

# ***Examining and improving the limitations of Gazis–Herman –Rothery car following model***

***Name: Hamid Al-Jameel (Research Institute: The Built and Human Environment)***

## **Abstract**

Simulation models are effective tools to solve traffic problems because of their feasibility to represent the most complex situations. Different car-following models have been used to simulate traffic movements. The car-following model known as Gazis-Herman-Rothery (GHR) is one of the earliest models that have been used since the late 1950's and up to this time. In this model, the acceleration of follower is based on the spacing and relative speeds between two vehicles (the follower and the leader).

This model has many limitations, for example there is no response (or zero acceleration or deceleration) for the follower when the relative speed between the leader and follower is equal to zero for any relative spacing between the two vehicles. Another limitation includes the effect of the leading vehicle on its follower even if the distance between them is so large. This effect obstructs the following vehicle from increasing its speed to reach its desired speed and this reflects unrealistic behaviour.

This paper tries to overcome the effect of large spacing due to car-following by using a spacing threshold to transfer the car-following regime to a free-flow regime.

Finally, sensitivity analysis has been made to select the values for parameters in cases of acceleration and deceleration. The modified model has been validated by using real data. The parameters of the model have been selected and suitable values of spacing threshold have been used in calibrating the model.

**Keywords: Traffic micro-simulation, car-following model, GHR model**

## **1 Introduction**

Car following rules can be considered as the basic unit to build any traffic simulation model since they describe the interaction between vehicles travelling at close distances (Brackstone and MacDonald, 1999). During the last five decades, several car-following models were used to interpret the influence of the leading vehicle on the following vehicle. This effect by the leading vehicle can be expressed as shown in the following relationship:

$$\text{Response} = \text{Sensitivity} \times \text{Stimulus} \quad \text{..... Equation 1}$$

where:

Response: represents the acceleration or deceleration of the follower

Sensitivity: a constant or a function of the follower's speed and spacing between the follower and its leader

Stimulus: represents the difference in speed between the follower and its leading vehicle

The Gazis-Herman-Rothery model (GHR) is an example of the response-stimulus relationship.

## 2 GHR-Model

The GHR model is considered one of the earliest car-following models. This model was developed by the General Motors Research Laboratory in Detroit in 1958 (Brackstone and McDonald, 1999). The model has been improved by different researchers for the last five decades.

According to Brackstone and McDonald (1999), the mathematical equation of this model is as shown in Equation 2 (see also Figure 1 for further explanation).

$$a_{n+1}(t+T) = c (V_{n+1}(t+T))^m [V_n(t) - V_{n+1}(t)] / [X_n(t) - X_{n+1}(t)]^L \dots \text{Equation 2}$$

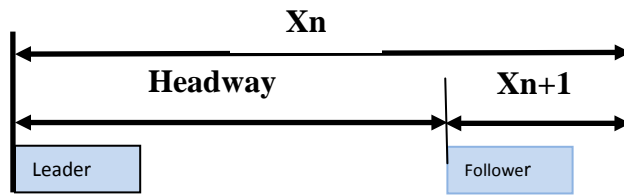
where:

$a_{n+1}(t+T)$  = acceleration/deceleration of the follower

$X_n(t)$ ,  $X_{n+1}(t)$  = position of leader and follower, respectively

$V_n(t)$ ,  $V_{n+1}(t)$  = speed of the leader and follower, respectively

$L$ ,  $c$ , and  $m$ : constant parameters



**Figure 1 A sketch illustrating the terms used for the relative positions of the follower and its leader**

According to Equation 1,  $a_{n+1}(t+T)$  represents “Response”. The difference in speed represents “Stimulus”, whereas the speed of the follower and spacing represent “Sensitivity”.

### 2.1 Development of the GHR-model

For several decades, researchers have significant interest in the GHR model. Table 1 shows a summary of the development of this model. Moreover, the most important parameters that had been found by different researchers are shown in Table 2.

### 2.2 Limitations of the GHR Model

The GHR model suffers from several limitations. Some of them have been resolved during its long history of development (as shown in Table 1). Despite the improvements of the GHR model, it still needs more work to represent real life traffic behaviour. The important limitations are summarised as follows:

- a. The follower reacts to any small changes in the relative speed of its leader (Olstam and Tapani, 2004).

- b. The follower is affected by its leader even if the distance between them is significant. To overcome this problem, a deterministic space threshold has been used as a separation between car-following and free flow regimes. If the spacing is more than this threshold, the follower is considered as unaffected by its leader. In this case, the follower will drive to attain his desired speed. Herman and Potts (1959) assumed a value of 61 metres as a deterministic space threshold. Aycin (2001) used 250 feet ( $\approx 75$ metres) as a deterministic threshold along with another limitation on the value of deceleration to move from the car-following to a free-flow state. Toledo (2003) used a similar value of 76 metres.
- c. There is no obvious connection between driver's behaviour and the parameters  $c$ ,  $m$  and  $L$  used in the GHR model (Gipps, 1981).

**Table 1 Most important historical development for the GHR model**

Researcher (s)	Findings	Mathematical expression
<b>Chandler, Herman and Montroll (1958)</b>	Acceleration/deceleration depends on relative speed only and it does not depend on the spacing between the follower and its leader	$a_{n+1}(t+T) = c [V_n(t) - V_{n+1}(t)]$
<b>Herman, Montroll, Potts and Rothery (1959)</b>	A new factor has been added which is the spacing between the following and leading vehicles	$a_{n+1}(t+T) = \frac{c [V_n(t) - V_{n+1}(t)]}{[X_n(t) - X_{n+1}(t)]}$
<b>Herman and Potts (1959) (See Brackstone and McDonald, 1999)</b>	Calibrated the preceding model and found good results with $r^2=0.8-0.9$	$a_{n+1}(t+T) = \frac{c [V_n(t) - V_{n+1}(t)]}{[X_n(t) - X_{n+1}(t)]}$
<b>Edie (1960)</b>	Added follower's speed as a new factor	$a_{n+1}(t+T) = \frac{C(V_{n+1}(t+T)) [V_n(t) - V_{n+1}(t)]}{[X_n(t) - X_{n+1}(t)]}$
<b>Gazis, Herman and Rothery (1960)</b>	Used different values of speed and spacing in terms of $m$ and $L$	$a_{n+1}(t+T) = \frac{C(V_{n+1}(t+T))^m [V_n(t) - V_{n+1}(t)]}{[X_n(t) - X_{n+1}(t)]^L}$
<b>May and Keller (1967)</b>	Calibrated the parameters of the sensitivity factors introduced by Edie in 1961	Used $m=1$ and $L=3$
<b>Aron (1988) (See Brackstone and McDonald, 1999)</b>	Classified driver's response into deceleration, constant speed and acceleration	Different values of $m$ and $L$ in different cases; acceleration, constant speed and deceleration
<b>Ozaki (1993) (See Brackstone and McDonald, 1999)</b>	Used also different sensitivity values	Different values of $m$ and $L$ in different cases

**Table 2 Most reliable estimates of the parameters m and L within the GHR model according to Brackstone and McDonald (1999)**

Source	m	L
Chandler <i>et al.</i> , (1958)	0	0
Herman and Potts (1959)	0	1
Hoefs (1972) (dcn no brk / dcn brk / acn)	1.5/.2/.6	.9/.9/3.2
Treiterer and Myers (1974) (dcn / acn)	.7/.2	2.5/1.6
Ozaki (1993) (dcn / acn)	.9/-.2	1/.2

