TESTING VISUAL ANGLE CAR FOLLOWING MODELS USING DIFFERENT SETS OF DATA

Jalal Al-Obaedi

PhD student

University of Salford

Saad Yousif

Senior Lecturer

University of Salford

Abstract

The basic assumption in visual angle car following models is that the following distance between successive vehicles is a function of the object (i.e. leading vehicle) width. This paper examines the validity of this assumption using two types of data. Published real traffic data from instrumented vehicles in the USA and Germany have been used to check the ability of these models to replicate real traffic movements when both leading and following vehicles are “small cars”. Also, another type of data was used based on over 4 million cases of individual vehicles which have been abstracted from inductive loop detectors installed on the M25 and the M42 motorways in the UK. The data was then filtered and analysed to examine the following distance according to the type of the leader (i.e. Car or Heavy Goods Vehicle - HGV). The results show that while the visual angle car following models can successfully replicate real traffic movements based on the instrumented vehicles data, the assumption of leaving larger following distance if the leader is an HGV is found to be not the case for the majority of UK drivers. This will have a negative impact on the use of visual angle car following models to represent real traffic behaviour.

Keywords: Visual angle; car following; leader type; instrumented vehicle

1 Introduction and Background

According to Hoffman and Mortimer (1996), visual angle car following models can be represented using the assumption that the following distance (clear spacing) between successive vehicles is a function of the leading vehicle’s width. The angular velocity (θ) can be represented by the following equation:

$$\theta = 2\tan^{-1}\left(\frac{w}{2H}\right) \qquad \text{…. Equation 1}$$

Where:

w is the width of the leading vehicle, and

H is the clear spacing between the leading and the following vehicles.

Once the angular velocity is exceeded, these models assume that driver decision is to accelerate with a sign opposite to the sign of the angular velocity (Ferrari, 1989). This assumption results in the following distance to be affected by the type of the leading vehicle (i.e. a car following another car (C-C) having closer distance compared with a car following a heavy good vehicle(C-H)). Although some researchers suggested that this is a logical assumption, there has been a real argument about this assumption as shown below.

Parker (1996) examined the following distance between successive vehicles travelling in a platoon (assuming a maximum time headway of 5 seconds as a criteria for identifying platoons) on some sections of roadwork sites. The speed classes considered were 20-30 km/hr and 60-70 km/hr in order to represent lower and higher speeds at these sites. To estimate the following distance, average lengths of 4.2m and 11.2m for cars and HGVs, respectively were used. The results showed that the clear spacing between C-H was slightly less than that in the case of C-C.

This paper is produced and circulated privately and its inclusion in the conference does not constitute publication.

Yoo and Green (1999), based on a total sample size of 768,000, found that the following distance in the case of C-C was 10% less than that in the case of C-H. The study did not use any limitations for maximum headway or maximum speed difference.

Sayer *et al.* (2003) compared the average following distance between the cases where the leader is a passenger car with the cases where the leader is a light truck for speeds higher than 64 km/hr. The study used 108 participants to drive an instrumented passenger car. The maximum headway of 3 sec was used while the maximum difference in speed between the leader and the follower was 1.5m/sec. A total of 1845 cases were used to establish that light trucks were followed by 5.6 m (0.19 sec) shorter than when passenger cars were followed.

Recently, Brackestone *et al.* (2009) used data from an instrumented vehicle to study the effect of the leader on the gap headway (from rear of the leader to the front of the subject vehicle) in urban and rural areas in the UK. Data were obtained from six primary drivers while they were driving the instrumented vehicle and 123 drivers while they were following the subject (instrumented) vehicle. A maximum following headway (gap headway) of 2 sec was used while speeds were grouped for every 5m/sec. Cases where the acceleration exceeds +0.6m/sec^2 were ignored based on a study by Sultan (2000). The main finding of their study was that trucks/vans are followed by a shorter distance than that where cars are followed.

