime. In the case of the deceleration regime, only the speed of the instrumented vehicle was higher than the speed of the commuter bus. Figure 7 and 8 show the speed profiles of the commuter bus and the instrumented vehicle throughout the entire study. The study shows that as the speed of the instrumented vehicle increases, the travel distance-difference between the instrumented vehicle and the bus decreases. Figure 9 shows the speed of the instrumented vehicle and the distance-difference of the bus following experiment.

The standard deviation of the distance-difference was higher in the acceleration regime than in the deceleration regime, the standard deviation of the distance difference was 17.83 and 16.87 for the acceleration and deceleration regimes respectively. The standard deviation of the relative speed was lower in the acceleration regime than in the deceleration regime, the standard deviation of the relative speed was 0.995 and 1.050 for acceleration and deceleration regimes respectively.

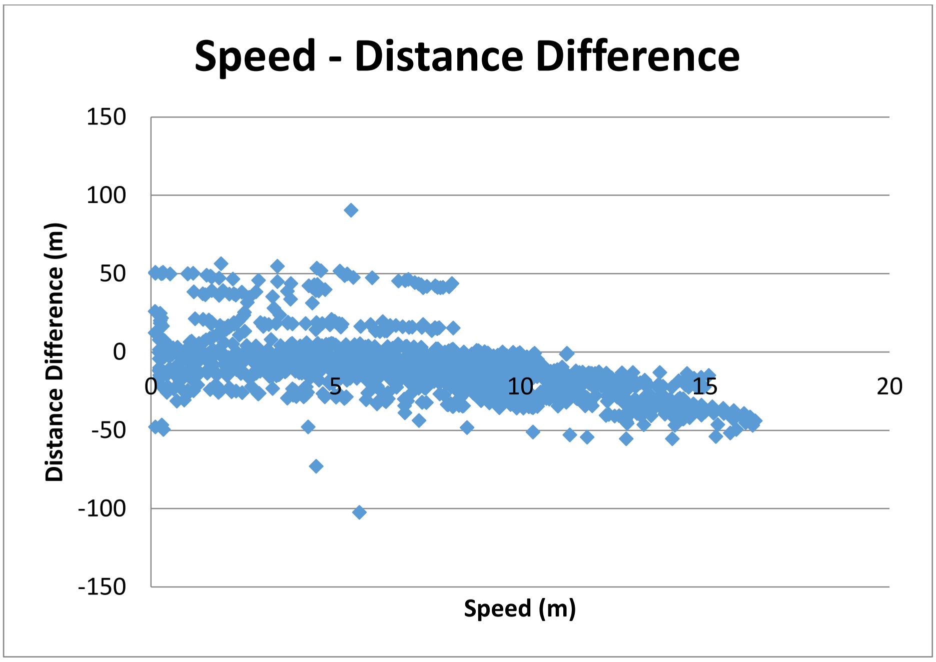

Figure 9. Plot of Car Speed and Distance-Difference of Car and Bus on the Corridor

The study showed that the average speed of 7.76 m/s and acceleration of 0.73 m/s^2 for the commuter bus in the acceleration regime was higher than the average speed of 7.26 m/s and acceleration of 0.72 m/s^2 for the instrumented vehicle following behind. However, in the deceleration regime, the average speed of 7.74 m/s for the commuter bus was less than the average speed of 7.87 m/s of the instrumented vehicle but the average deceleration of 0.66 m/s^2 for the commuter bus was higher than that of the instrumented vehicle of 0.63 m/s^2. This is expected as in the process of the commuter bus slowing down, the car following behind may not be able to react immediately until at a point in time when the distance between them becomes smaller. Also since the driver of the car following behind could not see beyond the vehicle in front to be able to assess the situation ahead, the driver may take some time to react to the slowing down of the vehicle in front.

Equation (5) was modelled using a total of 1658 time series data obtained from the bus following the experiment. The model in equation (5) predicts the safe following travel distance between the following vehicle and the lead vehicle (*i.e.*, bus or large vehicle) taking into consideration the acceleration and the speed of the following vehicle as well as the speed difference between the follower and its leader. The model produced an r^2 value of 0.5 which could be considered as statistically significant.

