

DEVELOPING A NEW HYBRID SAFETY CAR-FOLLOWING MODEL

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Abstract

For more than five decades, car-following models have been developed based on different theoretical backgrounds and conditions. The importance of these models belongs to their representation of longitudinal movement for any simulation model. Therefore, the accuracy of the car-following model is still the core of strength of any simulation model. For the purpose of this study, a hybrid car-following model has been developed to represent "go and stop" conditions. These conditions mostly occur in a weaving section. This model has been developed as a corner stone for a microscopic simulation model of representation of driver behaviour at a weaving section. A new condition that improves a driver behaviour in a situation at which the driver should not accelerate under specific condition as approaching from decelerated leading vehicle. Some assumptions of this model have been adopted from the **CARSIM** model. After developing this model using Visual Compact Fortran (version 6.5), the developed model has been calibrated with a set of field data from Germany. The results show that this model is more reasonable than other models such as **Paramics**, **VISSIM, AIMSUN** and **CARSIM** using the same set of data. This model show significantly improvement in representing the reality than the others.

Keywords: AIMSUN, Car-Following Model, CARSIM, Paramics and VISSIM.

الخلاصة

لقد طورت نماذج التتابع للمركبة (Car-Following Models) في العقود الخمسة الماضية بناءاً على قواعد وظروف نظرية مختلفة. ان اهمية تلك النماذج تعود الى تمثيل الحركة الطولية لاي نموذج محاكاة، لذافان نموذج تتابع المركبية (Car-Following Model) يعتبر الجزء الاساس في التعبير عن قوة نموذج المحاكاة.ان الغرض من هذه الدراسة هو تطوير نموذج محاكاة لتمثيل ظروف الذهاب والتوقف والتي غالبا ما تحدث في مقطع المناورة (Weaving Section). يعتبر النموذج المعد في هذا البحث كحجر اساس لبناء نموذج محاكاة يمثل سلوك السائق في مقطع المناورة (Weaving Section). يعتبر المحد في هذا البحث تم وضع شرط جديد لتحسين سلوك السائق وهو عدم تاوز السائق التعجيل التسارعي للمركبة الخاصة به في حالة اقترابه من مركبة متبلطئة. لقد تم تبني بعض الفرضيات الحاصة بنموذج المناورة (Visual Compact Fortran (Version 6.5). في هذا البحث تم وضع يرط جديد لتحسين سلوك السائق وهو عدم ومعايرته مع بيانات حقلية من المانيا. لقد بينت النتائج ان هذا الموذج هو الاكثر واقعية من النماذج الاخرى مثل: ومعايرته مع بيانات حقلية من المانيا. لقد بينت النتائج ان هذا الموذج هو الاكثر واقعية من النماذج الاخرى مثل: ومعايرته مع بيانات حقلية من المانيا. لقد بينت النتائج ان هذا النموذج هو الاكثر واقعية من النماذج الاخرى مثل: ومعايرته مع بيانات حقلية من المانيا. لقد بينت النتائج ان هذا النموذج هو الاكثر واقعية من النماذج الاخرى مثل: ومعايرته مع بيانات حقلية من المانيا. لقد بينت النتائج ان هذا النموذج هو الاكثر واقعية من النماذج الاخرى مثل: ومعايرته مع ورد اعلاء يظهر ان التحسينات التي اعتمدت في بناء هذا النموذج كانت اكثر قبوليه في تمثيل الواقع من بقية النماذج المعروفة والتي تم الاشارة اليها اعلاه.



1. Introduction

The selection of the suitable car-following model is a crucial task in developing a simulation model. Therefore, different car-following models have been developed and tested. These models are GHR, CARSIM, AIMSUN, WEAVSIM and Paramics (Gazis *et al.*, 1960; **Beneckohal**, 1986; Zarean, 1987; and Panwai and Dia, 2005). The assumptions of GHR, CARSIM and WEAVSIM have developed using Visual Compact Fortran as test bed. Then, they have been tested under different sets of data including different traffic conditions. The results of these tests showed that CARSIM is the more reasonable in replicating the reality among the others in representing different traffic conditions (AL-Jameel, 2009 and 2010). Therefore, some of the CARSIM assumptions have been adopted to develop this carfollowing model. Accordingly, a new car-following model has been developed. This model was developed to represent the weaving section. High interactions and stop and go conditions need considerable attentions to be correctly represented. So, this was down by selecting the suitable limits of reaction time, buffer spacing, start-up delay and other characteristics as discussed in the following sub-sections.

