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Al-Jameel, HAE

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Towards the Simulation of Ramp Weaving Sections

Hamid H.E.Al-Jameel¹

¹*School of Computing, Science and Engineering,
University of Salford, Salford, M5 4WT,
United Kingdom*

Email: hamidathab@yahoo.com

Abstract:

Motorway weaving sections entail intensive lane changes which lead to high turbulence within such sections. Different methods, such as mathematical modelling, have been adopted to analyse traffic behaviour and to determine weaving section capacity. However, simulation methods have proved to be more effective than other mathematical methods. Therefore, a simulation model has been developed for this purpose and this model has been calibrated and validated with field data from normal and weaving sites. Different configurations of weaving sections are in use, such as “major weave” which occurs between two major roads and “ramp weave” that occurs between minor road (i.e. on-ramp) and major road (i.e. motorway). This study focuses on ramp weave only since the data available from sites represent this configuration. Field data was used to calibrate and validate the newly developed simulation model. The results from the newly developed model showed good fit with the field data in terms of calibration and validation. The model has been applied to assess the effect of weaving length under different number of lanes for ramp weave sections, the percentage of heavy goods vehicle and the different volume ratios. The results showed that weaving length has an effect on capacity up to a certain limit, after which its effect dissipates. The presence of heavy goods vehicles also causes a high reduction in the capacity of the weaving section and this reduction has been estimated. Other factors, such as volume ratio, have a significant effect on the capacity of weaving section.

Keywords: weaving section capacity, ramp weave, HGVs effect

1. Introduction

More attentions have been directed towards microscopic simulation models in the last two decades because of several merits of using this approach. These are ability of simulation to provide visual environment and managing many problems, such as congestion and signal control optimisation, which cannot be solved by traditional tools because of the complexity of the road transport system. In addition, these microscopic models help more in applying different scenarios without disrupting the traffic and using expensive sources (Hidas, 2005). Paramics, AIMSUN and VISSIM are examples of well-known micro-simulation models used in practice.

The existing simulation models suffer from several limitations especially when trying to represent weaving areas. For example, the AIMSUN model allows vehicles to go in the wrong direction if it could not find a suitable gap to change lanes after a maximum time called “lost vehicle” which indicates a failure in the model (Hidas, 2005). Prevedouros and Wang (1999) reported that the INTEGRATION model has several limitations such as waiting at the divergence point and making long queue which do not occur in reality. Questionable

capacity and gap acceptance have been reported in the CORSIM simulation model for weaving sections (Zhang and Rakha, 2005). Moreover, under heavy flow, VISSIM is unable to model weaving sections (Gomes *et al.*, 2004). Similarly, AIMSUN, CORSIM and Paramics also have the same problem under heavy flow in the weaving area as reported by Sarvi *et al.* (2011).

To overcome these limitations which affect the accuracy of estimating the weaving capacity using existing simulation models, there is a need for developing a new simulation model. Therefore, this study is devoted to the development of a simulation model to evaluate the capacity of weaving section and to applying different scenarios to improve weaving section performance.

2. Weaving section

Weaving can be defined as the crossing of two or more traffic streams while travelling in the same general direction along a specific section of a highway without the aid of traffic control devices such as traffic signals and traffic signs (HCM 2000). The HCM classifies weaving into three types, namely: Types A, B and C. This classification is based on the minimum number of lane changes that are expected by weaving vehicles.

A few studies were found in the literatures that relate to this study. For example, Zarean and Nemeth (1988) adopted the WEAVSIM microscopic simulation model to investigate the effect of the different arrival speeds on the operation of weaving sections. Subsequently, the researchers suggested a regression model for the modelling of weaving sections based on the results from simulation. However, this model does not include the cooperative behaviour in its algorithm which is predominately observed in weaving sections.

Cassidy and May (1991) compared the speed of weaving and non-weaving vehicles results from six procedures; the 1985 HCM, Leisch method (Leisch, 1979), JHK method (Leisch, 1984), Fazio method and Polytechnic Institute of New York (PINY) (Pignataro *et al.*, 1975, Zhang, 2005), with field data. The results show that no one of these procedures was adequate because the speed was insensitive to flow. In addition, the HCM (2000) has proved to be inaccurate because it estimates weaving capacity based on the assumption that density at capacity is equivalent to 27pcphpl without giving reasons behind the selection of this value. This was reflected by other studies using simulation models such as Skabardonis *et al.* (1989), Zhang (2005) and Lee and Cassidy (2009).