The values of the GHR model calibration parameters we obtained is in relation to only a car following a commuter bus with no lane restrictions. It is not surprising that the calibration parameters obtained were different in the two following regimes *i.e.*, acceleration and deceleration regimes, since in the deceleration regimes the commuter bus and the car tend to slow down. For the acceleration regime, the calibration parameter values of m = 0 and l = 0.1 shows that the acceleration of the following vehicle depends on the relative speed and the difference in the distance travelled. For the deceleration regime, the calibration parameter values of m = -0.1 and l = 0 show that the deceleration of the following vehicle depends on the speed of the following vehicle and the speed difference between the commuter bus and the following vehicle. In the study we obtained c values of 1.19 and 1.04 for the acceleration and deceleration regimes respectively. It can be seen that the c value for the acceleration regime was higher than the deceleration regime.

6.1. Comparison with other GHR Calibration Parameters

Table 2. Presents the most Reliable Estimates of the GHR Model's Parameter (Brackstone and Mcdonald, 1999) and Bus following Parameter Estimate for the GHR Model

Source	m	l
Chandler et al. (1958)	0	0
(Herman and Potts, 1959)	0	1
Hoefs (1972) (dcn brk/acn) [a]	0.2/0.6	0.9/0.9/3.2
Treiterer and Myers (1974) (dcn/acn) [a]	0.7/0.2	2.5/1.6
Ozaki (1993) (dcn/acn) [a]	0.9/-0.2	1/0.2
Bus-following study (dcn/acn) [a]	-0.1/0	0/0.1

[a] dcn/acn: deceleration/acceleration; brk: deceleration with the use of brakes

The calibration parameter values of m = 0 and l = 0 we obtained for the GHR model with the bus-following data agrees with the values obtained by Chandler *et al.*, (1958) in both acceleration and deceleration regimes respectively, however, our estimates of parameter m = 0 only agrees with the value obtained by Herman and Potts (1959) in the acceleration regime (See Table 2).

In the deceleration regime, the parameter estimate we obtained for m = -0.1 and l = 0 differs from the values obtained by Hoefs (1972) (m = 0.2 and l = 0.6), Treiterer and Myers (1974) (m = 0.7, l = 0.2) and Ozaki (1993) (m = 0.9 and l = -0.2). The values we obtained (especially the negative value for m) may be as a result of the following vehicle's driver not able to see beyond the commuter bus (*i.e.*, large vehicle) to react quickly to any incidents that may cause the leading vehicles ahead of the large vehicle to react such as braking. Since the following drivers could not see beyond the large vehicle ahead of them, their response in decelerating and eventually stopping may be slow and depend on the response (*i.e.*, lit brake lights) of the large vehicle they are following. In situation where a small vehicle is following a small vehicle as the other studies may be based on, the reaction of the driver of the following vehicle may be different since they could see beyond the lead vehicle.

In the acceleration regime, the bus-following GHR parameter value of l = 0.1 we obtained varies slightly from the value obtained by Ozaki (1993) (l = 0.2) compared to Hoefs (1972) (l = 3.2), and Treiterer and Myers (1974) (l = 1.6). The variation may also be due to the following vehicle not able to accelerate to the desired speed since they could not estimate the speed of the vehicles ahead because they could not see beyond the vehicle they are following.

	Following the bus to Polton Town Centre			
	Acceleration		Deceleration	
	Relative Speed (m/s)	Distance Difference (m)	Relative Speed (m/s)	Distance Difference (m)
Average	-0.46	14.28	0.18	14.72
	Following the bus to bus to Edinburgh			
	Acceleration		Deceleration	
	Relative Speed (m/s)	Distance Difference (m)	Relative Speed (m/s)	Distance Difference (m)
Average	-0.52	7.16	0.09	7.50

6.2. The Trends of the Relative Speed and Distance Difference

Figures 4-7 below show that the average relative speed between the bus and the test vehicle from Edinburgh to Polton Town Centre was less than that from Polton Town Centre to Edinburg during the acceleration regime. In the deceleration regime, the average relative speed was greater when following the bus to Polton Town from Edinburgh than when following the bus to Edinburgh from Polton Town Centre. In both instances of acceleration and deceleration regimes, the average distance difference (*i.e.*, average distance travelled between bus and test vehicle) when following the bus to Polton Town Centre was higher than when following the bus to Edinburgh from Polton Town Centre. These trends may be due to the fact that there was heavy traffic in and/or around Edinburgh during the peak hours as vehicle speeds are reduced and hence cover less travel distance at a point in time compared to traffic in and/or around Polton Town Centre which may not be as heavy as in Edinburgh.