This model has been developed based on the assumptions adopted from **CARSIM** model as mentioned in the above paragraph. Each assumption governs the behaviour of the following vehicle in terms of the amount of acceleration/deceleration that would be produced.

1. Methodology

The methodology for this study is summarised by showing the main assumptions of the acceleration that have been adopted by this model and then explaining the calibration of the model with field data.

2.1 Acceleration Procedure

The acceleration procedure represents the main parts of the car-following model because it governs the nature of response of the following vehicle as shown in **Figure1**.





Fig. 1 Acceleration Flow-Chart for the Developed Car-Following Model.

2.2 Desired Speed Conditions

When a driver is not constrained by his/her leader, he will drive to reach his/her desired speed. This speed represents the maximum speed that a driver tries to reach when there are no other constrains such as a vehicle ahead, speed limit, and bad weather conditions. If there is no obstruction ahead of the subject vehicle, the driver will drive to reach this speed which is generated once a vehicle enters the system from a truncated normal distribution (with mean and standard deviation either assumed according to the type of road or determined from field data). A driver uses the normal acceleration in order to reach his/her desired speed. Therefore, the acceleration obtained from this condition could be represented by this symbol ACC_A .



2.3 Vehicle Mechanical Ability Condition

As the vehicle is generated in the system, the type of each vehicle is assigned as either a passenger car or a heavy good vehicle. A passenger car has more mobility in the movement and manoeuvre because of its short length and light mass. These differences in these characteristics have been translated in the amount of acceleration/ deceleration that can be achieved by each type of vehicles (ACC_B) as shown in Table 1.

 Table 1 Maximum Acceleration & Deceleration of Passenger Cars (ITE, 1999).

Speed (km/hr)	0-32	32-48	48-64	64-80	80-96	>96
Max acceleration (m/s ²)	2.4	2.0	1.8	1.6	1.4	1.4
Max deceleration (m/s ²)	4.9					

2.4 Slow Moving Conditions

When a vehicle moves slowly due to platoon conditions, the spacing between this vehicle and its leader is governed by the length of the leading vehicle and the buffer space between the two vehicles. This buffer space has different values ranging from 1.8m to 3m and its value depends on the type of a vehicle (Benekohal, 1986 and Yousif, 1993). The smaller value is used for a passenger car and is higher than a HGV. However, different studies reported the opposite, i.e., passenger car following HGV with smaller headway than passenger car following passenger car (Sayer *et al.*, 2003 and Brackstone *et al.*, 2009). In addition, these studies included different conditions such as low and high speed, the gender of driver and his/her age. Therefore, the buffer space was used as a constant value in this model.

The acceleration obtained from this case is determined according to the following conditions which are governed by the following equations (Benekohal, 1986):

POSL-POSF >= L+ BSeq.(1)

 $POSL-(POSF+SPF+0.5((ACCc)Dt^{2}) - L-BS \ge 0.0...eq.(2)$

$$ACCc = \frac{POSL - POSF - SPF - L - BS}{0.5Dt^2} \dots eq.(3)$$

Where;

POSL=position of leading vehicle (m). POSF=position of following vehicle (m). SPF= speed of follower (m/s). ACCc= acceleration of following vehicle due to slow conditions (m/s²). Dt= scanning time (sec).

2.5 Stopping Distance Conditions

To satisfy the safety conditions for a vehicle within the developed model, a sufficient space must be provided at every time of scanning to stop safely even the leading vehicle stops suddenly. The acceleration or deceleration that satisfies this condition can be determined from the following equations (Benekohal, 1986):-



POSL-(POSF+SPF+0.5*ACC_D *Dt²) -L- BS>= maximum of (SPF+ ACC_D *Dt)RT or $(SPF+ACC_{D} *Dt)RT+ (SPF+ACC_{D} *Dt)^{2}/(2MDF)-(SPL)^{2}/(2MDL) \dots eq.(4)$ Consequently, the solution of this equation will consist of two parts: The first part is:

 $ACC_{D} =$

And the second part is:

POSL-(POSF+SPF+0.5*ACC_D*Dt²)-L- BS >= SPF+ACC_D *Dt) RT+ (SPF+ ACC_D *Dt) $^{2}/$ (2MDF)-(SPL)²/(2MDL).....eq.(6)

Therefore, the minimum value from these two parts will be selected to represent the safe case at which a safe distance will be adopted.

