



## SIMULATION MODEL OF TRAFFIC OPERATIONS ON SINGLE CARRIAGEWAY ROADS: MODEL CALIBRATION AND VALIDATION

Zamri Bujang<sup>1</sup> and Othman Che Puan<sup>2</sup>

<sup>1</sup>Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, Sarawak, Malaysia

<sup>2</sup>Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor, Malaysia

E-Mail: [bzamri@unimas.my](mailto:bzamri@unimas.my)

### ABSTRACT

The current Malaysian procedure for a detailed evaluation of the capacity and effects of various road and traffic characteristics for single carriageway roads, which is adopted directly from the American Highway Capacity Manual, is inadequate and inaccurate since several aspects used in the method such as the consideration of the recreational vehicles and trucks are not directly applicable to the Malaysian traffic characteristics. The validity of the analysis is debatable since the way in which the effect of motorcycles on overall performance of the roadways is considered is not clear. The existing simulation models of traffic operations on single carriageway roads also suffer from a similar weakness. Therefore, there is a need to develop a comprehensive traffic simulation model to carry out this task. Such a model must be capable of simulating traffic behavior for a range of road layout and geometry, at junctions and compositions of traffic which include motorcycles. This paper describes the development of a simulation model of traffic operations on single carriageway roads to assess and evaluate the speed/flow relationships and hence the road capacity from the simulation model for a given road geometry and traffic demand.

**Keywords:** simulation model, traffic behavior, capacity, traffic operations.

### INTRODUCTION

The rapid growth of road traffic has become a major concern to traffic engineers and transportation planners worldwide. This rapid growth has affected not only the road traffic behaviour but also the travel pattern of the community to commute from their origin to any of their preferred destination. The trend in Malaysia shows that the number of vehicles on the road has increased every year [1]. The increment of the number of vehicles on the road will have a significant effect on the capacity of the road and the level of service, and it will also increase the road congestion especially during peak hour.

With the advances in computers and simulation techniques, it is now possible to model any roadway network and simulate traffic flow on the roads in a very realistic fashion. Traffic simulation modeling is becoming more attractive and effective tools in studying traffic issues. This enables traffic engineers and transportation planners to investigate the effect of changes in the network geometry, capacity analysis and traffic control strategies on traffic performance. The purpose of this study is to develop a simulation model of traffic flow on single carriageway roadways for a given road geometry and traffic demand.

### METHODOLOGY

Capacity defined as a measure of the effectiveness of the road in accommodating traffic. TRB (2000) [2] stated that the definition of capacity is based on the maximum sustainable rate per hour where individuals or vehicles could be expected to go through a point or at an identical section of lane or road in a specific duration of time under usual road, traffic and the controlled situation. Observing flow phenomena at or near capacity is a

challenge to attain practically. After HCM was first published in 1965, there has been extensive discussion of methods for capacity evaluation [3]. Peterson (1977) recommended that diverse methods discovered different resolutions to identical issues.

#### Factor affecting speed/flow relationship and capacity

The operational characteristics of single carriageway roads are determined by the following factors:

- Lane width and lateral clearance
- Vertical and horizontal alignments
- Traffic composition
- Directional split
- Environmental effects
- Traffic interruptions

#### Simulation model of traffic flow

The main behavioural sub-models used in microsimulation in traffic flow are described below.

##### a) Car following model

Car following model is of particular importance to traffic safety. Not only because close following with excessive speed is known to increase the risk for rear-end collisions, but also because car following behavior determines the distribution of gaps that exist at any particular point of measurement in a traffic stream. Researchers such as Gazis *et al* (1961) [4], May *et al* (1967) [5], Kohler (1979) [6], Gipps (1981) [7], Miyahara (1994) [8], Cho (2008) [9], had studied and modeled drivers' car following behavior. Their studies and models varied in objectives and ranged from an empirical



approach to complex mathematical and simulation modelling approaches.

The car following model adopted for this study is the one described by Mahdi (1991) [10]. This model would provide sufficient large safe following distance so that there will be no rear-end collision if the preceding vehicle comes to a stop instantaneously. ChePuan O. (2004) [11] proposed the following equations of car following distance relationships for Malaysian traffic characteristics:

$$H(\text{all vehicles}) = 2.98 + 1.16V \quad (1)$$

$$H(\text{car - car}) = 1.26 + 1.19V \quad (2)$$

$$H(\text{car - HGV}) = 4.04 + 1.12V \quad (3)$$

$$H(\text{HGV - HGV}) = 9.33 + 1.21V \quad (4)$$

$$H(\text{HGV - car}) = 5.17 + 1.19V \quad (5)$$

Where H is the distance headway (m) and V is the vehicle speed (m/s).