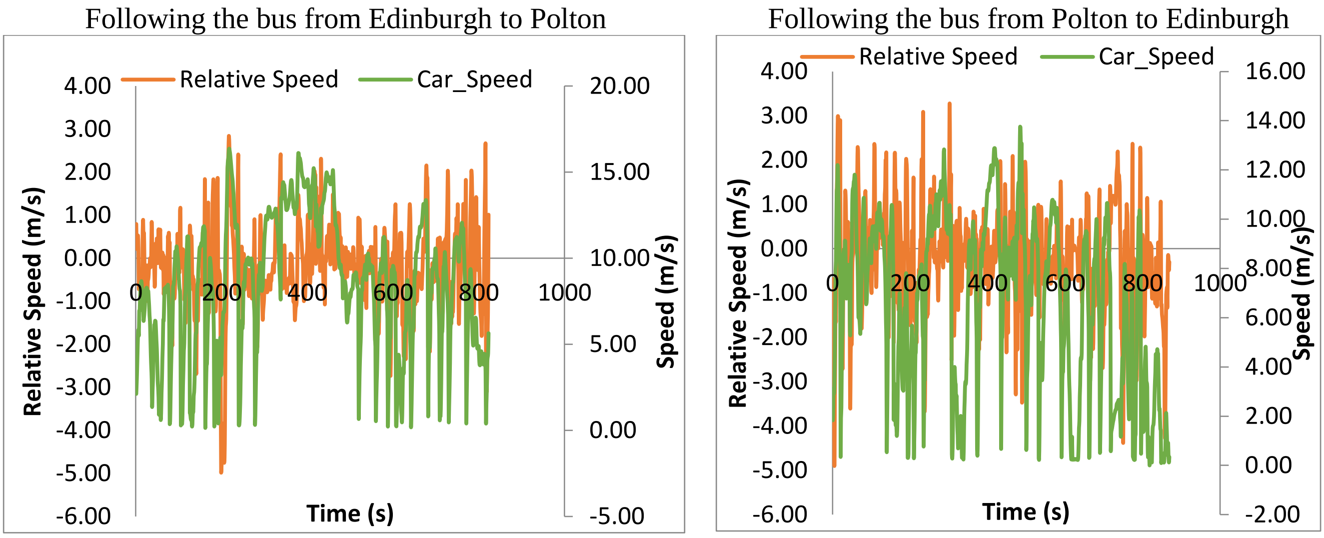

Figure 4. Time-Relative Speed-Speed relationship of Bus following; from Edinburgh to Polton (Left) and from Polton to Edinburgh (Right)