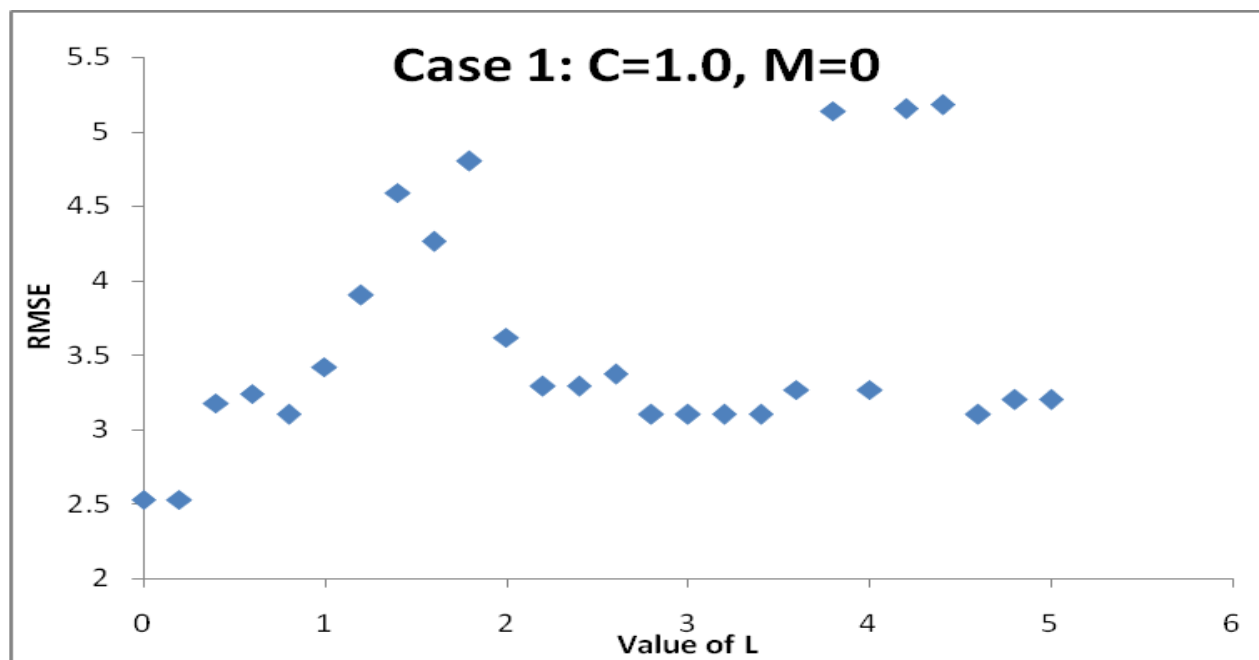
(Note: dcn/acn: deceleration/acceleration and brk/no brk: deceleration with and without the use of brakes)

### 3 The Model / Program

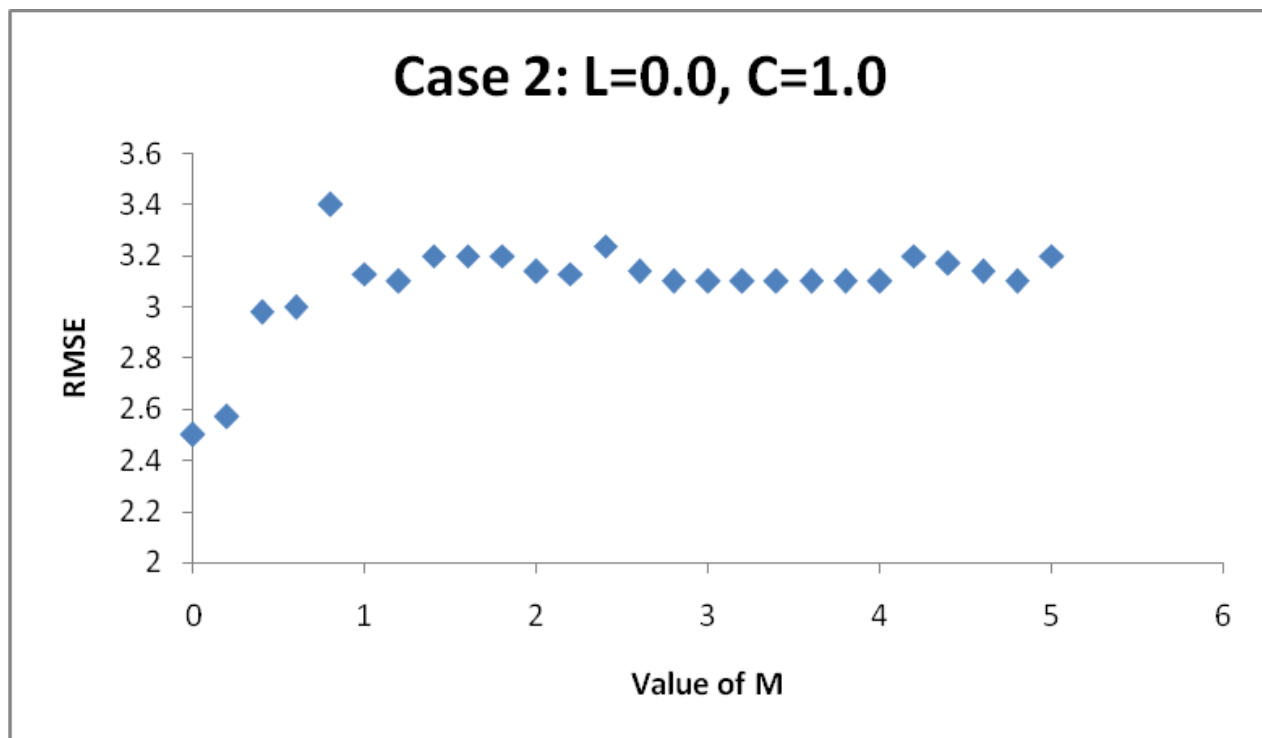
In this paper, a computer model was developed based on the mathematical equations representing the GHR model. The model was built by using Visual FORTRAN Language (6.5). The real data used to calibrate the model consists of two tests from California, USA. The data was collected during daylight by using video cameras and radars to measure the speed and spacing for the two vehicles, namely leader and follower (Saechan, 2009). In the computer program, actual field data for the leader has been used in order to see how the program mimics reality by comparing data for the follower with that obtained from the field. The real data (field data) consists of two parts: one for speed and another for space headway.

The statistical test used in this calibration is the Root Mean Square Error (RMSE). This statistical test is used as an index to show any differences between the computed and observed data. The results take a value equal or greater to zero. If the result is zero, it is considered an ideal value, and vice versa.