### b) Overtaking model

Related to the car following behavior is the overtaking behavior. Overtaking is one of the common phenomena that may be observed on single carriageway roads. If a slower vehicle is in front of the agent, it may decide to overtake this vehicle. This decision depends on the velocity difference between the two vehicles and the

available space to overtake the vehicle, both in front and to the right of the other vehicle. The definitions of some of the variables used for simulating an overtaking manoeuvre are shown in Figure-1.

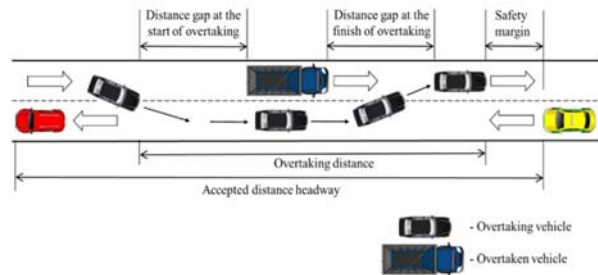


Figure-1. Definitions of some of the overtaking variables.

### Model input

There are two types of input data generally required in a traffic simulation model as follows; (a) the physical characteristics of the system and, (b) the characteristics of the traffic. The detailed information of various aspects of the characteristics to be modeled may be present in each type of the data as explained in Table-1.

Table-1. Common input data used in most traffic model.

Type of data	Information required
Physical characteristics: Single carriageway roads Priority junctions	Length of the road section, number of lanes and width, horizontal & vertical alignments. Location, number of approaches, types of traffic control
Traffic characteristics: Vehicular data Driver's data	Vehicle types, traffic flow and composition. Directional flow, headway distribution. Desired speed & critical merging gap.
Simulation requirement	Simulation time

## RESULTS AND DISCUSSIONS

The various assumptions and simplifications involved in the development of a traffic simulation model in this study with regards to the traffic process are to reduce the complexity of the model. Therefore, any outcome of the resulting model is only an approximation of the real situation. However, if assumptions and simplifications are incorrectly made, a model may be far from replicating all the important components of traffic behavior. In this instance, the capacity of a model representing the behavior of a traffic system under investigation is considered a satisfactory, and in the most efficient way must be assessed before the model can be used with confidence.

### Model calibration

Model calibration is a process in which model output is compared with operation data collected in practice. In a given situation where the agreement is poor, parameter values and/or assumptions are adjusted in order

to provide a better agreement between observed and predicted values. The model developed for this study was calibrated using several sets of typical data of road and traffic characteristics. One of the aspects used for calibrating the model as developed in this study is the time-distance diagram. A time-distance diagram, i.e. a plot of the positions of each vehicle over a period of time, can be used to examine the movement of each individual vehicle as it progresses along a road section. In simulating the drivers' car following behavior, this diagram is used to provide a useful means of evaluating the correctness of the model.

The simulation of traffic operations on two roads without junctions, each 4 km long, was used to examine the time-distance diagrams for vehicle movements away from a junction. It is assumed that one of the roads with a continuous non-overtaking section, was flat and straight. In this study, the road with a non-overtaking section, flow levels of 200 veh/h/dir and the road with a continuous overtaking section, a flow of 200 veh/h/dir were used.



In Figure-2 and Figure-3, two examples of time-distance diagram, which were drawn for recorded data, are shown. These trajectories of individual vehicles in one direction of travel appear as lines, which climb from left to right. As indicated in Figure-2, the headway and spacing can also be obtained from this diagram.