This paper, firstly, examines the ability of the visual angle model (which was previously described by Al-Obaedi and Yousif (2009)) to replicate real traffic movements when both leading and following vehicles are “small cars” using published real traffic data from instrumented vehicles in the USA and Germany. The assumption of leaving higher following distance when the leading vehicle is an HGV rather than a small car is then examined through analysing a larger database of individual vehicles extracted from inductance loop detectors on the Active Traffic Management section of the M42 motorway J5-6, as well as data from the M25 motorway J15-16.

2 Testing the visual angle model based on data from instrumented vehicles

2.1 Description of the data

Two sets of published data from instrumented vehicles have been used to test the capability of the visual angle model to replicate real traffic movement when both the leader and the follower vehicles are “small cars”. The first set (Data set 1 from Germany) is taken from Panwai and Dia (2005) which is based on two vehicles’ trajectories while these vehicles are travelling at stop-and-go conditions for a distance of 2.5 km and for a period of 300 seconds. The speed range was between 0 and 60 km/hr. The second set (Data set 2 from the USA) is taken from Sauer and Andersen (2004) where the instrumented vehicle follows its leader with speeds between 95 and 120 km/hr for a period of 120 seconds.

2.2 Method of testing

A simple simulation program using Visual FORTRAN has been prepared based on the visual angle model assumptions described by Al-Obaedi and Yousif (2009). For each data set, the input data of the program represents speeds and positions of the leading vehicle at each time interval (taken as 0.5 sec), initial speed of the follower and the initial spacing between the two vehicles. The program outputs are speeds, positions and the clear spacing of the follower vehicle at each time interval. The comparison between the actual and the simulated results has been made using the actual and simulated clear spacing at each time interval. The Root Mean Square Error (RMSE) has then been calculated for each case using Equation 2.

$$RMSE = \sqrt{\frac{(ds - da)^2}{n}} \qquad \text{...Equation 2}$$

Where:

ds is the simulated spacing between two vehicles (m).

da is the actual spacing between two vehicles (m).

n is the number of observations.

2.3 Simulation results

Figures 1 and 2 represent the comparison between the actual and simulated following distance for Data set 1 and Data set 2, respectively. The RMSE is shown in each figure (i.e. 4.09 and 4.43, respectively). Both figures show good agreement between the actual data and simulated results.

It is worth mentioning that Data set 1 has been used extensively in evaluating many of the well known microscopic simulation models such as PARAMICS (Duncan 1995), VISSIM (Wiedmann 1974) and AIMSUN (Barceló *et al*., 1996). The best result (i.e. lower RMSE) was achieved by the AIMSUM model where the RMSE value was 4.99 (Panwai and Dia, 2005). For both sets of data and using the visual angle model, the RMSE values are below 4.99 (see Figures 1 and 2). This gives the impression that the visual angle model fits the actual data (for these two cases) reasonably well.

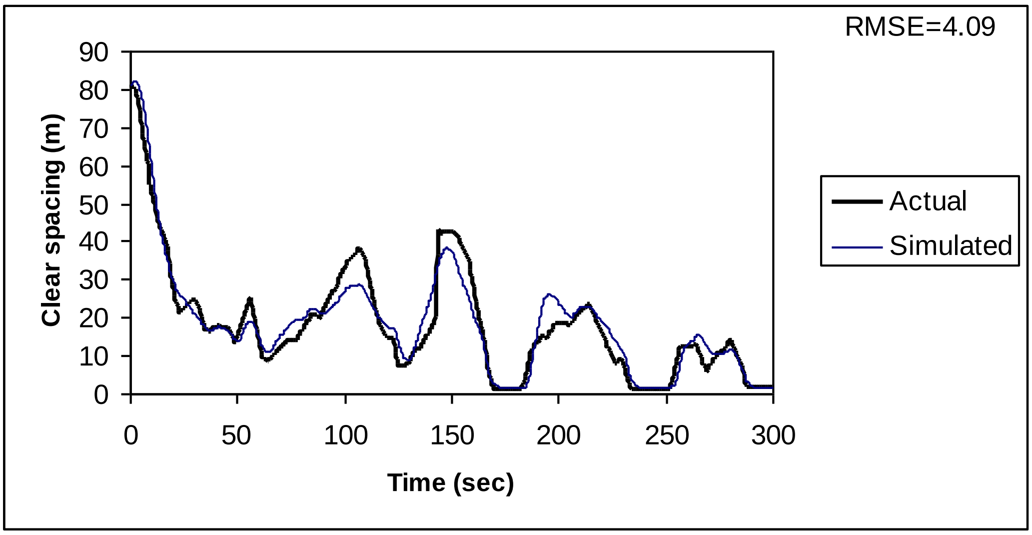


Figure 1 Actual and simulated following distance for Data set 1 (from Germany)