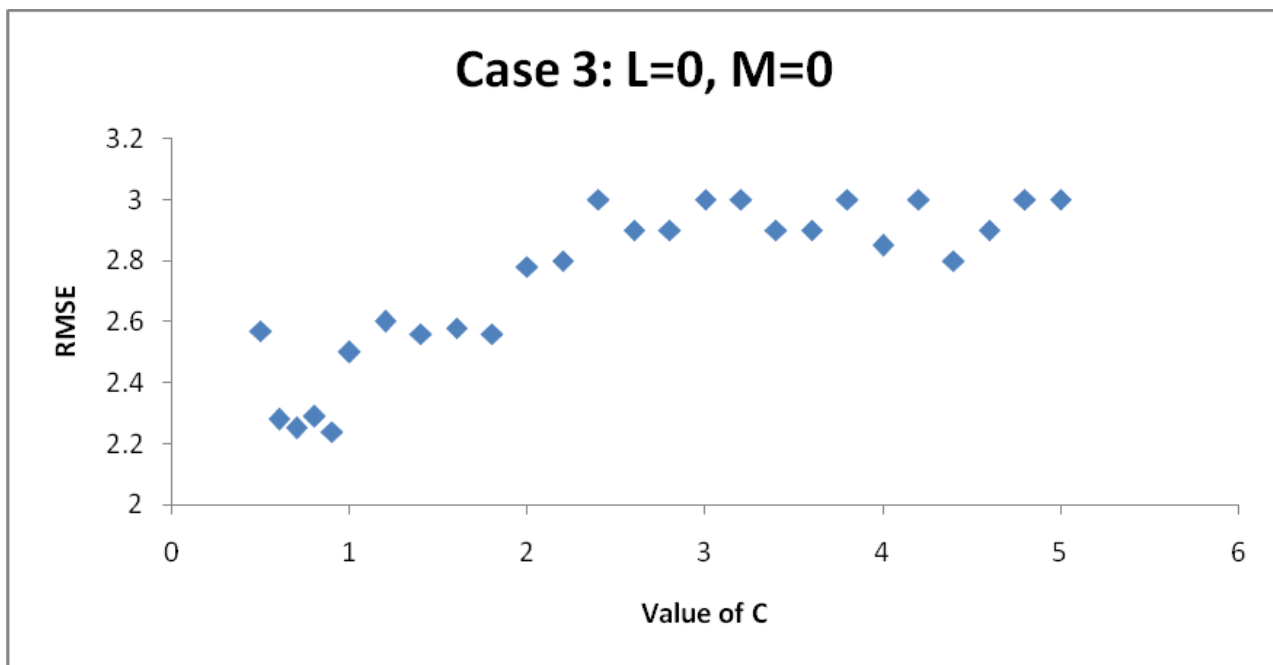
A calibration process has been conducted to select the parameters L, m and c. These parameters represent the constants of the GHR model as shown in Equation 2. Different values have been used, ranging from 0 to 5, 0 to 3 and 0 to 10 (with an increment of 0.2) for L, m, and c, respectively. Several iterations have been carried out in the model to get the best values for these constants. In these iterations, both symmetrical and unsymmetrical behaviour have been tested. For symmetrical behaviour, the same value for the model parameters have been used for acceleration and deceleration cases, whereas for the unsymmetrical behaviour, a certain value has been used for the parameter in case of acceleration and a different one for deceleration. The results of the calculations have been presented in Figures 2 to 7 (Cases 1 to 6). For each case from these six cases, one parameter is changed and the others remain constant in order to investigate the relationship between RMSE and each variable separately. Depending on the data from both field tests, the best combinations of these parameters are as shown in Table 3.



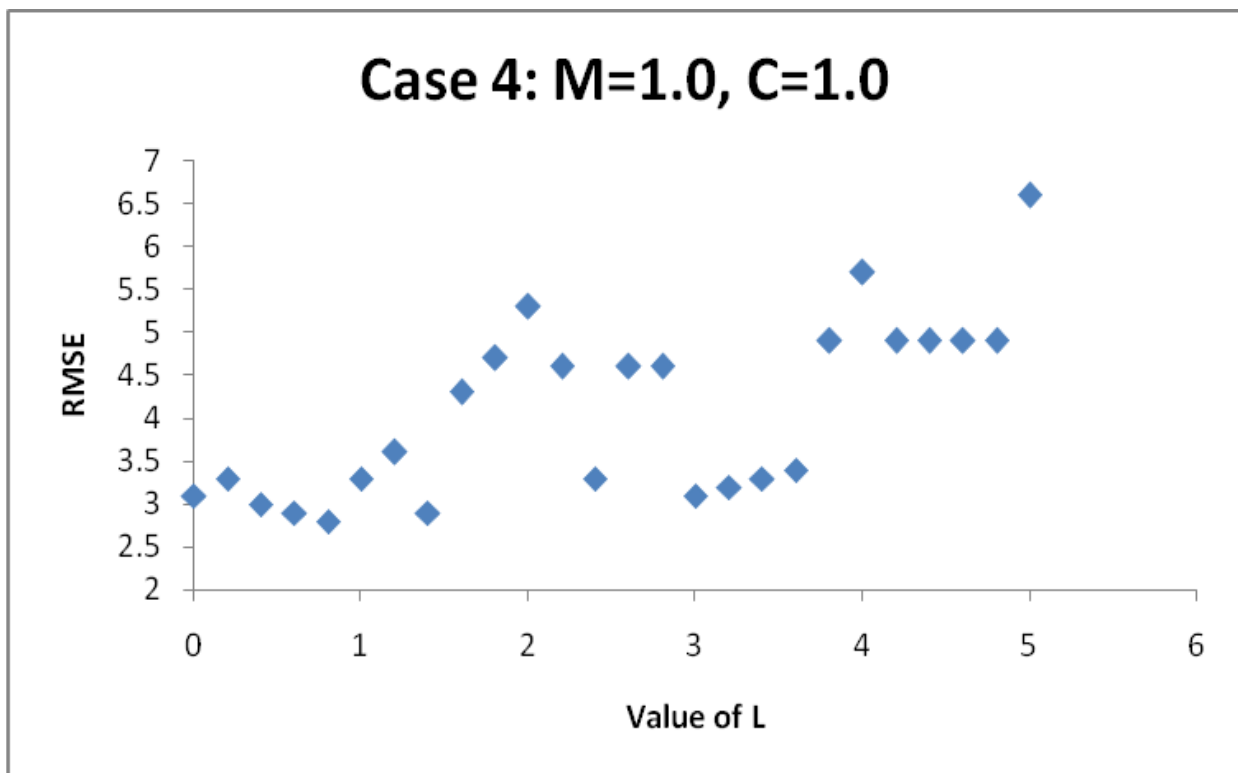
**Figure 2 RMSE vs. L for  $c=1$ ,  $m=0$**



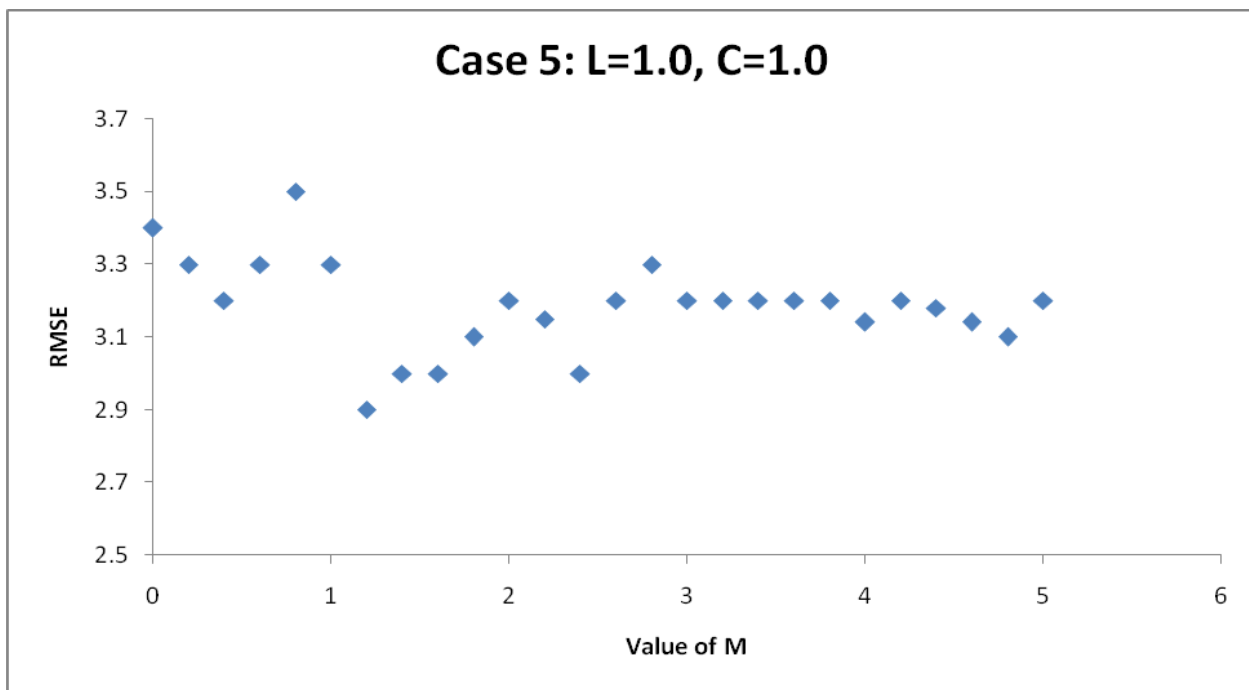
**Figure 3 RMSE vs. m for  $L=0$ ,  $c=1$**