Geometric characteristics have effects on the behaviour of drivers in any type of facility (HCM 2000). The coefficient of friction and grade of road have an effect on acceleration and deceleration of vehicles (Lee, 2008). The ITE (2010) reported that the maximum acceleration rate can be determined as:

 $ACC = f(g)(m/sec^2)$eq.(7) Where:

ACC is the maximum acceleration rate at a speed in level terrain (m/sec^2) .

f is the coefficient of friction.

g is the acceleration of gravity (9.81 m/sec^2) .

Whereas, the effect of grade can be expressed as:

ACC_v=ACC-(Gg)/100.....eq.(8)

where;

 ACC_g is the maximum acceleration rate at a speed on grade (m/sec²).

G is the gradient of the roadway segment (%).

2.6 Moving From Stationary Condition

When a vehicle stops under platoon conditions and then it tries to move due to the movement of the leading vehicle, its acceleration (ACC_E) in this case depends mainly on the type of this vehicle. Therefore, the amount of start-up delay, in this study, was taken as 1 second which is suitable for driver with shorter reaction time and 2 second which is suitable for the rest of drivers (Benekohal, 1986).

2.7 Approaching from a Deceleration Vehicle Condition

In this condition, when a vehicle approaching from another vehicle but there is a spacing less or equal to 76m and the difference in speed between the leader and follower is relatively high and the leader decelerates but according to the preceding conditions the vehicle needs to accelerate for a certain point and then decelerate. This is a high challenge for the existing safety car-following models and according to these models the driver behaviour at this



situation is unreasonable. Therefore, this condition has been adopted. In this condition, when a driver approaches from a decelerating vehicle and the separating distance is less or equal to 76m and the speed is increased, the speed of the vehicle in this case will be constant when the difference in speed is greater than 2m/sec. This is because that in reality, the driver seeing that his/her leader decelerates so he will not accelerate but try to maintain his speed for a certain distance and then take the appropriate action. The ACC_F represents the symbol of this acceleration.

2. Calibration of the Developed Car-Following Model

The calibration of car-following model has been implemented with sets of field data using statistical tests. The specifications of the statistical tests and field data will be explained in details in the following sections.

There are several tests: Firstly, the Root Mean Square Error (RMSE) which is considered from a good test to make a comparison between empirical and simulated data (Wu *et al.*, **2003 and Panwai and Dia**, **2005**).

$$RMSE = \sqrt{\frac{1}{N} \sum_{n=1}^{N} (Val1 - Val2)^2}....eq.(9)$$

Where;

Val1 and Val2 are the simulated and observed values, respectively.

N is the number of observations.

Secondly, the Error Metric (EM) is also used for comparing empirical and simulated data (**Panwai and Dia**, 2005). It can be expressed by the following equation:

$$\mathbf{EM} = \sqrt{\sum (\log \frac{\operatorname{Val1}}{\operatorname{Val2}})^2}....eq.(10)$$

The EM is used by **Panwai and Dia** (2005) as a measure of <u>precision</u> between the simulated and field data. This measure is affected by the number of points which are considered in the comparison of simulated and field data.

The field data was collected by the Robert Bosch GmbH Research Group. It was gathered by using an instrumented vehicle to record the relative speed and space headway (**Panwia and Dia**, 2005). This data consists of two vehicles: the leader and follower. This set of data provides a comparison of the distance between the leader and follower as shown in Figure 2. This set of data is characterised by: A range of speed between 0 and 60 kph.

- Three stop situations.
- The duration of this test is 300 seconds.

The selection of calibration parameters could be a serious issue. Basically, the developed car-following model can be classified as a safety model or non-collision model. Therefore, the reaction time is a critical factor that affects the spacing between the follower and leader and this parameter is taken from the accumulative curve according to **Johansson and Rumer** (1971). Several iterations have been implemented to select the suitable reaction time and then it is considered as a constant.