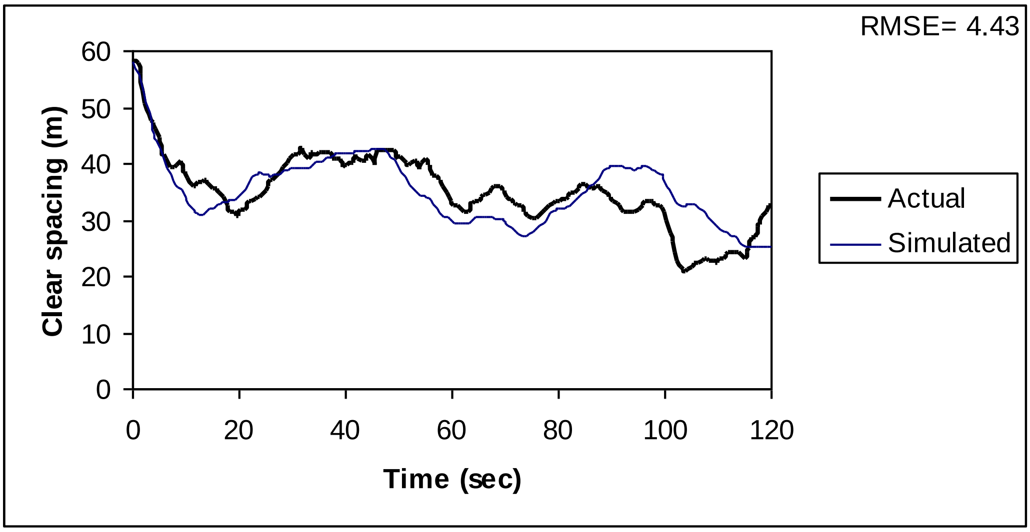


Figure 2 Actual and simulated following distance for Data set 2 (from the USA)

This paper is produced and circulated privately and its inclusion in the conference does not constitute publication.

3 Examining the following distance according to type of leader

3.1 Description of the data (from the UK)

A full 14 days of individual vehicles raw data, extracted from inductance loop detectors on the Active Traffic Management section of the M25 J15-16 and the M42 J5-6 motorways, are used. The data represent speed, headway and length for each vehicle reaching the detector for each specific lane and directions. The whole data represents more than 4 million leader/follower cases.

3.2 Methodology

This section describes the methodology that has been used to filter and analyse the data according to the type of leader. The main purpose of the filtering process is to exclude any cases of "free flow" conditions and concentrate on those cases with "close following".

3.2.1 Defining the types of vehicles

The types of vehicles are not defined by the provided data (i.e. Cars or HGVs). Therefore and for the purpose of this study, each vehicle' type is identified from its length. The lengths of vehicles are investigated from typical manufactures data sources. Mainly three types of vehicles are considered, these are Cars, Vans and HGVs. Table 1 represents a summary for typical ranges of lengths commonly found on British roads for each vehicle type.

Table 1 Typical ranges of lengths of vehicles

Vehicle type	Length	Remarks
Cars	2.6-5.4	Limousine vehicle not considered
Vans	3.4-6.4	Include small vans
HGVs	5.6-25.5	Including light goods vehicles

While the table suggests a value of 5.4m as the limit between Cars and HGVs, it is not possible, for example, to distinguish Cars from Vans or Vans from HGVs just by considering the lengths obtained from the data. Other researchers include Vans and HGVs in one category when comparing the following distance in the case of C-C and C-H (For example, see Sayer *et al.* (2003) and Brackestone *et al.* (2009)). Therefore and in order to satisfy the assumption that Cars and HGVs are not combined in one group, it was decided to exclude such uncertainty within the lengths of vehicles. For this reason, a value of 4.5m has been used as a maximum length for Cars and a value of 7.0m as a minimum length for HGVs. This means that any vehicle with a length between these two values is ignored and not considered in the calculations.