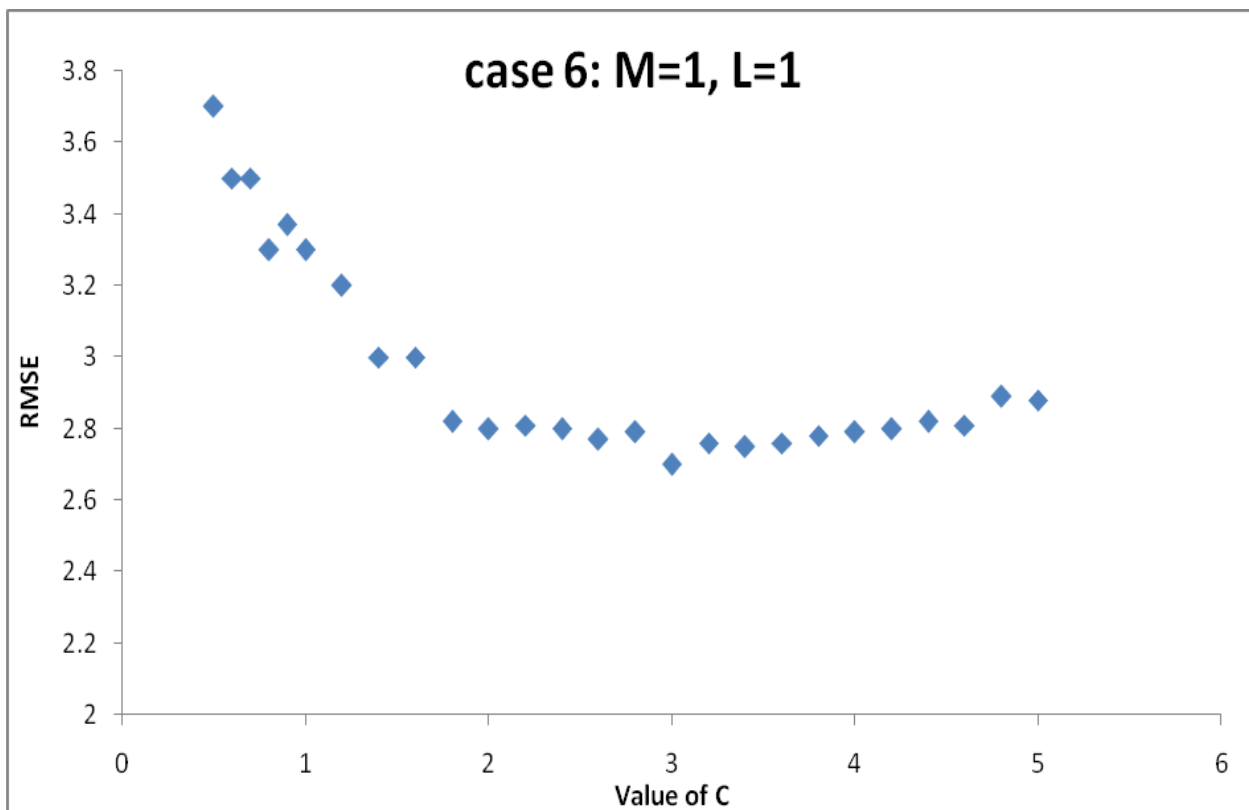
**Figure 4 RMSE vs. c for L=0, m=0**



**Figure 5 RMSE vs. L for m=1, c=1**



**Figure 6 RMSE vs. m for L=1, c=1**



**Figure 7 RMSE vs. c for m=1, L=1**

**Table 3 Results of the best combination of the calibrated GHR parameters**

Combination of the parameters	M	L	c	RMSE
❖ Acceleration:	1.0	1.0	1.0	0.78
❖ Deceleration:	1.0	1.3	1.2	
❖ Acceleration:	1.0	1.0	1.0	0.79
❖ Deceleration:	1.1	1.4	1.2	
❖ Acceleration:	1.0	1.1	1.0	0.75
❖ Deceleration:	1.1	1.4	1.0	
❖ Acceleration:	1.0	1.1	1.2	0.55
❖ Deceleration:	1.1	1.4	1.2	

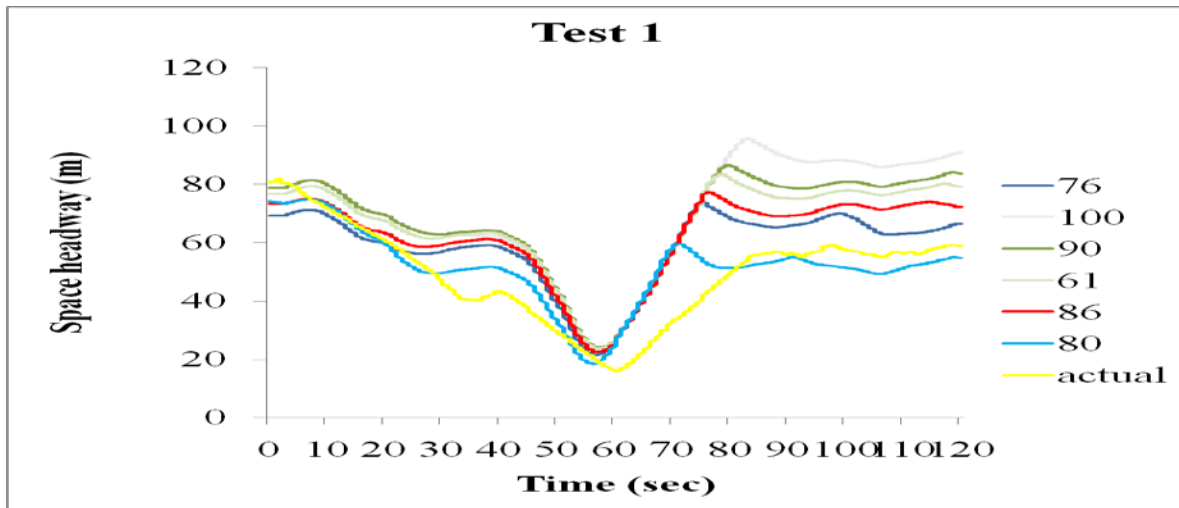
#### 4 Calibration

The calibration has been carried out for two tests at different spacing thresholds. The real data has been used in the program to find the optimum value of spacing threshold. Each test has been discussed separately in the following sections.