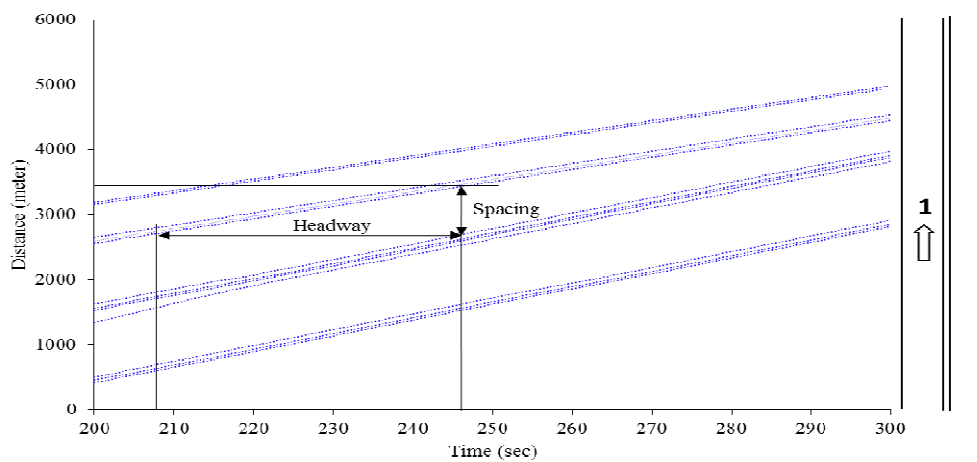
As a whole, the diagrams show some of the usual traffic phenomena such as catching up, platooning, overtaking, and leaving the platoons. It could be seen that when the flow increases, the diagram is dense with the trajectory lines.

Figure-3 shows the trajectories of vehicles in both directions of travel on an overtaking section for direction

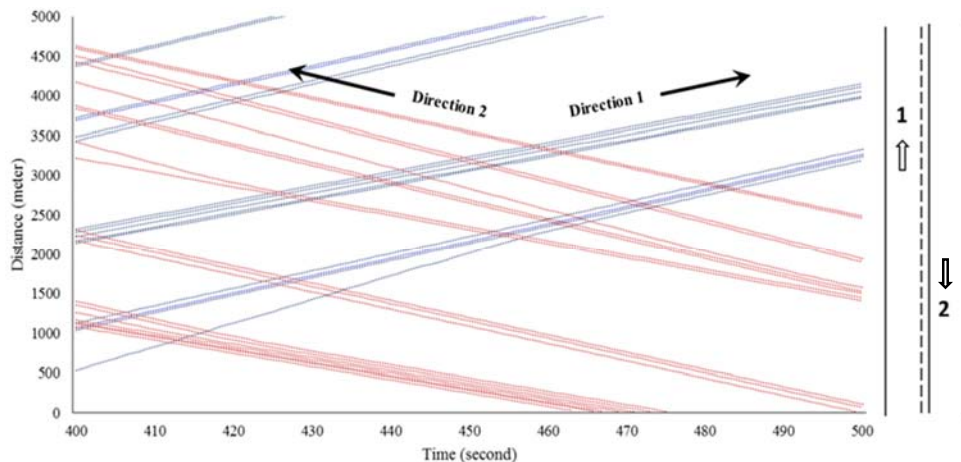
one and a non-overtaking section in the other direction of travel.

The above examples of the time-distance diagram show smooth vehicle trajectories. There were no conflicts between the lines for the cases where the road is a non-overtaking section. On an overtaking section, there were no conflicts between the overtaking and opposing vehicles. Such characteristics of the diagrams indicate that all components of the model functioned properly for this aspect.

According to Vasconcelos (2014) [12], trajectory data also can be used to calibrate the Gipps car following model compared using the normal macroscopic traffic stream variables of speed, flow and density.



**Figure-2.** Vehicle trajectories in Direction 1 of traffic on a non-overtaking section with a traffic flow of 200 veh/h/dir.



**Figure-3.** Vehicle trajectories in both direction of traffic with a traffic flow of 200 veh/h/dir.

**Table-2.** Characteristics of the simulated road sections used for model validation process.

Length (km)	Bendiness (deg/km)	Hilliness (m/km)	Verge width (m)	Junction (nos.)	Visibility (m)	Average overtaking section (%0)	HGVs (%)
3.5	63	23	3	0	650	89	5
3.5	63	23	3	6	392	46	30
3.5	53	0	3	0	371	42	15
3.5	53	18	0	0	272	25	15
3.5	110	0	3	0	250	22	15
3.5	134	0	3	0	250	22	15
3.5	134	0	3	6	250	22	15

### Model validation

This study includes model validation that refers to the ability establishment of the calibrated model which replicates the real traffic systems. Normally traffic and road performance parameters are used for this process. In this study, to measure the model performance, the average journey speed (for all vehicles) and the average traffic delay to the minor road vehicles were used.

