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Al-Jameel, HAE

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## **Evaluation of Car-following Models Using Field Data**

**Author: Hamid A.E. Al-Jameel (*Research Institute: Engineering Research Centre*)**

### **Abstract**

Traffic congestion problems have been recognised as a serious problem in all large urban areas. It significantly reduces in urban mobility. Therefore, it has become a major concern to the transportation and business community and to the public in general. Different techniques have been proposed to alleviate this problem. One of these is Traffic simulation technique. It has been used effectively because they can represent real life, to some extent, and apply different strategies without the need to make physical change on site before implementing such strategies. Car-following models represent the basic unit that governs the longitudinal movement for each traffic simulation model. The efficiency of a traffic simulation model does mainly depend on its core units: car-following and lane changing.

In this study, three car-following models (namely, CARSIM, WEAVSIM and PARAMICS) were tested. The first two of these models were rebuilt using Visual Compact FORTRAN Version 6.5. The models were tested using three different sets of data from single lane traffic. These sets of data have been collected using two different methods of collecting data from three regions. In addition, different traffic conditions have been included in this data such as high speed, low speed and “stop and go conditions”.

The results indicated that CARSIM gave the most accurate representation of real life situations. Therefore, the assumptions of this model were adopted in a newly developed model to represent traffic behaviour in weaving sections to evaluate the factors affecting the weaving capacity.

Keywords: Traffic micro-simulation, car-following model, CARSIM and WEAVSIM.

### **1. Introduction**

Traffic congestion problems have been recognised as a serious problem in all large urban areas. It significantly reduces in urban mobility. Therefore, it has become a major concern to the transportation and business community and to the public in general. Different techniques have been proposed to alleviate this problem. One of these is Traffic simulation technique. It has been used effectively because they can represent real life, to some extent, and apply different strategies without the need to make physical change on site before implementing such strategies. Car-following models represent the basic unit that governs the longitudinal movement for each traffic simulation

model. The efficiency of any traffic simulation model depends mainly on the accuracy of the car-following and lane changing assumptions (Panwia and Dia, 2005).

In this study, the algorithms of three car-following models are explained briefly and the results of testing these models using different sets of data are also illustrated.

## 2. Car-following models

Several car-following models have been proposed to govern the longitudinal movement of vehicles in a traffic stream as shown in Figure 1. Pipes (1967) suggested that the follower normally maintained safe time headway of 1.02s from its leader. This value was extracted from a recommendation in the California Vehicle Code (Choudhury, 2007). These models were then followed by various models with different theoretical backgrounds and assumptions.

In general, car-following models can be classified into three groups; Sensitivity-stimulus, safety or non-collision criteria and Psychophysical models (Olstem and Tapania, 2004).

Firstly, sensitivity-stimulus models, these models were introduced by GM Research Laboratories and represent the basis for most models to date. The Gazis-Herman-Rothery (GHR) model represents this group. This model was tested under three sets of data with different parameters (linear and non-linear). Different thresholds have been suggested to indicate the following behaviour from free-following (Al-Jameel, 2009). However, this model is still unable to mimic most traffic conditions. In addition, there is no obvious connection between the model parameters and driver's characteristics as reported by Gipps (1980). Therefore, it is unable to represent the car-following in the weaving section because of complex traffic behaviours such as stop and go conditions.

Secondly, safety or non-collision criteria models assume that a driver maintains a safe distance between him/her and the leader to prevent a collision at any time of movement (Brackstone and McDonald, 1999). CARSIM and WEAVSIM are examples for this group.

Thirdly, psychophysical models assume that a driver will respond (acceleration or deceleration) after a certain threshold. This threshold can be represented by a relative speed or a distance (Brackstone and McDonald, 1999). PARAMICS is a good example of this group.

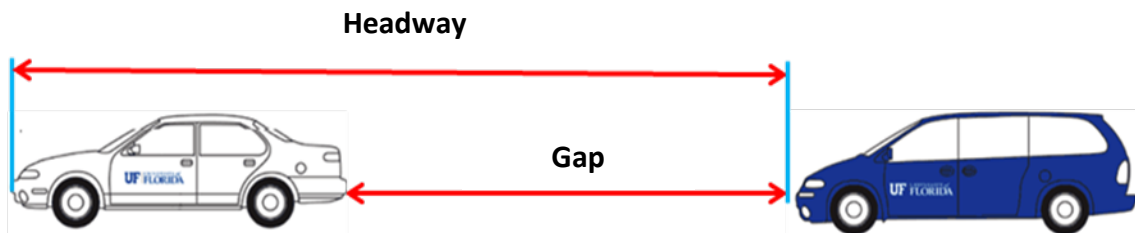


Figure 1 Longitudinal (headway) space between leading and following vehicles.