These simulation models mainly depend on field data to represent the behaviour of drivers through the calibration and validation processes. Moreover, most weaving data suffer from either limited samples or incomprehensive data (Lee and Cassidy, 2009).

Here in the UK, there is an obvious lack of field data for weaving sections. Developing a simulation model for a specific case depending on data from other environmental conditions or different rules and systems of driving may lead to inaccurate results. Therefore, in this study and in order to overcome these problems, seven weaving sections were adopted and used in the calibration and validation processes of the simulation model which was developed to study such sections.

3. Developed model

The developed model consists of sub-models such as car-following, gap acceptance, lane changing and weaving processes. The algorithms of these processes were programmed using Visual Compact Fortran as bed test.

3.1. Car-following rules

The developed car following model governs the longitudinal movement of vehicles in a lane by selecting a suitable acceleration/deceleration (Al-Jameel, 2009). If a driver has no obstruction, s/he will drive to reach the desired speed or choose the maximum deceleration in the case of an emergency when her/his leader suddenly stops. In addition, a driver will use her/his normal acceleration/deceleration when s/he exceeds the desired speed or speed limit. These different accelerations have been included in this model.

The selection of a suitable car-following model is a crucial task in developing a simulation model. Therefore, different car-following models were developed and tested. These models were GHR, CARSIM, WEAVSIM and Paramics (Al-Jameel, 2009 and 2010). The assumptions of the GHR, CARSIM and WEAVSIM were developed using Visual Compact Fortran as the test-bed. Then, these models were tested under different sets of data including different traffic conditions. The results of these tests showed that CARSIM was the most reasonable model in replicating reality amongst others in representing different traffic conditions (Al-Jameel, 2009 and 2010). Therefore, most of the CARSIM assumptions were adopted to develop this car-following model. Accordingly, a new car-following model was developed to represent the weaving section. High interactions and stop and go conditions need considerable attention to be correctly represented. This was done by selecting suitable limits of reaction time, buffer spacing, start-up delay and other characteristics in order to test this model with field data as discussed below.

The model was compared with field data reported by Panwia and Dia (2005) as shown in Figure 1. Root mean square error (RMSE) and error metric (EM) have been used as good indication to test the accuracy of the developed model (Panwia and Dia, 2005). The results show that the developed model gave the lowest error than other models which have been compared under the same set of data as indicated in Table 1.

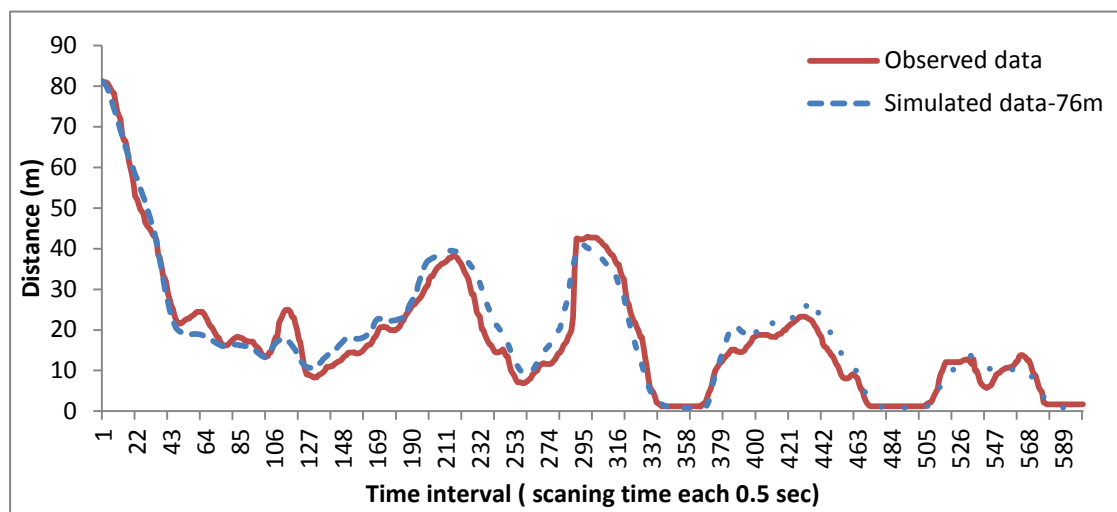


Fig.1. Calibration of simulation with observation data using different effective distances

Table 1 Performance of car-following rule for selected simulation models (Panwai and Dia, 2005).