The validation procedure involves the collection of the field data that includes the input data required by the model and the data corresponding to the output information. Upon confirmation, the model is then run using the appropriate input data and the output of the model is compared with that of the field observations. In conjunction with the speed/flow/geometry (S/F/G) relationships that was established by Lee *et al.* (1993) [13], the model in this study is developed in considering the effects of road geometry and priority junctions on journey speeds explicitly even though the effect of turning movements on through traffic is not included in the relationships.

Table-2 was created to list out the details of several road sections with their individual characteristics. In the table, it could be seen that these road sections were made up of different combinations of a range of vertical and horizontal alignments, verge widths, overtaking values (overtaking sections), and sight distances.

In this model, it was run for flow levels between 100 - 1400 veh/h/dir with HGVs ranging from 5% to 30% for each road section. A directional split of 50/50 was assumed in all runs.

It is due to the effects of random process, the model was run between three to five times to reflect on the

fluctuations for each set of the data. This is evidence as illustrated in Figure-4, Figure-5 and Figure-6 where they show the sample plots of the speed/flow/geometry relationships for comparison with the relationships derived by Lee *et al.* (1993) [13]. In terms of Figures clarity, the average of three to five runs represent each simulated speed/flow point.

Using Lee *et al.* [13] relationships for flow levels between 100 and 1000 veh/h/dir, the overall speed/flow/geometry relationships as partly shown in the Figures indicated good agreement with those calculated flow levels. In the process, due to the random inputs, some fluctuations are expected in the simulated speeds and flows in the model. It could be seen, the model tends to predict slightly higher journey speeds than those calculated from Lee *et al.* [13] relationships for flows higher than 1000 veh/h/dir. Lee *et al.* [13] relationships for the range of the road layouts and traffic characteristics were used to calculate the plotted simulated journey speeds from all runs against the values in assessing the overall performance of the model.

It is best concluded from the results of the above comparisons, the real world behavior of drivers and vehicles for a relatively wide range of road layouts and traffic characteristics can be presented using the simulation model developed from this study. However, good agreements between the simulated and Lee *et al.* [13] speed/flow/geometry relationships may be obtained if there are only few turning movements at the individual junctions for road sections, where priority junctions are included.

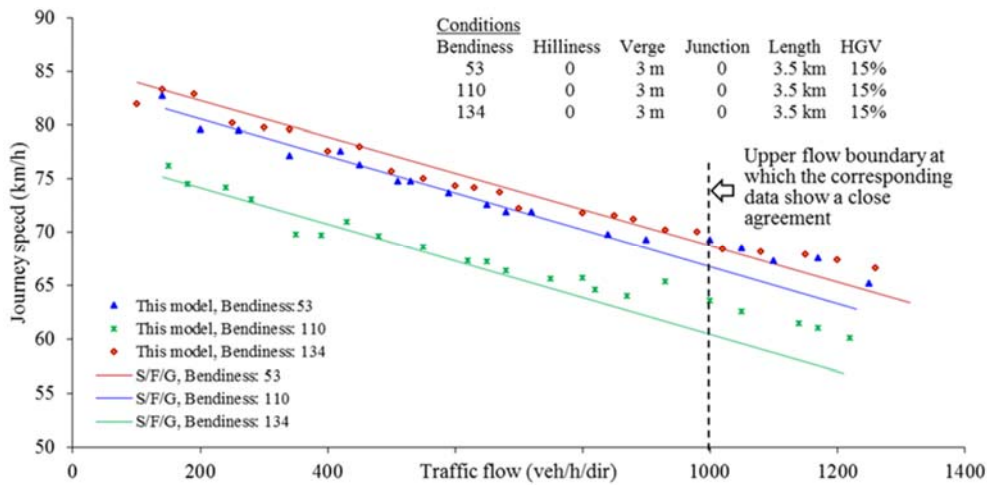


Figure-4.Speed/flow plots based on simulation and S/F/G relationships for different bendiness.