The algorithms of CARSIM, WEAVSIM and PARAMICS are briefly explained in the following sub-sections.

## 2.1 CARSIM model

CARSIM (CAR-following SIMulation) is a freeway simulation program. This model has been developed according to some of the assumptions that have been introduced by Benekohal and Treiterer (1988). In the model, five situations were used to describe the degree of response (acceleration or deceleration). These situations are:

- If there is no restriction from the preceding vehicle, the driver will drive to reach his desired speed or speed limit.
- The non-collision criterion that prevents the following vehicle from colliding with the leader at any time even if the latter brakes suddenly. The deceleration will be calculated according to the following equations.

$$X_L - (X_F^i + V_F^i * T + 0.5(a_f * T^2)) - L - K \geq \text{Expression} \dots\dots\dots \text{Equation (1)}$$

$$\text{Expression} = \max \left\{ [V_f + a_f * T] * c, [V_f + a_f * T] * c + \frac{[V_f + (a_f * T)]^2}{2 * df} - \frac{V_L^2}{2 * dl} \right\} \dots\dots \text{Equation (2)}$$

Where:

- $X_L$  = position of leading vehicle at time (t+T).
- $X_F^i$  = position of following vehicle at time (t).
- $V_F^i$  = speed of following vehicle at time (t).
- L = length of vehicle (m).
- K = buffer space (m).
- $a_f$  = acceleration of vehicle at time (t).
- $V_i$  = desired speed of following vehicle (m/sec).
- T = scanning time (sec).
- C = reaction time (sec).
- dl = maximum deceleration (m/sec<sup>2</sup>).
- $X_F^f$  = position of following vehicle at time (t+T).

- The headway of vehicles in the slow speed or stationary conditions should always be more than the buffer space with an average of 1.8m and standard deviation of 1.7m (Yousif, 1993). In this case, the acceleration or deceleration can be determined using the following equation:

$$X_L - (X_F^i + V_F^i * T + 0.5(a_f * T^2)) \geq L + K \dots\dots\dots \text{Equation(3)}$$

- In the case of moving from stationary, the amount of response depends mainly on the type of vehicle. In addition, the start-up delay, which is the time required to move from a stationary

position after the leading vehicle moves, was found to be on average equals to 2 seconds for HVG and 1.7 for cars (Yousif, 1993).

- e. The amount of a response (acceleration/deceleration) for each vehicle at any time is based on the vehicle's mechanical ability. A passenger car has a quicker response than a heavy goods vehicle, as reported by ITE, 1999.

This model was introduced to solve problems of stop-go conditions inherited in some models such as *INTRAS* (Benekohal and Treiterer, 1988). In addition, this model is capable of representing different traffic situations such as motorway and urban roads (Benekohal and Treiterer, 1988).

Aycin and Benekohal (2001) examined five car-following models, NETSIM, INTRAS, FRESIMS, CARSIM and INTELSIM, in terms of the stability, performances and characteristics of car-following behaviour. They found that vehicles in NETSIM and CARSIM car-following models have approximately the same headway which equals to the reaction times. In addition, they also reported that INTRAS and FRESIM representing unrealistic acceleration variations and high maximum decelerations. Then, they concluded that CARSIM represents greater headway than NETSIM and provide more realistic results. Finally, they argued that INTELSIM can provide similar speed and headway to those of drivers.

## 2.2 WEAVSIM model:

The car-following incorporated in this model is based on a combination of two conditions (Zarean, 1987 and Iqbal, 1994):

- The following vehicles always seek a desired headway which will be a function of vehicle speed, relative speed and vehicle's type.
- A collision criterion will be applied to avoid a collision.