Simulator	The developed model	AIMSUN (4.15)	VISSIM (v3.70)		Paramics (v4.1)
			Wiedemann74	Wiedemann99	
EM	2.01	2.55	4.78	4.50	4.68
RMSE	3.49	4.99	5.72	5.05	10.43

3.2. Lane changing rules

Lane changing represents transferring vehicle from the subject lane to an adjacent lane under different conditions. Two types of lane changing have been adopted in this study, namely discretionary and mandatory. The discretionary lane changes are implemented when a driver has a desire to increase her/his speed or to avoid being locked behind slower vehicles (Sultan and McDonald, 2001). Whereas, mandatory lane changes are achieved in order to reach the destination, i.e. a driver has to change lanes to be in the right direction such as weaving process.

The field data collected by Yousif (1993) and Sparman (1979) were used for the purpose of comparison with the simulated data for two lane normal sections as shown in Figure 2. The results demonstrate that the trend from simulation approximately matches reality in terms of frequency of lane changes (FLC). This behaviour can be represented by an increase in the FLC with an increase in flow up to 2000 veh/hr followed by a decrease in FLC as shown in the Figure. The main factors that have been adjusted during this calibration process are the gap acceptance parameters ($\beta_1=0.5$, $\beta_2=0.6$, $\beta_3=0.5$, $\beta_4=0.8$) as used in the following equations for lead and lag parts of the gap. Note that for both equations, the first term (i.e. LD and LG) should be equal or more than zero.

$$LD = \beta \quad \text{---} \quad \text{---} \quad (1)$$

$$LG = \beta \quad \text{---} \quad \text{---} \quad (2)$$

Where;

LD is the minimum lead gap (m).

LG is the minimum lag gap (m).

β_1, β are calibration parameters.