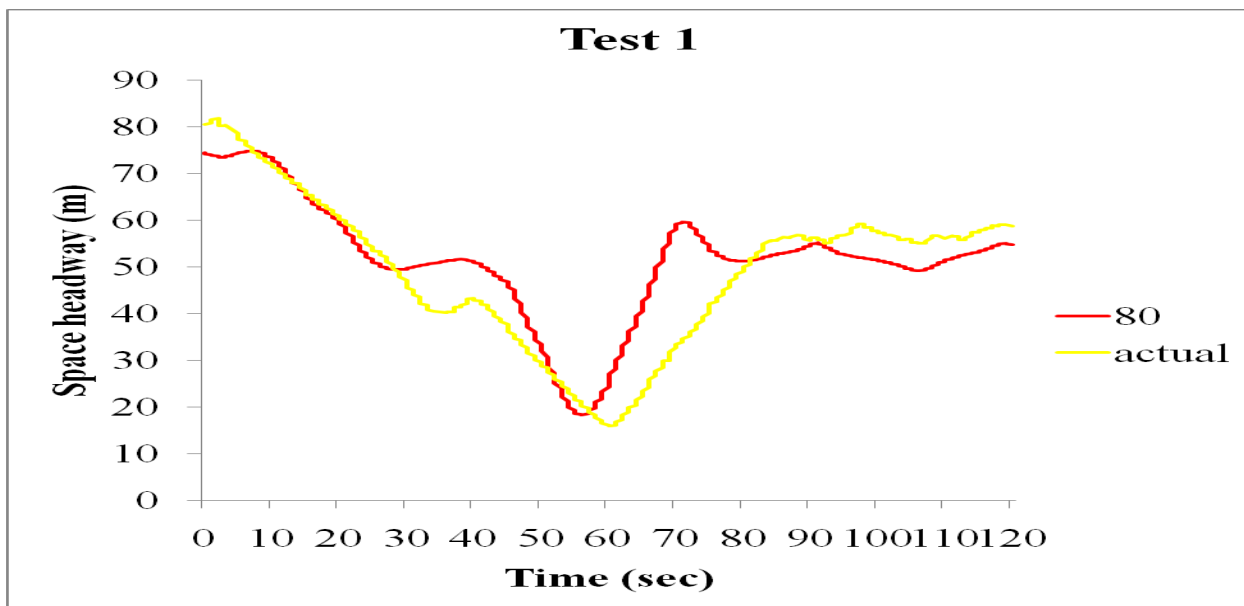
##### 4.1 Calibration - Test 1

In this section, the selection of the best value of spacing threshold will be discussed. Test 1 is one of two tests which were carried out in the USA, as discussed before. This test consists of having two vehicles, a leader and a follower, travelling over a period of 120 seconds. In addition, this test consists of two parts of real data for speed and space headway. In each part, there is a need to know the optimum value for a spacing threshold from different selected values of these spacing thresholds for the actual speed and space headway data. Beside this, different values of spacing threshold, which were used here, have been taken from previous studies such as Herman and Potts (1959) and Toledo (2003).

Figure 8 shows the different values of spacing thresholds for simulated vehicle behaviour against the space headway for actual vehicle behaviour for a period of 120 seconds. It indicates that 80 metres gave the best results in terms of closeness to the actual field data. This is shown separately in Figure 9.

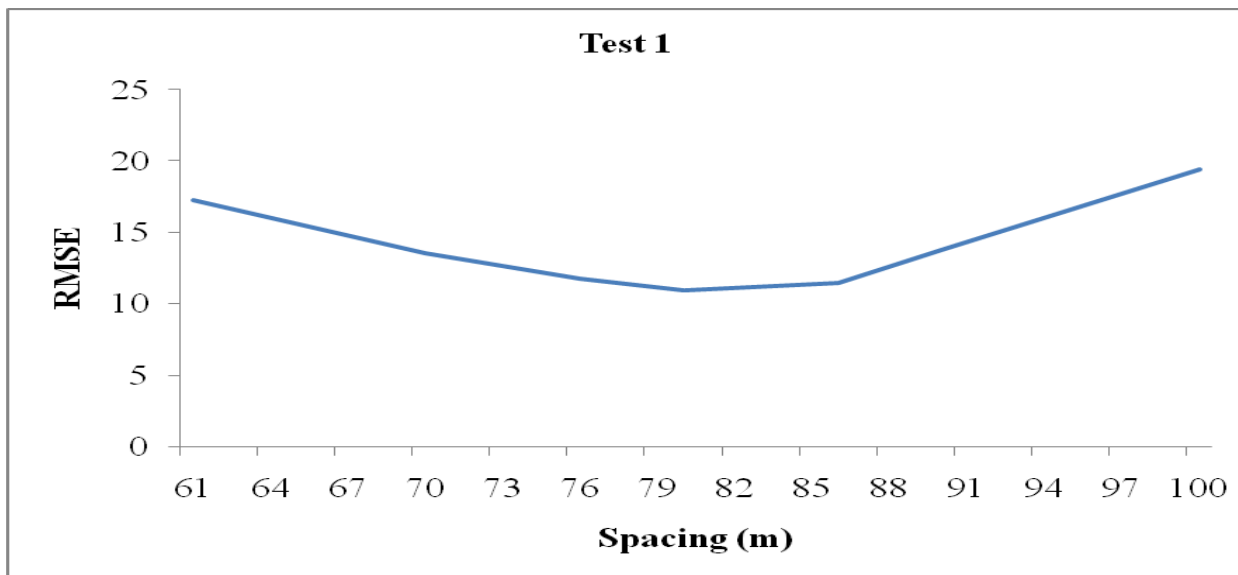
**Figure 8 Different values of spacing threshold compared with actual data for space headways**





**Figure 9 Actual field data vs. 80 metre threshold value for space headways**

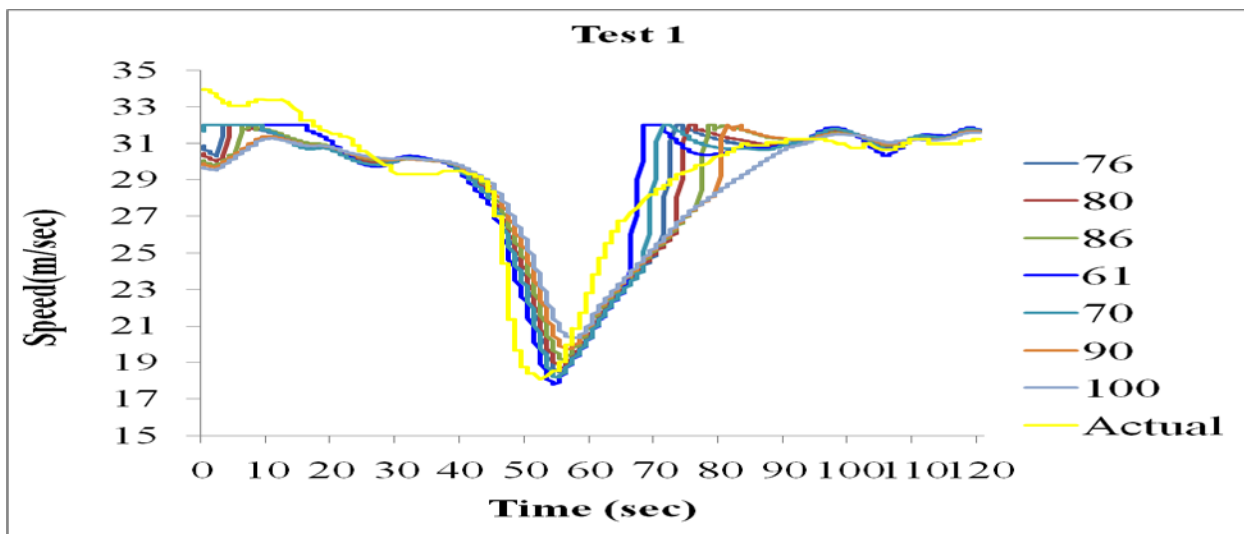
Also, when testing for RMSE, the 80 m spacing threshold represents the optimum value, as shown in Figure 10.