By using these two conditions, each speed and location of any vehicle will be determined. Thus, three conditions are used in this model (Zarean, 1987 and Iqbal, 1994):

- a. As the leader has come to a complete stop the following vehicle should also come to stop while keeping space headway of at least equal to the length of the leader plus a safety distance (S.D).

$$X_L - X_F^f \geq L + K \dots\dots\dots \text{Equation (4)}$$

$$X_F^f = X_F^i + V_F^i / 2 * a_f \dots\dots\dots \text{Equation (5)}$$

By substituting in Equation (4) then:

$$a_f = -V_F^i / 2 * (X_L - X_F^i - L - K) \dots\dots\dots \text{Equation (6)}$$

- b. When the updated speed of the leader is greater than zero but less than the current speed of the follower the follower should decelerate to avoid a collision. The safe space headway is calculated as following:

$$X_L - X_F^f \geq L + K + c * V_{FD}^2 / 2 * MED - V_{LD}^2 / 2 * MED \dots\dots\dots \text{Equation (7)}$$

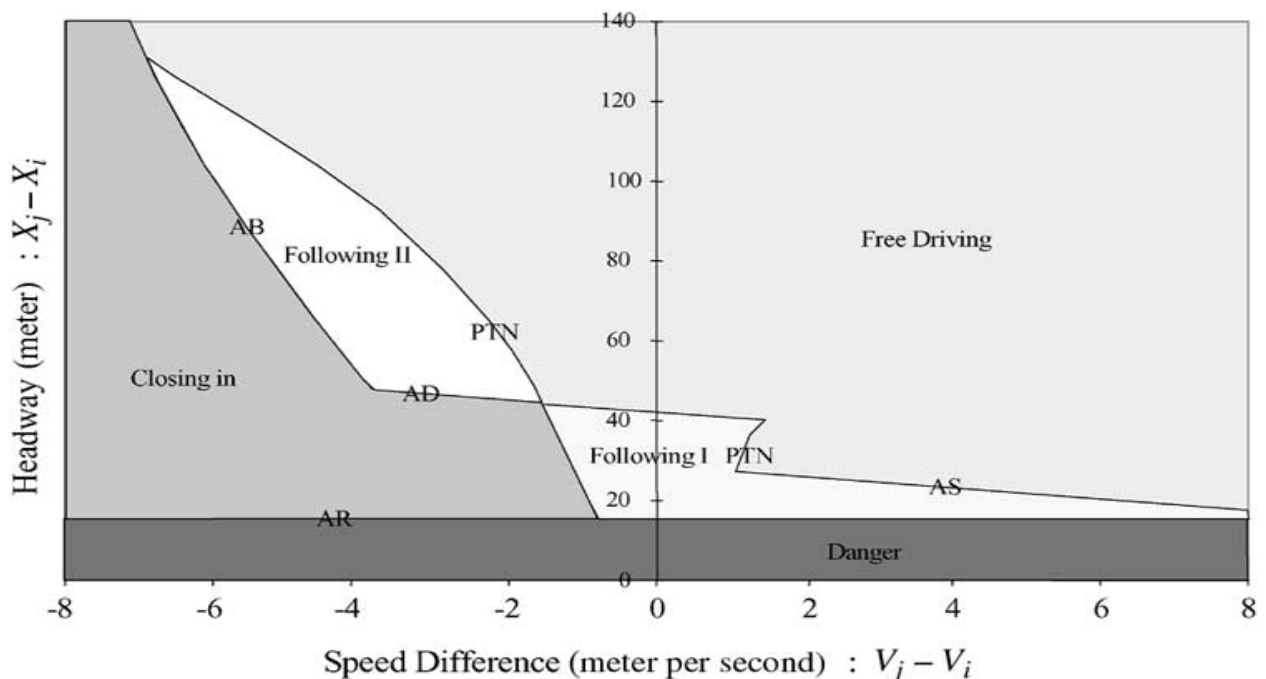
The basic concept here is that a follower maintains headway equal to the length of vehicle plus buffer spacing. In order to determine the deceleration the updated position of the follower must be substituted into the above equation.

- c. As the updated speed of the leader is greater than the current speed of the follower, the space headway for this case can be expressed as:

$$X_L - X_F^f \geq L + K + c * VFD \dots \dots \dots \text{Equation (8)}$$

### 2.3 PARAMICS Model

PARAMICS is traffic simulation software that is widely used to design and analyse different highway facilities such as intersection, merging section and roundabouts. The brief description of car-following model in terms of acceleration and deceleration was discussed in Panwia and Dia (2005).