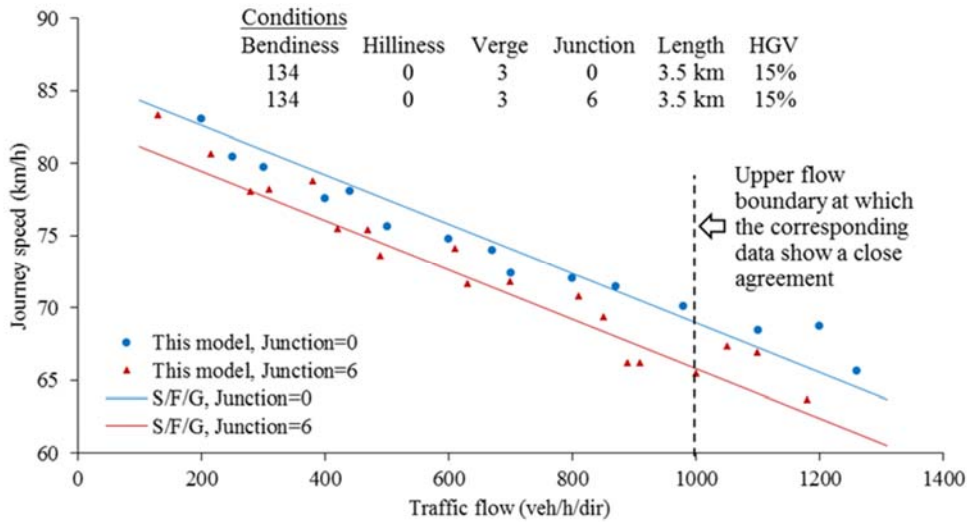


Figure-5.Speed/flow plots based on simulation and S/F/G relationships for different numbers of T-junctions.

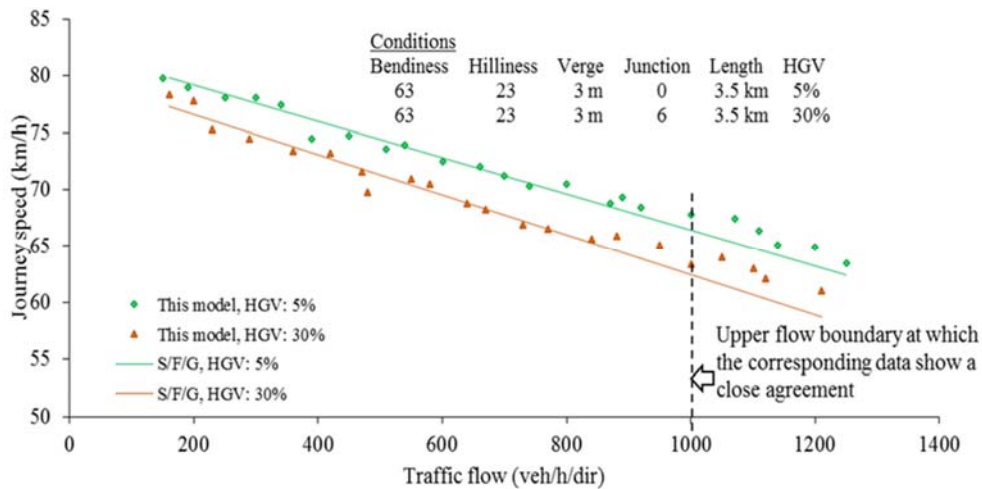


Figure-6.Speed/flow plots based on simulation and S/F/G relationships for different percentages of HGVs.





## CONCLUSIONS

This study concluded that the simulation model developed has been calibrated and validated over a wide range of road and traffic conditions. During the development process, the following aspects were considered:

- Vehicle trajectories,
- Average journey speeds.

All the aspects as stated above were considered adequate in its evaluation in order to provide an indication of the reliability of the model. To do so, the model was modified from various aspects of programming logic, in achieving good agreement with the theoretical and the results from the previous studies. In this study, emphasis was given to the speed/flow/geometry relationships because this aspect is the main concern. Although the relationships derived by Lee et al (1993) [13] were used for comparisons; calibration and validation process were carried out without compromising the reliability of the original OSCA model.

The summary illustrated above suggests that the developed model adequately represent the behavior of traffic on single carriageway roads, with and without considering turning movements at priority T-junctions. Therefore, the results of the simulation model can be used with confidence to draw conclusions corresponding to the objectives of the analysis.

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