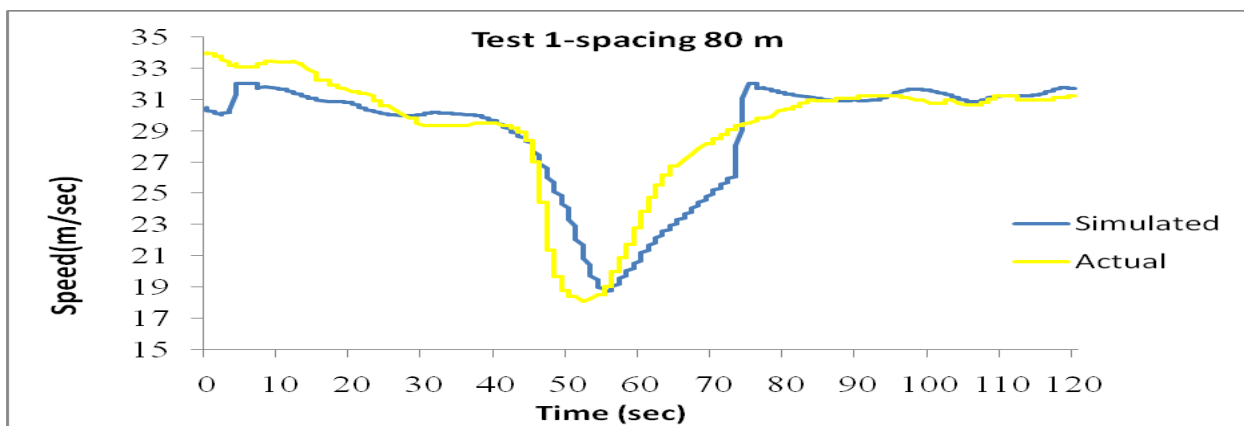
**Figure 10 Different values of spacing threshold against RMSE values for space headways**

Figure 11 shows how different simulated spacing thresholds vary against actual ones in terms of real speed data. Figures 11 to 13 indicate that the 80 m spacing threshold is the best value. Figure 13 indicates that the 80 m value represents the minimum value of RMSE (i.e. optimum value).

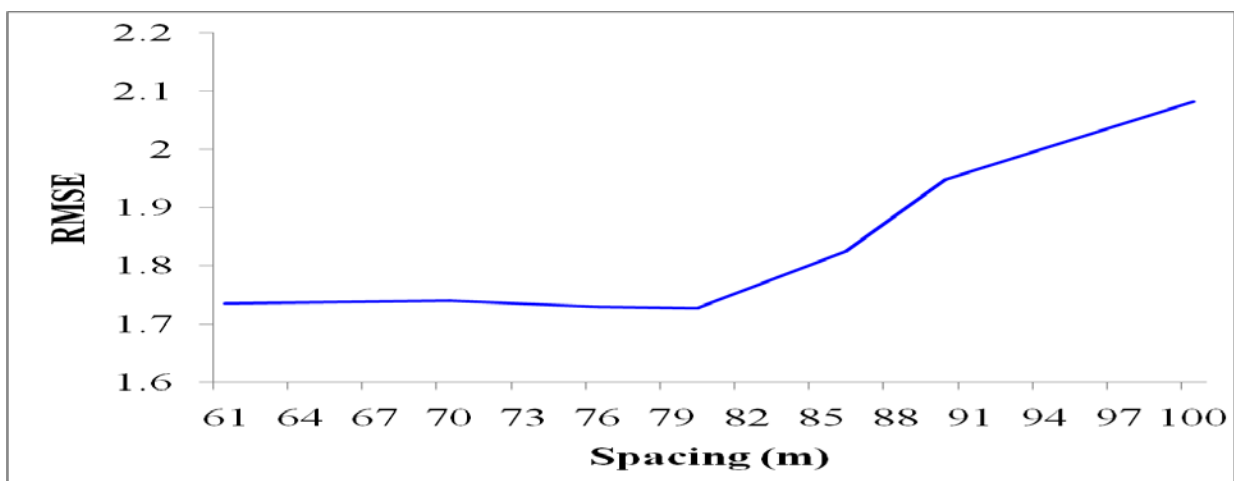
In summary, the optimum value of a spacing threshold for both speed and space headway when compared with real data is 80 m.



**Figure 11** Different values of spacing threshold compared with actual data for speeds



**Figure 12** Simulated values of speed compared with actual data



**Figure 13** Spacing thresholds against RMSE values

## 4.2 Calibration - Test 2

Again, this test consists of two parts of real data: speed and space headway. To obtain the optimum value for the spacing threshold, different values of spacing threshold have been tested against actual data. Figures 14 and 15 represent different values of spacing threshold versus real speed data. Figure 16 shows actual field data versus a value of 80 m. To determine the optimum value, the minimum RMSE is used. Figure 17 shows that a spacing threshold of 86 m is the optimum.

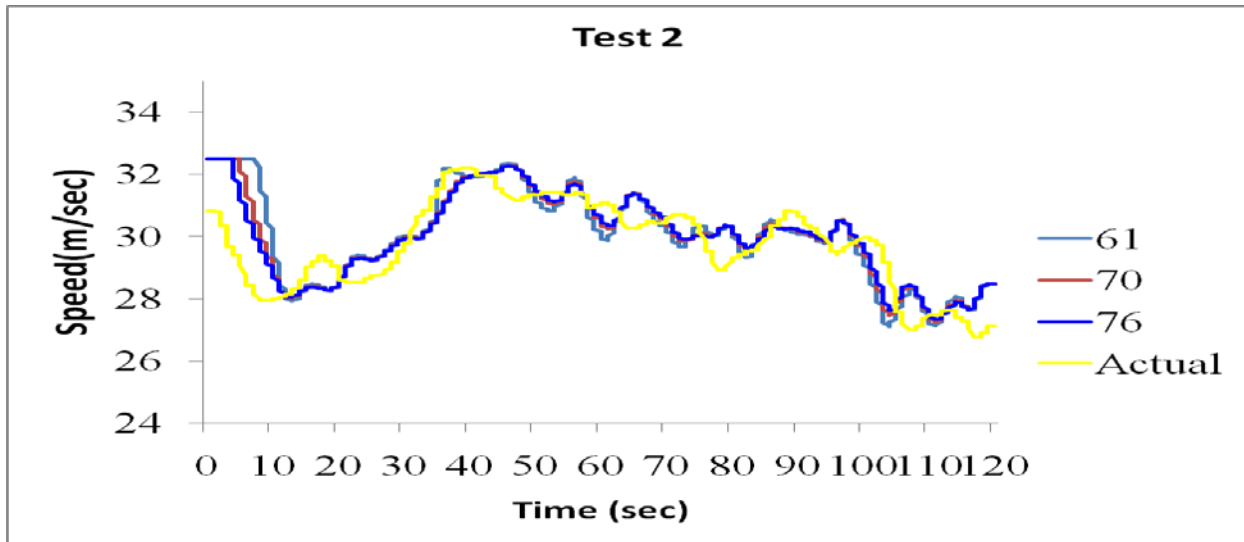


Figure 14 Different values of spacing threshold compared with actual data for speeds