**Figure 2 Car-following phase-space diagram (Panwai and Dia, 2005).**

Five situations were investigated at which there were different responses of the following vehicles which were noted according to different thresholds. Figure 2 indicates the location of vehicles depending on the relative speed and relative headway. After identifying the vehicles' situation in Figure 2, the correct equation of the response can be chosen. For more details see ((Panwia and Dia, 2005).

### 3. Rebuilding the models

Visual Compact FORTRAN has been used to rebuild CARSIM and WEAVSIM depending on the algorithms of these models as discussed in section 2. In each model, a warm-up and cool-off sections have been used to reduce the error from unstable conditions in the start and end of the sections. A warm-up time is also used to reduce the instability that may occur in *the start time of the program*.

#### 4. Statistical Tests

To assess the difference between the simulation outputs with the field data, two measures are used: the Root Mean Square Error (RMSE) and Error Metric (EM) (Panwai and Dia, 2005). These parameters can be determined as shown in Equation (9) & (10).

$$\bullet \text{ RMSE} = \sqrt{\frac{1}{N} \sum_{n=1}^N (\text{Val1} - \text{Val2})^2} \dots\dots\dots \text{Equation (9)}$$

Where:

Val1 and Val2 are the simulated and observed values, respectively.  
N is the number of observations.

$$\bullet \text{ EM} = \sqrt{\sum \left( \log \frac{D_{si}}{D_f} \right)^2} \dots\dots\dots \text{Equation (10)}$$

Where;  
Dsi = simulated distance (m).  
Df = observed distance (m).

The EM is used by Panwai and Dia (2005) as a measure of precision between the simulated and field. However, this measure is inadequate as noted during this study because it is affected by the number of points which are considered in the comparison of simulated data and field data. Consequently, the values of RMSE were adopted in this study rather than the EM ones.

#### 5. Data sets

Three models of car-following have been tested via field data. These data are:

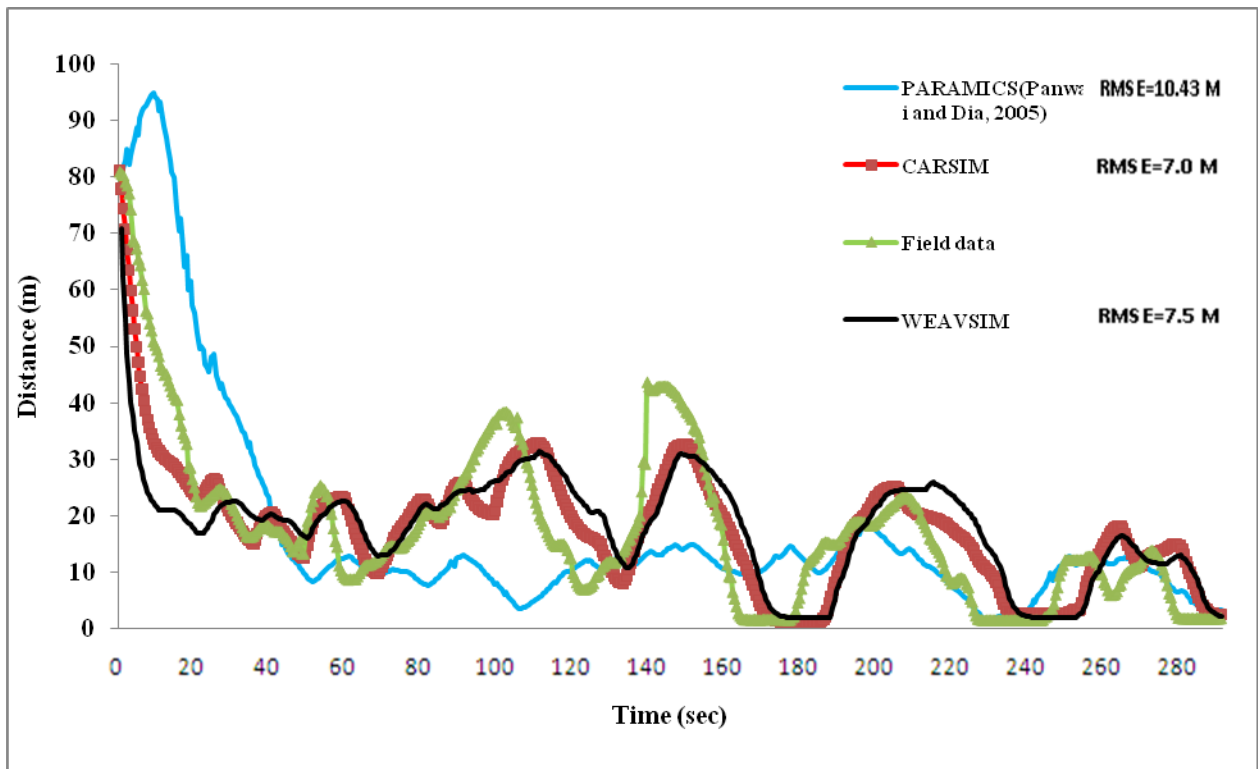
##### 5.1 The data from Germany:

This 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 3. This set of data is characterised by:

- A range of speed between 0 and 60 kph.
- Three stop situations.
- Test duration of 300 seconds.

Figure 3 represents the field data from Germany and the results from the three simulation models. The field data ranges from free-flowing conditions in the first part of curve (up to 30 sec.) to a slow speed condition at the end of test. Through the slow speed conditions, the leader came to a complete stop at three positions as shown in Figure 3.

PARAMICS was tested by Panwia and Dia (2005) with this set of data. The results, as shown in Figure 3 indicate a significant difference between PARAMICS and field data. The first variation is within the free-flow region up to 30 seconds. This shows bad handling of the model under free-flow conditions. The second variation is within the slow speed and stop/go conditions. Again, the behaviour of the model tends to give a shorter headway than what the real data suggests. Therefore, in free-following the model seeks larger headway than real data and vice versa.



**Figure 3 Data from Germany, CARSIM, WEAVSIM and PARAMICS simulated data.**

Then, WEAVSIM is compared with field data as shown in Figure 3. This model can represent the free-following case better than PARAMICS. The main difference between the model and PARMICS is that WEAVSIM adopts a shorter headway than the latter. However, there is a difference between the model and the field data as shown in Figure 3. Another factor, which determines the behaviour of this model in such a case, is the reaction time. In the case of increasing this factor, the curve seems to give better results but this leads to more discrepancies in the slow speed region.

On the other hand, the RMSE for PARAMICS is 10.43 m whereas it is 7.5 m for WEAVSIM. So the latter is better than PARAMICS in the amount of error between field and simulated data.

A third model, CARSIM represents the driver behaviour more accurate than other models as shown in Figure 3. This model is similar to WEAVSIM but it is better than the latter in different experimental situations. Moreover, the value of RMSE for CARSIM is less than WEAVSIM's model (RMSE=7.0 m).