3.2.2 Selection of the maximum (critical) headway for "following behaviour"

Vehicles are travelling on a specific roadway section are either in free, following or emergency regimes (Yang and Koutsopoulos, 1996). A free vehicle is unaffected by the preceding vehicle due to either a large spacing between the vehicles or because the speed of the leader is much higher than that of the follower. A following vehicle is forced to travel at a speed close to that of the leader due to absence of opportunity of overtaking (Bennett, 1994). Therefore, critical headway (Bennett, 1994) is the limit between the free and following regimes. An emergency case happens when a vehicle is forced to travel with a headway less than the driver's desired due to for example forced lane changing.

Different values for critical headway have been suggested according to previous research work. Table 2 gives some of the critical headways values which have been used in different countries.

The table suggests that the critical headway varying from 3-6 seconds. The study by Brackestone *et al.* (2009) uses gap headway (rear to front) instead of the time headway.

Table 2 Summary of critical headway values as used by different researchers

Critical Headway (sec)	Country	Reference
4	Australia	Bennett (1994)
3.0	New Zealand	Bennett (1994)
6.0	Canada	Bennett (1994) and Krumins (1988)
5.0	UK	Parker (1996)
3.0	USA	Sayer *et al.* (2003)
2.0 (representing gap headway)	UK	Brackestone *et al.* (2009)

For the purpose of this study, it is believed that drivers' decisions to accelerate or decelerate are mainly based on the clear spacing and relative speed between the successive vehicles. This assumption is supported by most of the existing car following models (see for example, Benekohal and Treiterer (1988), Gipps (1981), Hidas (1996)). Moreover, using of the critical headway based on the time headway criteria (from front to front) as used by the majority of previous studies will result in ignoring the effect of vehicle's length on driver's behaviour. Also, real traffic data suggests that the length of vehicles have increased in recent years. Based on the above, a value of 2.0 sec. for the gap headway as used by Brackestone *et al.* (2009) has been selected as the critical headway. This means the critical time headway (front to front) will be varying according to the length of the leading vehicle.

3.2.3 Selection of maximum relative speed difference for "following behaviour"

A value of 1.5m/s (5.4km/hr) is selected as the maximum speed difference between the leading and the following vehicles. This value is suggested by many other previous studies (see for example Sayer *et al.* (2003) and Zhang and Bham (2007)) to represent the maximum speed difference at steady state conditions (car following regime). Speeds are grouped in 10km/hr class intervals in order to check the clear spacing and the time headway between the successive vehicles for each speed class.

3.2.4 Analysing method

The raw data from the M25 and the M42 motorway sites combine all vehicles in all lanes and in both directions based on time events. Therefore it is necessary to separate the successive vehicles according to their lanes and their directions. A computer program using FORTRAN has been written for this purpose. The results are separated into files representing successive vehicles for each lane and for each site. These files have then been analysed further using another computer program to filter the data using the above described methodology (i.e. for vehicle type, critical headway and relative speed). The outputs of the later program are the average speed, headway and following distance for each speed class interval and according to the leading vehicle's type (i.e. C-C or C-H).

It should be noted that random sets of the results of this filtering process have been examined further for any errors or unusual/unexplained data. This examination process was done manually. In general the results of the filtering process seemed logical. However, in relatively very few instances, the results showed that there have been cases where the headway between successive vehicles was very small (i.e. less than 0.3sec) involving, in some cases, high speeds for successive vehicles. In practice, this is not possible and a closer manual look into such abnormal cases indicates that the inductance loop detectors have failed to recognise that this involve trailers (i.e. one long vehicle) rather than two vehicles (a leader and a follower with such small headways). Such cases were deleted from the final set of data which was used in the main analysis. . .