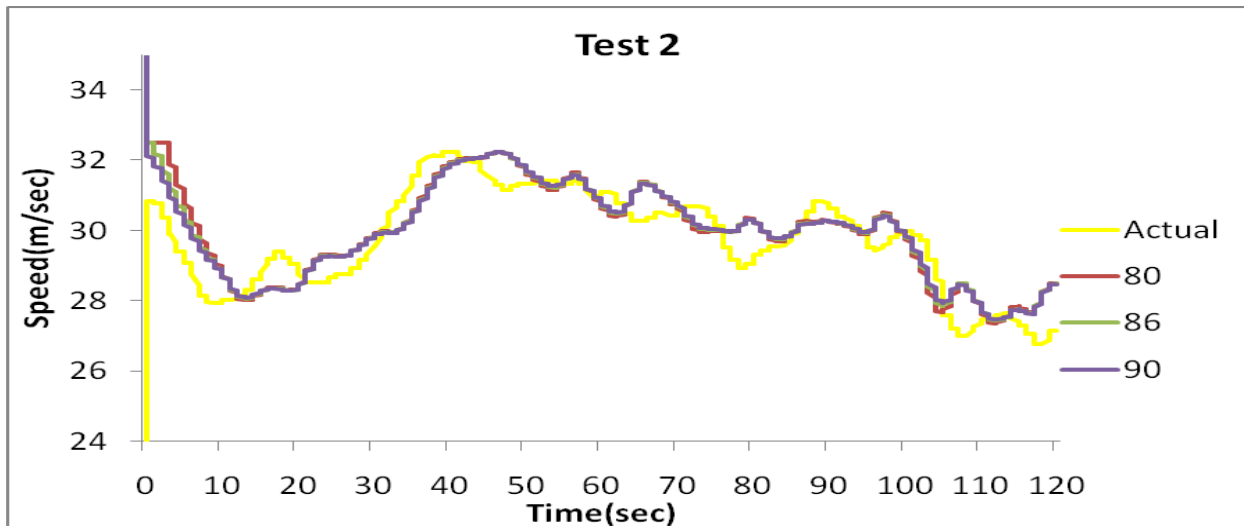
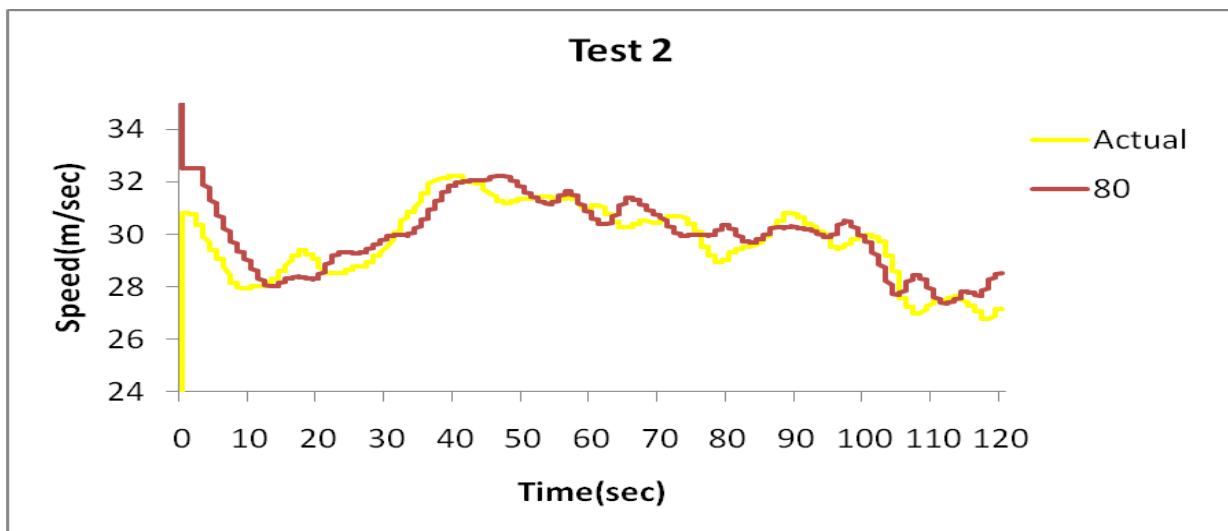
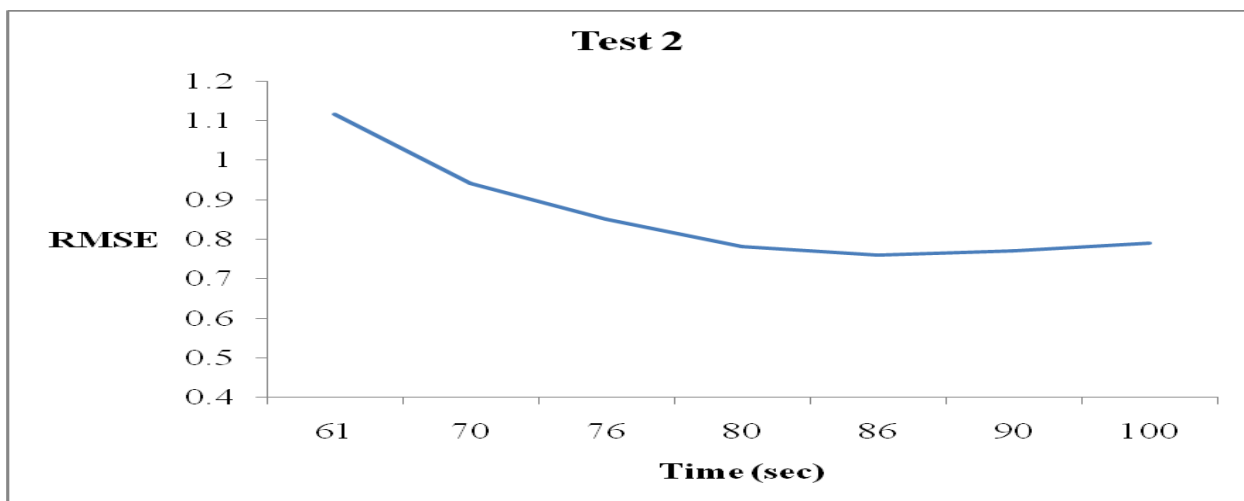


Figure 15 Different values of spacing threshold compared with actual data for speeds



**Figure 16** Values of spacing threshold at 80 m compared with actual data



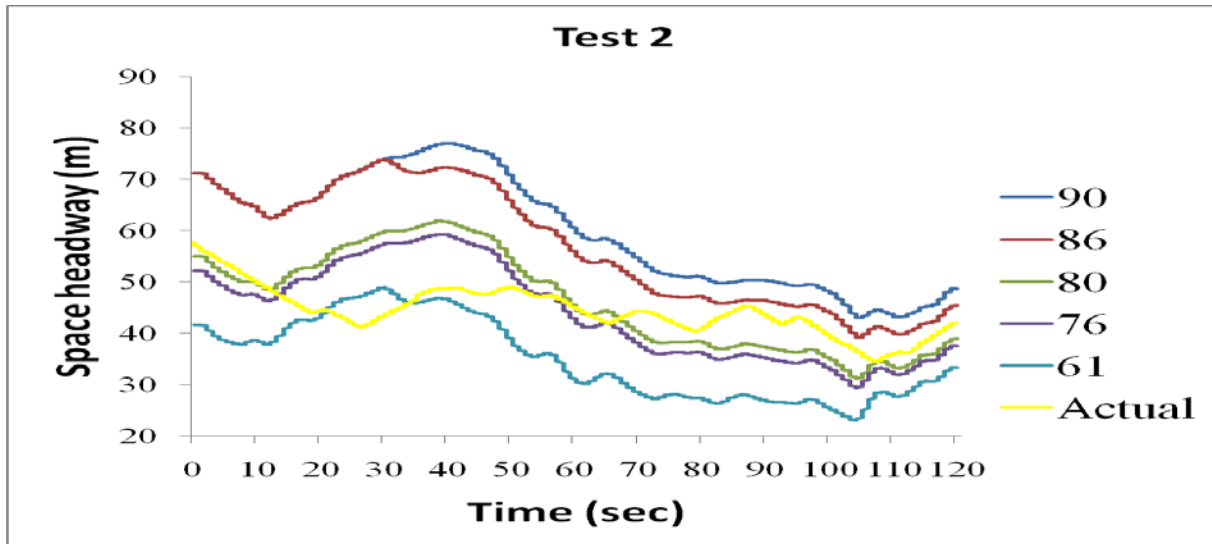
**Figure 17** Different values of spacing threshold against RMSE values

Figure 18 shows different threshold spacing values against actual space headway data. The 76 and 80 m spacing thresholds are the closest to the actual curve. Figure 19 illustrates how the 80 m value is close to the actual data, whereas Figure 20 shows that 80 m is the optimum since it corresponds to the minimum value of RMSE.