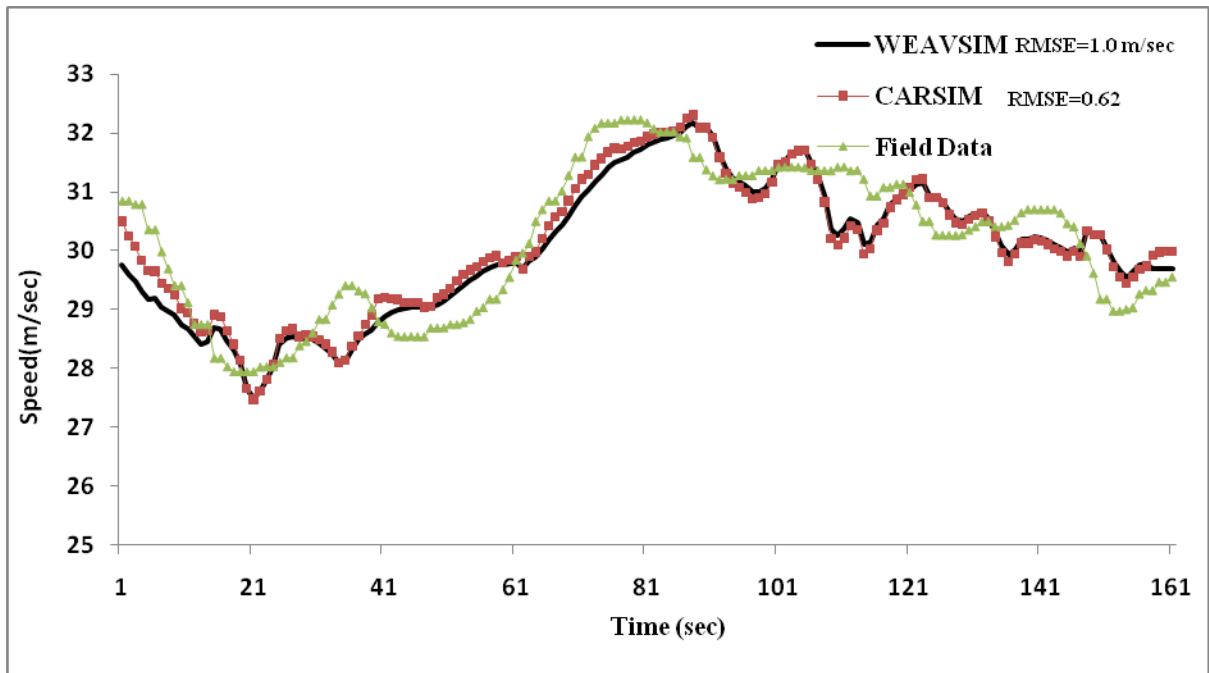
## 5.2 The data from California

Two experiments were conducted to gather two sets of data by using an instrumented vehicle (Sauer et al., 2004). Data has been collected by the following vehicle in this test and the previous one. This data represents two vehicles: leader and follower.

The characteristics of this set of data are:

- A range of speed between 27 and 108 kph.
- The duration of the test is 162 sec.
- No-stopping situations





**Figure 4 California data, CARSIM and WEAVSIM simulated data.**

Figure 4 illustrates the comparison between field data and simulated data, CARSIM and WEAVSIM. In this set of data, both CARSIM and WEAVSIM gave reasonably similar results. However, the value of RMSE of CARSIM of 0.63 m/sec is less than that of Zarean (1.0 m/sec). Therefore, CARSIM is considered better than WEAVSIM in such situation.

### 5.3 The USA data

A new method of collecting data was adopted in this test. In this method, hidden video cameras, they were covered by other things, were used to monitor the behaviour of drivers to avoid the effect of influencing the drivers who were used as part of the experiment. In this method of collecting data, valuable information was obtained because the instrumented test vehicle is the lead vehicle. The driver of the lead vehicle can be any normal driver who can drive legally. The specifications of this set of data are:

- A range of speed between 14 and 43 kph.
- The space distance between vehicles ranging from 3 to 15m.
- The duration of the experiment is 176 seconds.

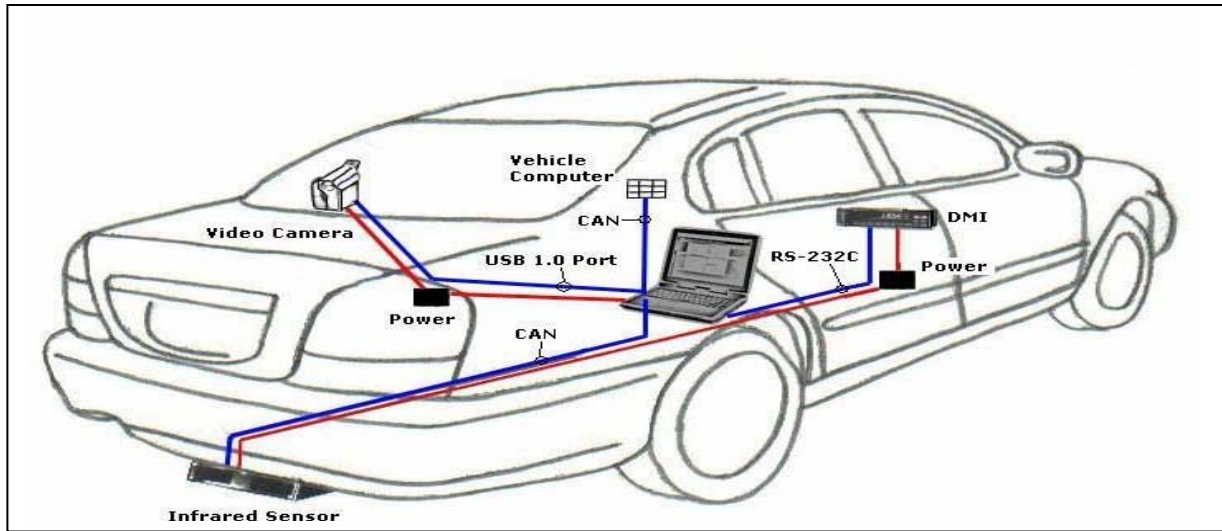


Figure 5 Test vehicle apparatus and connectivity diagram (Kim, 2005).