In brief, all characteristics of vehicles and drivers are considered constants and other factors have been changed. At this case, another condition has been used. In this condition,



when a vehicle at distance less or equal to 76 m from its leader and the latter decelerates. At this situation, the following vehicle will accelerate and then decelerate hardly and this behaviour is not realistic behaviour because the driver in reality can see the objects ahead according to his/her sight distance. This limit (76 m) has been selected according to two conditions. Firstly, it was reported that a following vehicle does not affect by its leader when the spacing between the following and its leading vehicle is greater than 76 m vehicles (Edie *et al.*, 1963 and Aycin, 2001). Secondly, different iterations have been carried out as shown in Figures 2 from case 1 to 6.However, this limit does not affect at case 1 to 3 because the following driver under the influence of its leader according to the assumption of the developed model and there is no chance for free following. Whereas, the 4th case (70) has the influence on the behaviour in the first part, free following case. This influence reduces from the difference between simulated and field data as shown in Figure 2-D and Table 2.

The 5th case of the iterations (76 m) shows how this condition improves the behaviour graphically and mathematically as shown in **Figure 2- E and Table 1- case 5**. However, the sixth case is still as the same as the fifth case without any change. This is because the limited distance, just few minutes, at which 80 m lasted so the effect of this case could not be considered. Moreover, the effect of length more than 90 m has been not considered because this set of data is within the limited spacing as shown in **Figure 2**.





A. Case 1



B.Case 2

Fig. 2 Calibration of Simulation with Observed Data using Different Effective Distances.





C. Case 3



D. Case 4





E.Case 5 Fig. 2 Continued

Figure 2 shows the difference of the spacing between the leading and current (following) vehicle and the time of test extending up to 300 seconds. The first part of this graph, up to 25 seconds, there is a difference from the observed data. This means that the behaviour in the free following case needs a correction. Moreover, there are other situations at which there are other differences between the simulated and observed data such as following at low speeds and at stop conditions.



F. Case 6 Fig. 2 Continued



Cases	Selected length	RMSE	EM	
1	40	4.73	2.02	
2	50	4.73	2.02	
3	60	4.71	2.02	
4	70	3.99	2.01	
5	76	3.49	2.01	
6	80	3.49	2.01	

Table 1 Different Effective Distances with their EM and RMSE Values.

Furthermore, **Figure 3** also shows the consistency between the simulated and the observed speed of following vehicle for the second case. On the other hand, another comparison has been implemented by using the same set of the data to calibrate other simulation models as indicated in **Table 2** with the developed model. **Table 2** shows each simulator with calculated values for each EM and RMSE. The minimum values of these measurements are corresponding with the AIMSUN. Whereas, the maximum values are for the paramics. Therefore, the AIMSUN is the best model among these models which mimics the reality. However, its value for the EM (2.55) is higher than the corresponding value obtained by the developed model (2.01). Moreover, the RMSE for AIMSUN (4.99) is higher than the value obtained by the developed model (3.49). Consequently, the developed model is the best among all these models in representing the car-following model.

Table 2 Performance of the Car-Following Model in the Selected Traffic Simulators(Panwai and Dia, 2005).

The		AIMSUN	VISSIN	Paramics		
Simulator	Developed Model	(4.15) Wiedemann 74		Wiedemann99	(v4.1)	
EM	2.01	2.55	4.78	4.50	4.68	
RMSE	3.49	4.99	5.72	5.05	10.43	





Fig. 3 Simulated Follower Speeds with Field Data.

3. Conclusions and Recommendations

The main conclusions that can be summarised from this study are:

- The graphical representation and mathematical tests (EM and RMSE) show that the developed model is closer to the observed data than other models such as the AIMSUN (4.15), VISSIM (v3.70) and Paramics (v4.1).
- The new condition adopted in this study has improved the developed model by reducing amount of error between the model and observed data (reducing the value of RMSE from 4.99 to 3.49).
- The developed car-following model could be the fundamental step to represent different sections such as merging, diverging and weaving.

5. References

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Notations

ACCc	Acceleration of following vehicle due to slow conditions
	(m/s^2) .
BS	Buffer space (m)
Dt	Scanning time (sec).
f	The coefficient of friction.
g	The acceleration of gravity (9.81 m/sec ²).
G	The gradient of the roadway segment (%).
L	Length of vehicle (m)
MDF or MDL	Maximum deceleration for follower and leader, respectively.
POSF	Position of following vehicle (m).
POSF	Position of following vehicle (m).
POSL	Position of leading vehicle (m).
POSL	Position of leading vehicle (m).
RT	Reaction time (sec).
SPF	Speed of follower (m/s).
SPF	Speed of follower (m/s).
SPL	Speed of leader.