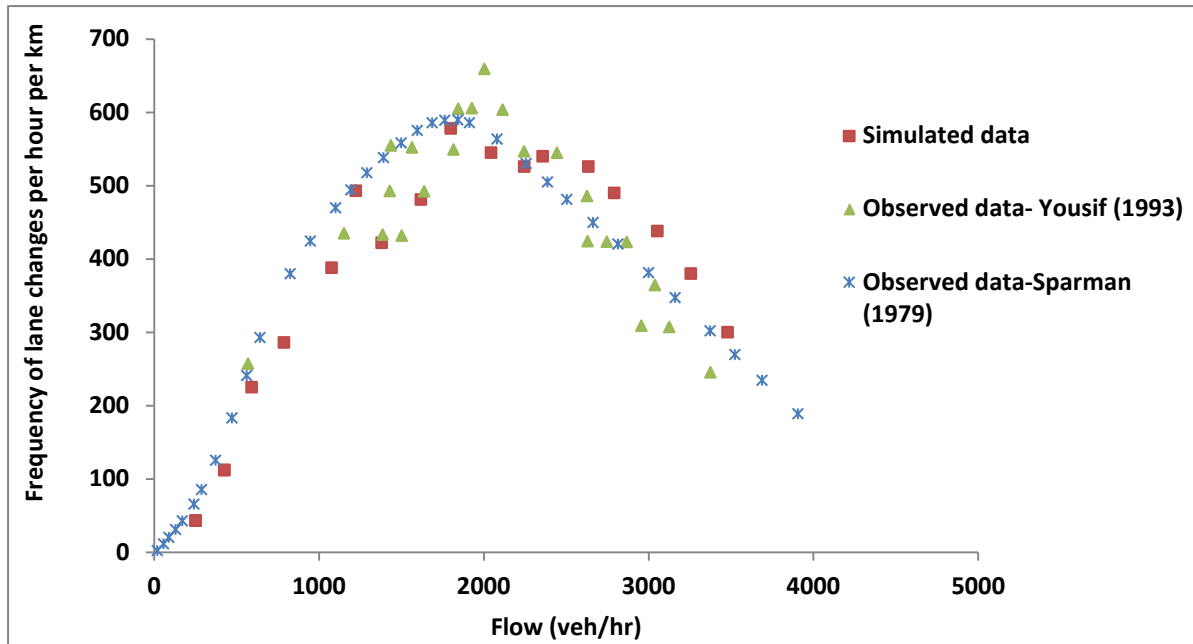


Fig.2. Frequency of lane changes from simulation compared with different sets of observed data for two-lane normal sections

4. Weaving rules

The main processes of weaving section can be summarised by the interaction between traffic streams coming from the on-ramp with that coming from the motorway. For normal motorway sections, the interaction includes the cooperative behaviour (i.e. shifting to adjacent lanes or staying in the same lane but with applying deceleration). For the case of sections with on-ramps, the same behaviour applies but without shifting to adjacent lane (in the case of one auxiliary lane).

Close following behaviour, which represents accepting small spacing between the changing vehicle and its leader as reported by Wang (2006), was also applied. After the close following behaviour, the changing vehicle returns to the normal case (i.e. the spacing gap increases to be as in the normal case). This process is called relaxation behaviour (Laval and Leclercq, 2008 and Cohen, 2004). In this study, the duration of close following behaviour for weaving vehicles, was adopted as 20 sec (Cohen, 2004).

4.1. Weaving behaviour

The weaving process consists of several complicated processes to reach the destination such as reducing and increasing the speed of vehicles involved in the weaving process among merging and diverging vehicles as shown in Figure 3. Based on real data from weaving sections as investigated by this study, it was found that the percentage of courtesy yielding exceeds 90%. On the other hand, the cooperative lane changing has been assumed for non-weaving vehicles when their decelerations are less or equal to -3 m/sec^2 . This value has been identified as the maximum deceleration value which could be applied to drivers under normal conditions as reported by (ITE, 2010).

Al-Jameel (2011) introduced the effective length which is the length at which most weaving vehicles completed their manoeuvres. This length is influenced by the geometric design such as weaving type and weaving length. According to Al-Jameel (2011), the effective length was about 200m for ramp weaving sections when the weaving length was more than 300m, whereas this length represented the whole of the weaving length for sections with lengths less than 150m for the same type. In this study, the effective length used instead of total weaving length to make a driver accepting high risk in terms of maximum deceleration. Other characteristics were also investigated such as volume ratio (VR) and weaving ratio (R).