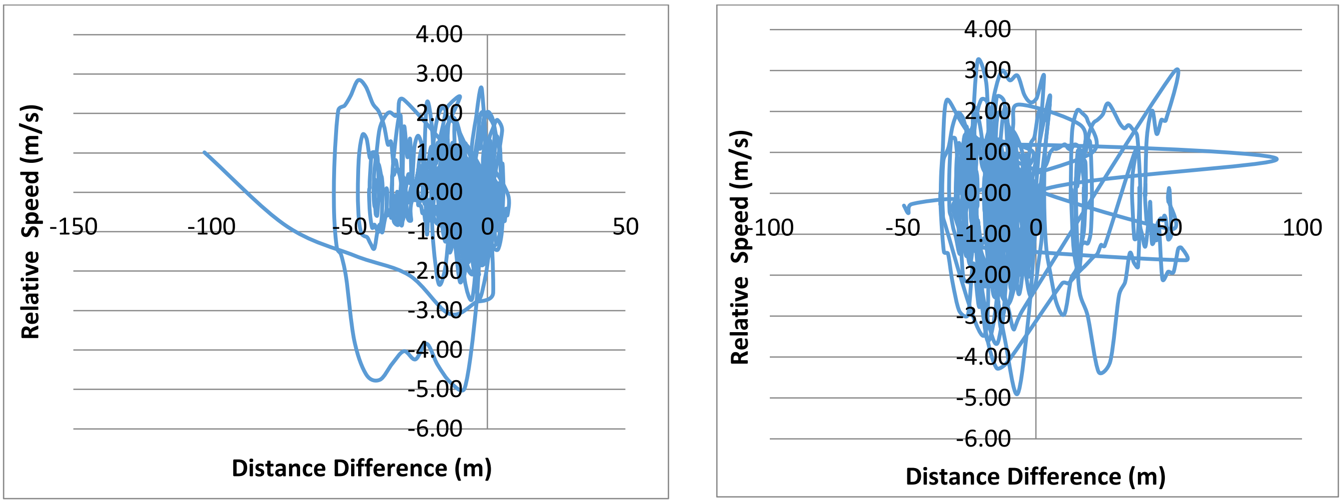

Figure 5. Distance Spacing – Relative Speed of Bus following; from Edinburgh to Polton (Left) and from Polton to Edinburgh (Right)

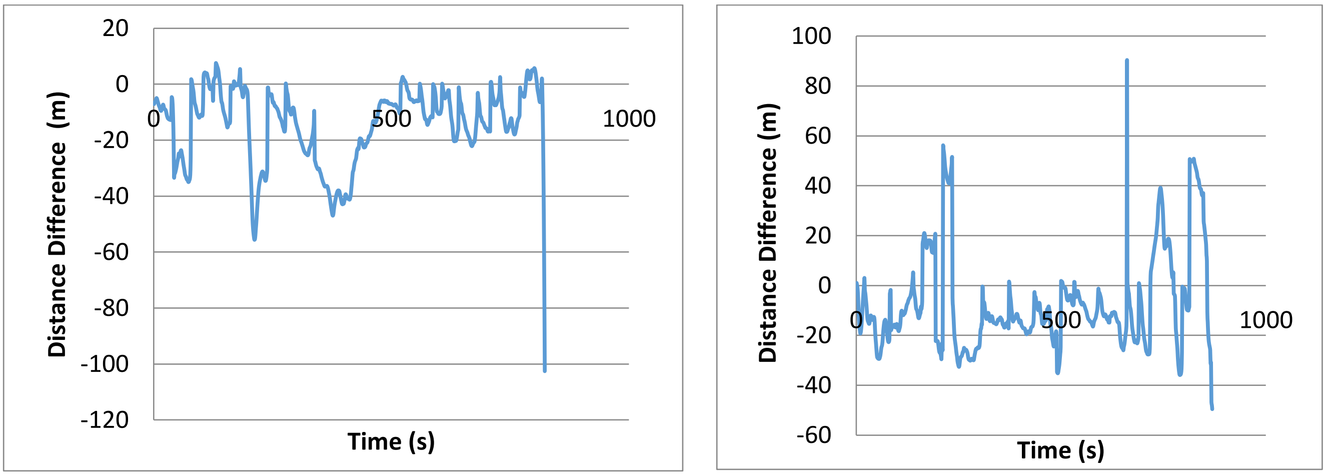

Figure 6. Time - Distance Spacing of Bus following; from Edinburgh to Polton (Left) and Polton to Edinburgh (Right)