3.2.5 Size of the analysed sample

While the initial data represents over 4 million cases, Table 3 represent the size of the remaining sample after filtering the raw data for both the M25 and the M42 motorway sites. Since the outer lanes on motorways are usually not utilised by HGVs, the data for these lanes have been ignored.

Table 3 Size of the analysed sample

Speed (km/hr)	Sample size			
	M25		M42	
	C-C	C-H	C-C	C-H
10-20	969	26	392	7
20-30	1754	156	1046	74
30-40	3162	518	1459	233
40-50	5586	1086	2210	420
50-60	8626	1835	2696	575
60-70	9938	2177	3557	1018
70-80	14251	4514	9493	3341
80-90	26103	12217	26269	14307
90-100	38508	6063	48238	8628
100-110	40429	2405	42154	1840
110-120	22778	590	13006	256
120-130	6406	52	6678	55
Subtotal	178510	31639	157198	30754
Total	210149		187952	

3.3 Results and discussion

The results of the data analysis are shown in Figures 3 and 4 for the M25 and the M42 motorways, respectively. The figures compare the average following distance between the cases of C-C and C-H for each corresponding average speed class interval and for each lane.

In general, the figures show that the average spacing for the case of C-C is slightly higher than that for the case of C-H for speeds ranges of up to 50-60km/hr. For speeds higher than 80km/hr for the M25 and higher than 60 km/hr for the M42, the data from the inside lane (lane 1) suggest that the spacing between C-H is slightly higher (about 3% for the M25 and 4% for the M42) than that for the case of C-C. For other lanes and for other situations, the average spacing between C-C or C-H vary with no clear consistency.

These findings are in disagreement with the basic assumption used for the visual angle car following models where the spacing for the cases of C-H should be higher than that for C-C. This will have a negative impact on the validity of this assumption and hence on the use of visual angle car following models to represent real traffic behaviour.