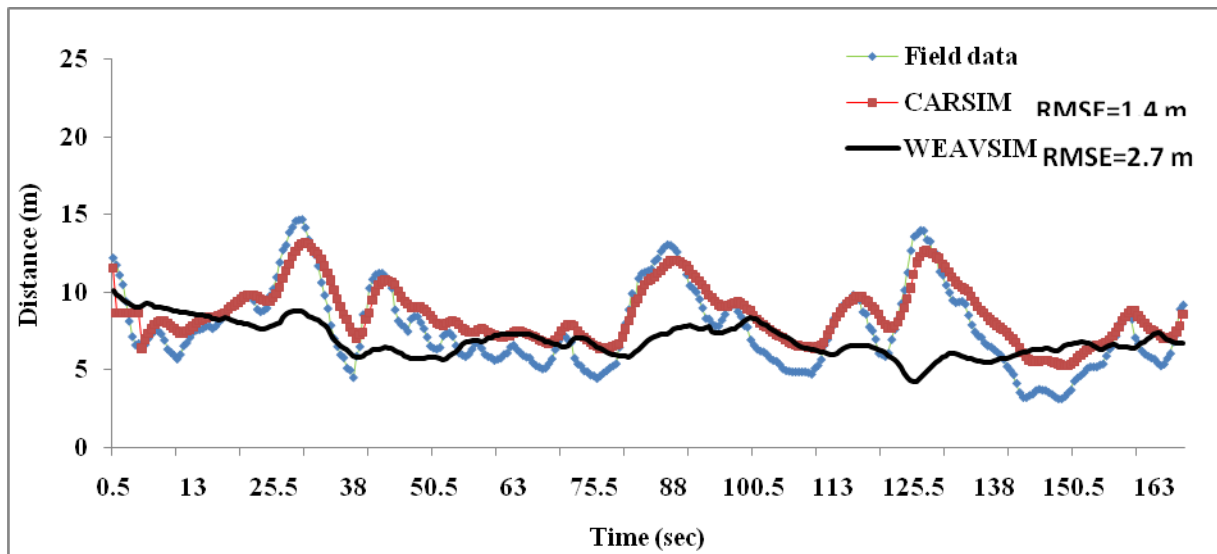


Figure 6 The USA data, CARSIM and WEAVSIM simulated data.

In this case, the following vehicle was the monitored vehicle and the driver of this vehicle was not made aware that he/she was monitored by others. Figure 5 indicates the components of the monitored system in the leading vehicle.

Figure 6 shows the results of the two models compared with the field data. The most important point here is that this data represents slow speed conditions. Thus, the CARSIM model here gave better results than WEAVSIM. In addition, the value of RMSE for CARSIM is 1.4m while that for WEAVSIM is 2.7m. Therefore, CARSIM is preferred for this test.

The results of the RMSE for the three tests are summarised in Table 1. According to these results CARSIM is the most accurate model amongst others tested when compared with real data.

Table 1 Results of simulated models with field data.

No. Of Tests	Test one (Germany)			Test two (California)		Test three(USA)	
	CARSIM	WEAVSIM	PARAMICS	CARSIM	WEAVSIM	CARSIM	WEAVSIM
RMSE	7.0	7.5	10.43	0.62	1.0	1.4	2.7

## 6. Conclusions

Car-following models have been developed using Visual Compact Fortran based on algorithms of CARSIM and WEAVSIM. In addition, PARAMICS model was also used. Therefore, these models approximately cover the most popular types of car-following models.

Three sets of data for different traffic conditions have been used. The results of testing these models with the available field data showed that the CARSIM model gave better results compared with other models. Therefore, the assumptions which CARSIM is based on were used in the newly developed model to evaluate the effect on capacity and delays of weaving sections on motorways.

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