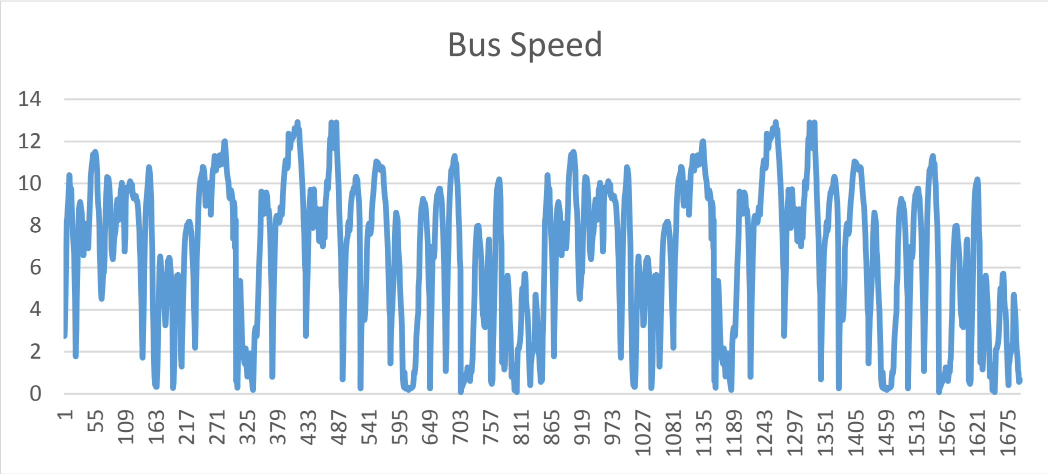

Figure 7. Shows Bus Speed Profile

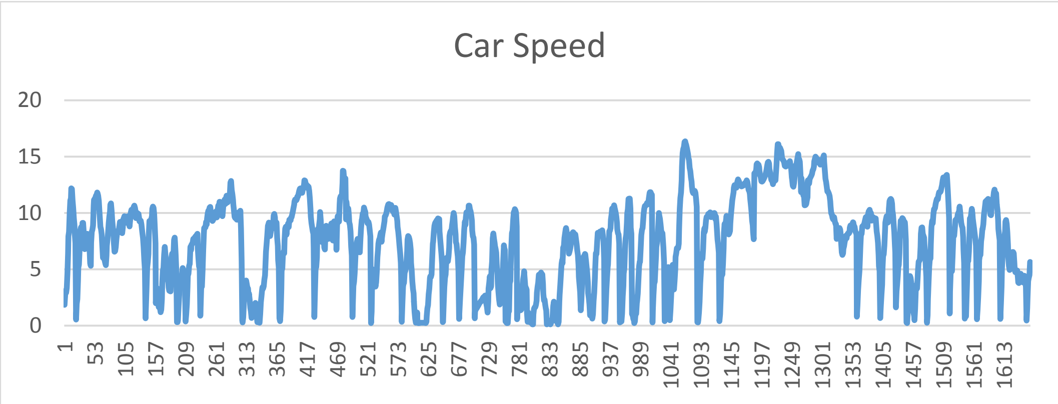

Figure 8. Shows Car Speed Profile

7. Conclusions

For this study, an instrumented vehicle in a mixed traffic lane (*i.e.*, no lane restrictions) followed a commuter bus which is equipped with a GPS based Performance Box from the City of Edinburgh to Polton Town Centre and the nearby towns and to the start point of the experiment in the City of Edinburgh. A bus following model was developed from the real traffic data which was collected during the experiment in Edinburgh and the surrounding areas. Using this model, it will allow shedding some lights on the safe following distance difference for a vehicle following a commuter bus in both urban and rural areas; which is not been researched before.

The findings from this study show that the behaviour of a car following a commuter bus i.e. large vehicle is influenced by the large vehicle (bus) and traffic characteristics. Due to the nature of the bus and the repeated stopping and driving pattern, this is a different case than following any other large vehicle such as a commercial vehicle for example, which contributed to further delays. Some of the observations during the experiment include observing lots of delays for the bus especially during peak hours. The car driver reported that following a bus was quite stressful due to the stopping/start nature of the bus driving patterns.

Also, results show that following a bus doesn't allow the car driver to be able to see ahead of him since the bus is a much larger vehicle than the car and therefore was blocking the vision for the car driver. This is common for most drivers when following behind a large vehicle (in this case, a bus) where they cannot see other vehicles immediately in front of the large vehicle in order to assess the condition of the traffic ahead. Our study shows that the average speed and acceleration of the commuter bus in the acceleration regime was higher than the average speed and acceleration of the instrumented vehicle following behind. However, in the deceleration regime, the average speed of the commuter bus was less than the average speed of the instrumented vehicle but the average deceleration of the commuter bus was higher than that of the instrumented vehicle.

In this study, the data collected was mainly obtained by using one driver. Further studies can investigate impacts of various drivers characteristics on the results. Further exploration of the the delays and stopping times patterns and impacts on emissions can also be investigated.We applied our data set on the general GHR model and produced calibration parameters that agree with some of the calibration parameters in the literature (Brackstone and Mcdonald, 1999). For future research into the bus following behaviour, we suggest that more data should be collected on different roads and at different times of the day and if possible include dedicated bus lanes (*i.e.*, with lane restrictions) to study the variability of driver behaviour in city centres where there are more bus journeys.

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