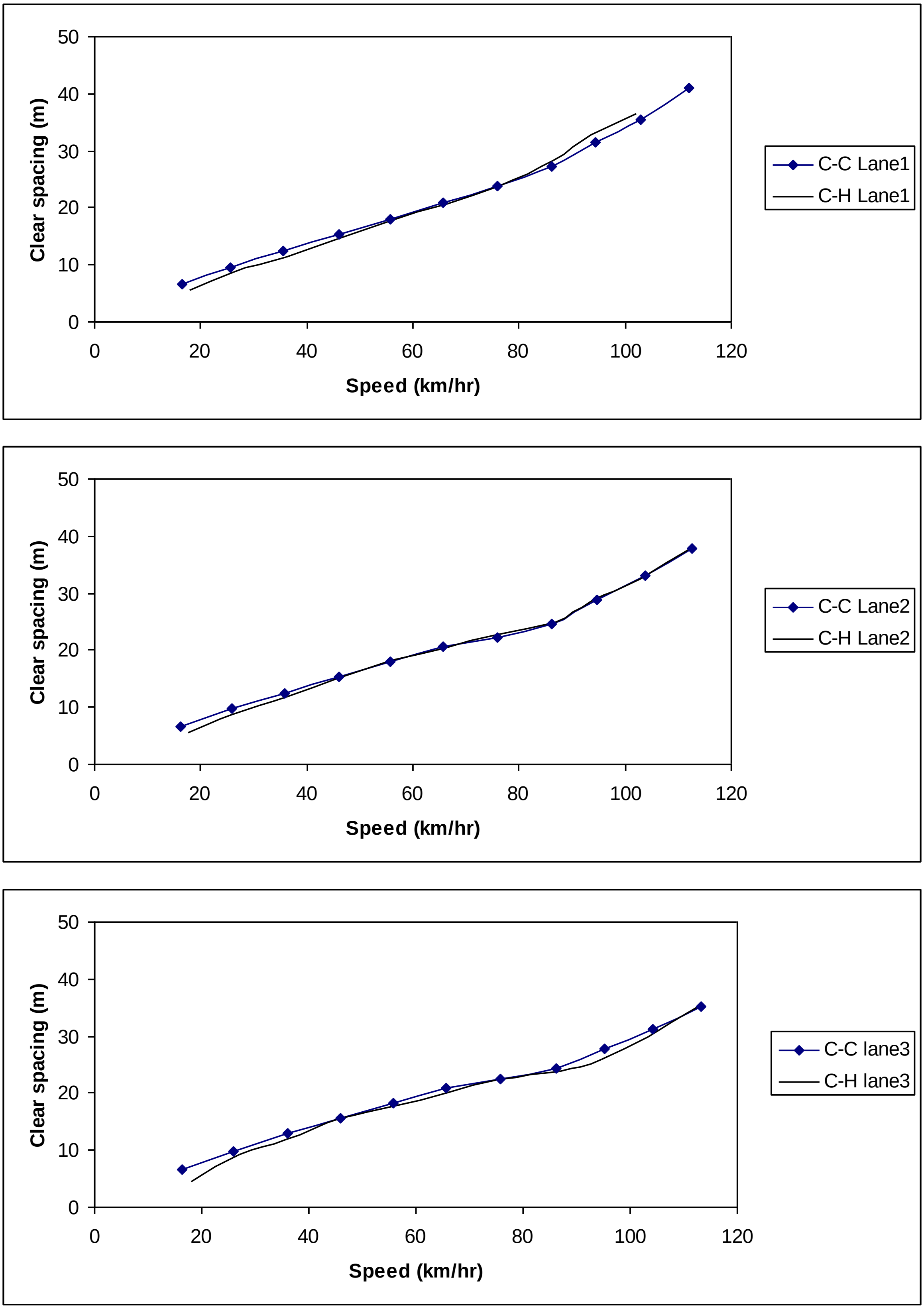
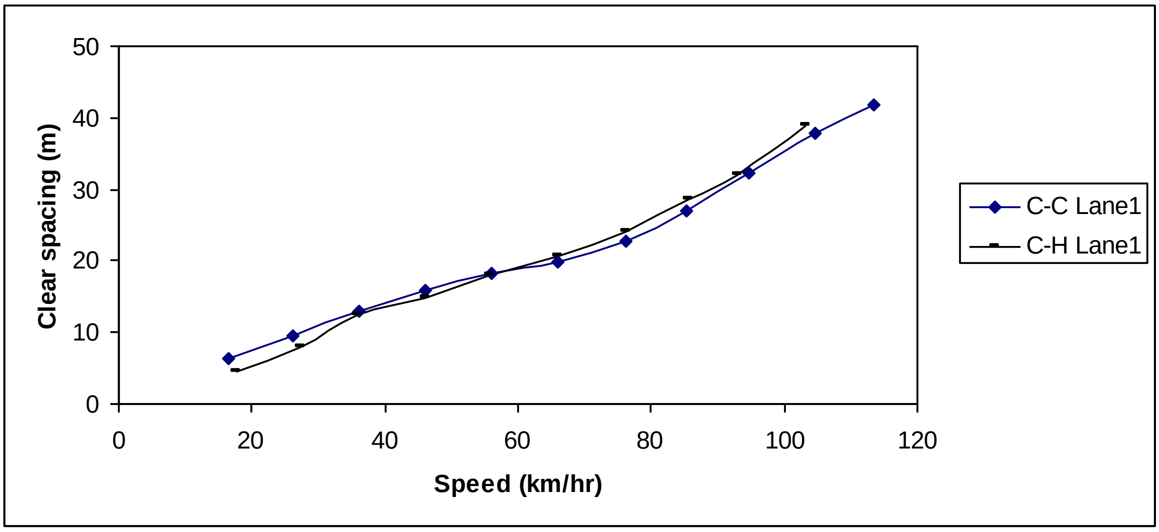


Figure 3 Average following distance for the M25

This paper is produced and circulated privately and its inclusion in the conference does not constitute publication.