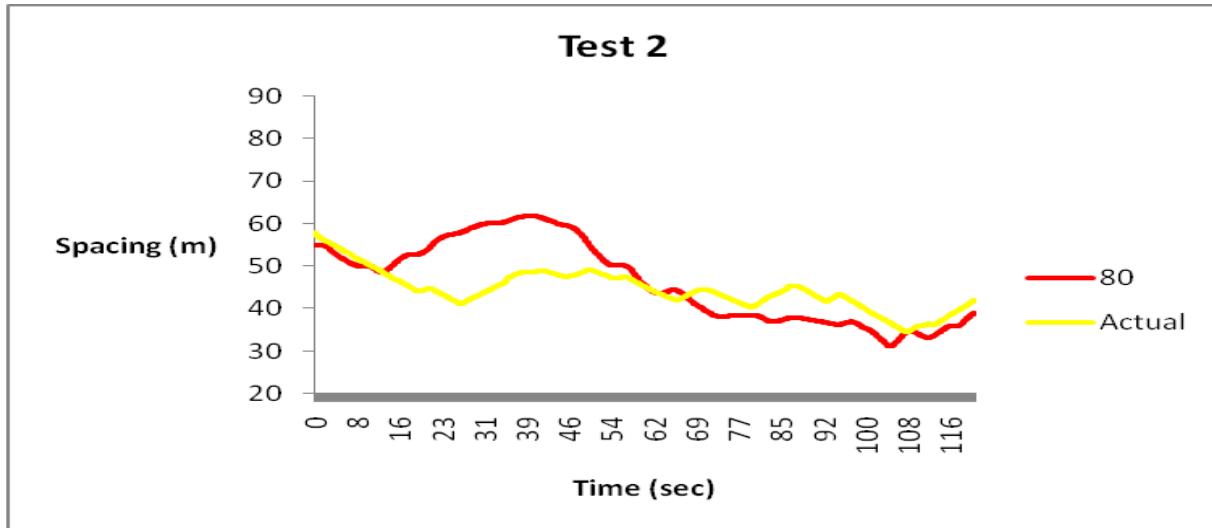
To determine the optimum value for the two parts of this test (speed and space headway real data), the obtained results indicate that there are two optimum values; one from real speed data (86 m) and the second from real space headway data (80 m).

To discuss this difference, let 86 m spacing threshold be the optimum value. In fact, this value represents the minimum value in terms of real speed value as shown in Figure 13, but the difference between this and the minimum value of 80 m in terms of real space headway is 7.73 m, as shown in Figure 20. Therefore,

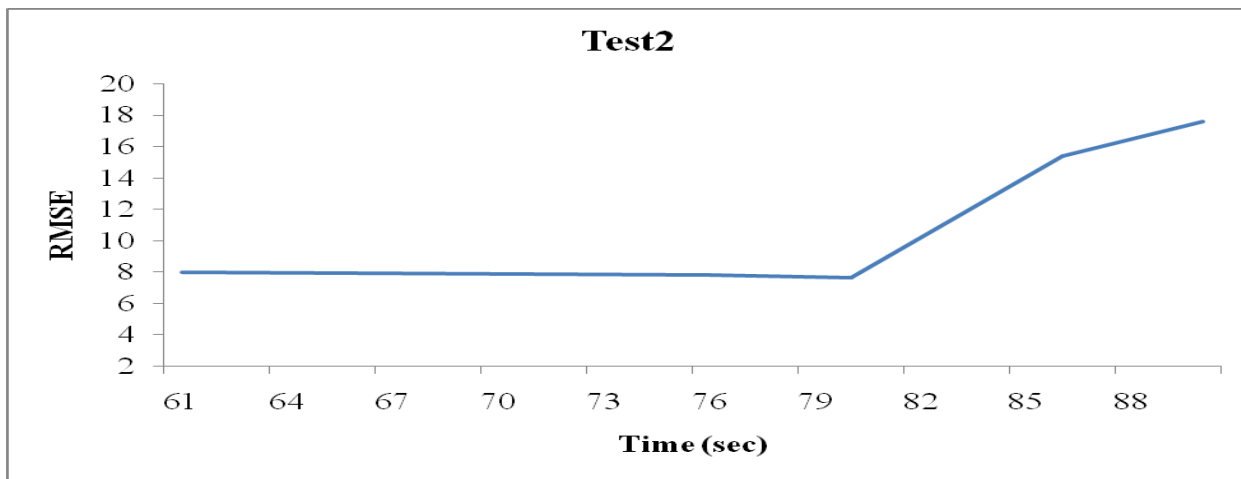
the 80 m value represents the optimum value, minimum value for RMSE, in term of space headway real data and the difference between this value and the minimum value (optimum) in terms of real speed data is only 0.02 m/sec as shown in Figure 13. This difference is trivial when it compares with 7.73 m for the 86 m spacing threshold. Accordingly, the 80 m spacing threshold can be considered as the optimum value.



**Figure 18** Different values of spacing threshold compared with the actual data



**Figure 19** Values of spacing threshold at 80 m compared with the actual data



**Figure 20 Different values of spacing threshold against RMSE values**

## 5. Conclusion

This paper states the limitations of GHR model and focuses on the spacing threshold since it has a significant effect on the behaviour of the follower. The parameters of GHR model ( $c$ ,  $m$  and  $L$ ) have been calibrated and the best combinations are as follows:

For acceleration:	$m = 1.0$	$L = 1.1$	$c = 1.2$
For deceleration:	$m = 1.1$	$L = 1.4$	$c = 1.2$

The results from the two tests state that the 80 m spacing threshold is the most suitable value amongst other values that were selected by different researchers. To get the best results for these parameters in the car-following model, more data is needed in the calibration process. Further data is needed to test different conditions such as with stop and go conditions.

## References

- Aycin, M.F. (2001) Development of a Car-following Model to Simulate Driver and Autonomous Intelligent Cruise Controlled Vehicular Traffic Flow. **PhD Thesis, University of Illinois.**
- Brackstone, M. And McDonald, M. (1999) Car-following: a historical review. **Transportation Research**, vol. 2, pp. 181-196.
- Chandler, R., Herman, R., and Montroll, E. (1958) Traffic Dynamics: Studies in Car Following. **Operations Research, Detroit, Michigan, 1958.**
- Edie, L. (1960) Car Following and Steady State Theory for Noncongested Traffic. **Port of New York Authority, USA.**

- Gazis, D.C., Herman, R. and Rothery, W. (1960) Nonlinear Follow-the-leader Models of Traffic Flow. **Research Laboratories, General Motor Corporation, Warren, Michigan, pp. 545-567.**
- Gazis, D.C., Herman, R. and Potts, R.(1959) Car-following of Steady-State Traffic Flow. **Research Laboratories, Detroit, Michigan, pp.499-502.**
- Gipps, P.G. (1980) A Behavioural Car-Following Model for Computer Simulation. **Transportation Research Part B**, Vol.15, pp.105-111.
- Herman, R., Montroll, E., Potts, R., and Rothery, R. (1958) Traffic Dynamics: Analysis of Stability in Car Following. **Research Laboratory, General Motors Corporation, Detroit, Michigan, USA.**
- Ma, X. and Andreasson, I. (2006) Estimation of Driver Reaction Time from Car-Following Data. **Transportation Research Record**. pp, 130-141.
- Olstam, J.J. and Tapani, A. (2004) Comparison of Car-following Models. **Swedish National Road and Transport Research Institute.**
- Pipes, L.A. (1967) Car Following Models and the Fundamental Diagram of Road Traffic. **Transportation Research**, Vol.1, pp.21-29.
- Saechan, P. (2009) Traffic Flow Dynamics Using Car-following Models. **MSc Dissertation, University of Salford**, unpublished work, UK.
- Sauer, C., Andersen, G.J. and Saidpour, A. (2004) A Detection and Avoidance of Collisions: the REACT Model. **Institute of Transportation Studies, University of California, Berkeley, USA.**
- Toledo, T. (2003) Integrated Driving Behaviour Modelling. **PhD Thesis, Massachusetts Institute of Technology.**