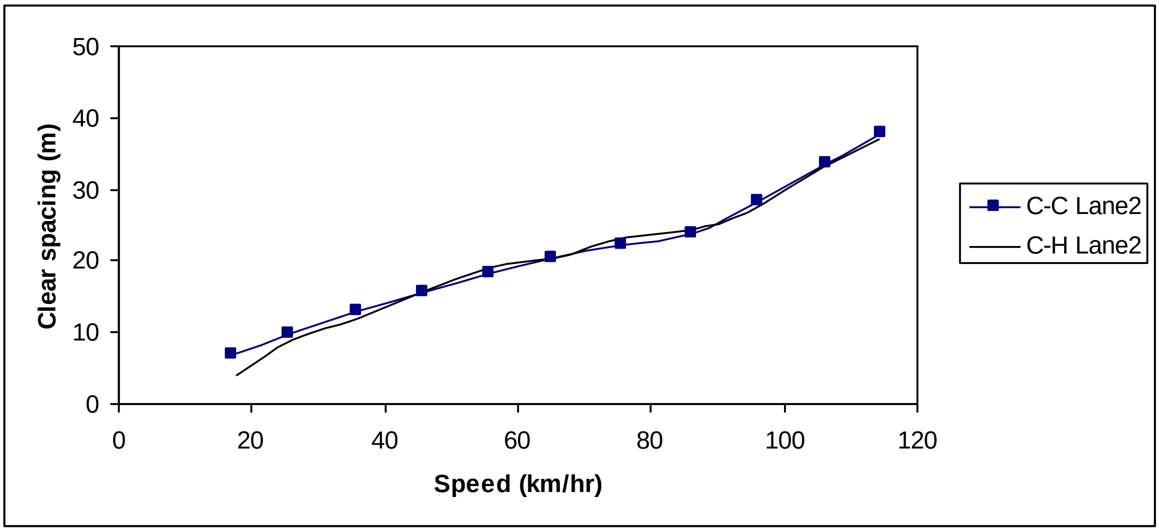


Figure 4 Average following distance for the M42

Comparing the results with other studies, these findings are in some disagreement with the above referred studies where the spacing for the case of C-C is either higher (Parker (1996), Sayer *et al.* (2003) and Brackestone *et al.* (2009)) or lower (Yoo and Green (1999)) than that for the case of C-H. The reasons for such differences could be summarised as follows:

- Some of the other studies did not test the following distance for all ranges of speeds. For example, Parker (1996) tested just two ranges of speeds of 20-30km/hr and 60-70km/hr and the study by Sayer *et al.* (2003) examined only the cases where speeds are higher than 64km/hr. In addition, there are some differences in defining maximum (critical) headway.
- The size of the data is much less than that used in this study.
- The study by Yoo and Green (1999) did not exclude free following cases from the given data.
- Most studies (except the study by Parker (1996)) used instrumented vehicles where the drivers may be informed about the purpose of the study and/or the behaviour of such drivers may be affected by the test conditions.

4 Conclusion and further work

Firstly, this paper examined the ability of visual angle car following model in replicating real traffic movement using published real traffic data from instrumented vehicles both from the USA and Germany. By comparing the simulated following distances (clear spacings) with those from the data, visual angle models are found to be able to replicate real traffic movements when both the leading and the following vehicles are "small cars".

Secondly, a large database of individual vehicles, extracted from inductance loop detectors on the Active Traffic Management sections of the M42 and the M25 motorways, has been used to examine the clear spacing between the successive vehicles according to the leader vehicle's type. Over 4 million leader-follower pairs were first filtered to ensure that "free-flowing" vehicles are excluded from the analysis using robust methodology for defining minimum headways and maximum speed difference. The data were then analysed for each individual site and for each individual lane. The main finding is that the clear spacing for the case of C-C is slightly higher than that for the case of C-H up to speed class interval ranges of (50-60)km/hr. For the inside lane (lane 1) in both motorways, the spacing for the case of C-H are higher that for C-C for speeds higher than 60km/hr. For other lanes, it seems that there is no difference between the cases of C-C and C-H. These findings give a negative impact on the use and the validity of visual angle car following models to represent real traffic behaviour. This is due to the fact that visual angle models enable the following distance for the case of C-H to be higher than the case of C-C for all ranges of speeds.

Comparing the results with other work, the findings from this study come in disagreement with most of other related previous studies. The main causes of such differences have been discussed in the paper.

Further work is needed to examine the effect of other factors such as the impact of weather on the following distance according to vehicles' types and the effect of speed limit controls on such distances.

Acknowledgment

The authors wish to thank Dr. Eddie Wilson (University of Bristol) for providing the individual vehicles raw data from the M25 and the M42 motorway sites.

References

Al-Obaedi, J. and Yousif, S. (2009) The use of visual angle in car following traffic micro-simulation models, **International Built & Human Environment Research Week (IRW)**. pp. 533-545.

Barceló, J., Casas, J., Codina, E., Fernández, A., Ferrer, J.L., García, D. and Grau, R. (1996) PETRI: A Parallel Environment for a Real-Time Traffic Management and Information System. **Proceedings of the 3rd World Congress on ITS (published on CD-ROM)**, Orlando, Florida, USA.

Benekohal, R.F., and Treiterer, J. (1988) CARSIM: Car-following model for simulation of traffic in normal and stop-and-go conditions. **Transportation Research Board** 1194, pp. 99-111.

Bennett, C. R. **A Speed prediction model for rural two-lane highways**. PhD Thesis, The University of Auckland, New Zealand

Brackestone, M., Waterson, B. and McDonald, M. (2009) Determinants of following distance in congested traffic. **Transportation Research Part F**. Volume (12) pp. 131-142.

Ferrari, P. (1989) The effect of driver behaviour on motorway reliability. **Transportation Research: Part B**, Volume (23B), No. 2, pp. 139-150.

Gipps, P. G. (1981) A behavioural car following model for computer simulation. **Transportation Research Part B**, Volume (15) pp. 105-111.

Duncan G.I., (1995) PARAMICS wide area Microscopic Simulation of ATT and Traffic Management, **28th ISATA Conference**, Stuttgart, Germany.

This paper is produced and circulated privately and its inclusion in the conference does not constitute publication.

Hidas, P. (1996) A car-following model for urban traffic simulation. **Traffic Engineering and Control**. Volume (39) p.p. 300-305.

Hoffman, E.R. and Mortimer, G.R. (1996) Scaling of relative velocity between vehicles. **Accident Analysis and Prevention**, Volume (28), Issue 4, July 1996, pp. 415-421.

Krumins, I.V. (1988). **Modelling Headway Distributions on Two-Lane Highways**. Report to Alberta Research Council, Edmonton.

Panwai, S. and Dia, H. (2005). Comparative Evaluation of Microscopic Car-Following Behaviour. **IEEE Transactions on Intelligent Transportation System**, Vol. 6, No. 3, pp. 314-325.

Parker, M.T. (1996) The Effect of Heavy Goods Vehicles on Following Behaviour on Capacity at Motorway Roadwork Sites. **Traffic Engineering and Control**, 37(8), pp. 524-531.

Sauer, C. and Andersen, G. J. (2004) **Detection and Avoidance of Collisions: the REACT Model**. Research reports, Institute of Transportation Studies, California Partners for Advanced Transit and Highways (PATH). University of California, Berkeley.

Sayer, J. R., Mefford, M. L., and Huang, R. (2003). The effect of lead vehicle size on driver following behaviour: Is ignorance truly bliss? **In Proceedings of the second international driving symposium on human factors in driver assessment**, training and vehicle design, University of Iowa.

Sultan, B. (2000). **The study of motorway operation using a microscopic simulation model**. PhD Thesis, University of Southampton, UK.

Wiedemann, R. (1974) "Simulation des Straßenverkehrsflusses," vol. Heft 8, Karlsruhe, Germany: Instituts für Verkehrswesen der Universität Karlsruhe.

Yang, Q. and Koutsopoulos, H. (1996). Q. Yang and H. Koutsopoulos , A microscopic simulator for evaluations of dynamic traffic management systems. **Transportation Research Part C**, pp. 113–129.

Yoo, H., and Green, P. (1999). **Driver behaviour while following cars, trucks and buses**. Report No. UMTRI-99-14. Ann Arbor, MI. The University of Michigan Transportation Research Institute.

Zhang, X. and Bham, G.H. (2007) Estimation of driver reaction time from detailed vehicle trajectory data. **Proceeding of the 18th IASTED International Conference**, pp. 574-579.