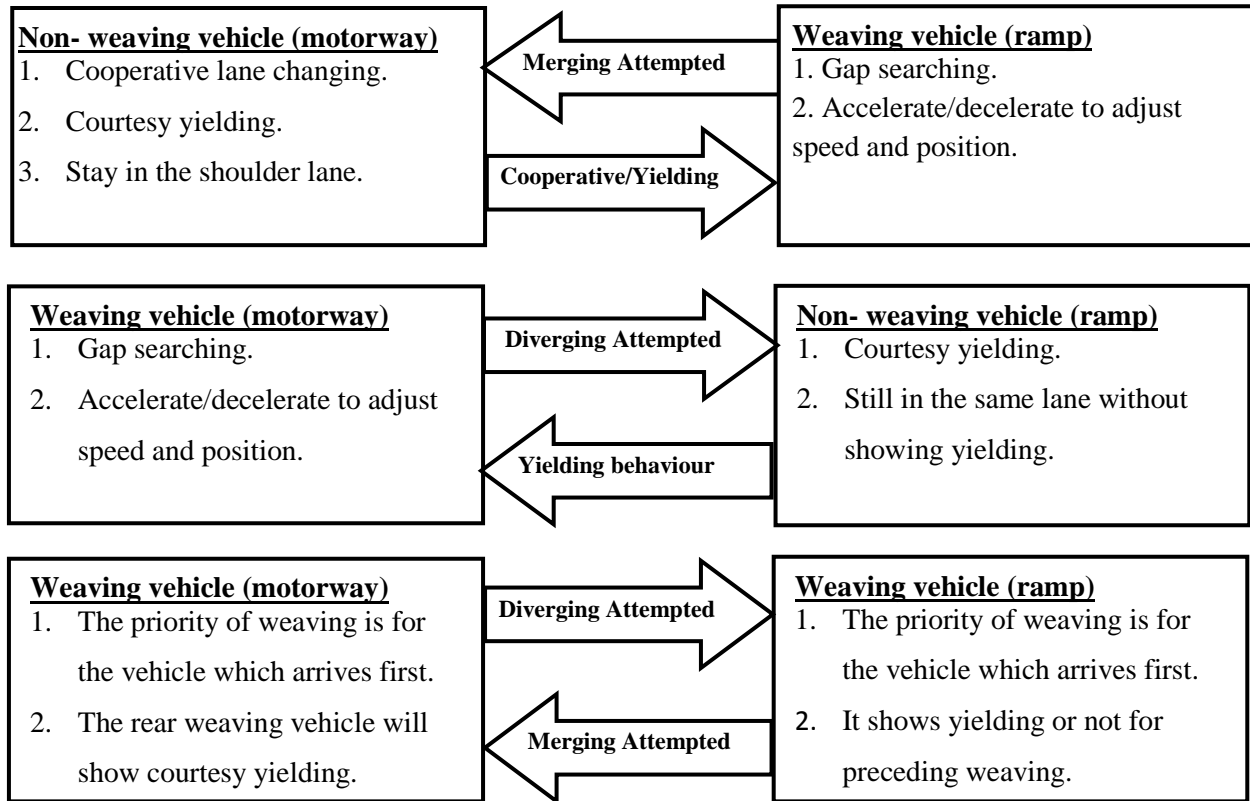


Fig.3. Interaction behaviours for weaving vehicles (motorway and ramp)

4.2. Testing the developed model with field data

The developed model was tested with field data collected from video recordings and data from the Motorway Incident Detection and Automatic Signalling (MIDAS). Figure 4 indicates the location of loop detectors at the weaving section on the M60 J2. The upstream loop detector was used as input for the simulation model and other loops were used for comparison with field data.

The type of this weaving section is Type A (ramp weave) with four lanes (i.e. the motorway consists of three lanes and one lane for the on-ramp). The length of the section is 400m with four lane weaving section. This set represented 130 minutes of data for both speed and flow and was used to calibrate the developed model.

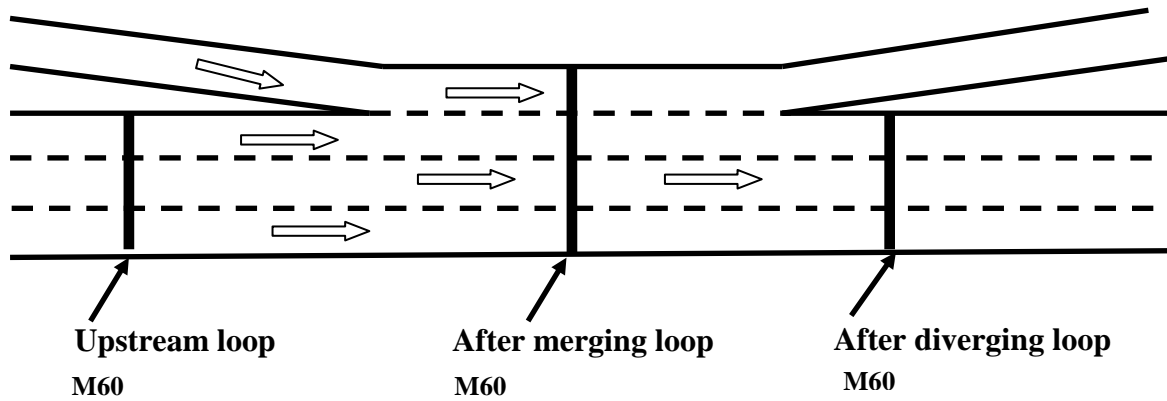
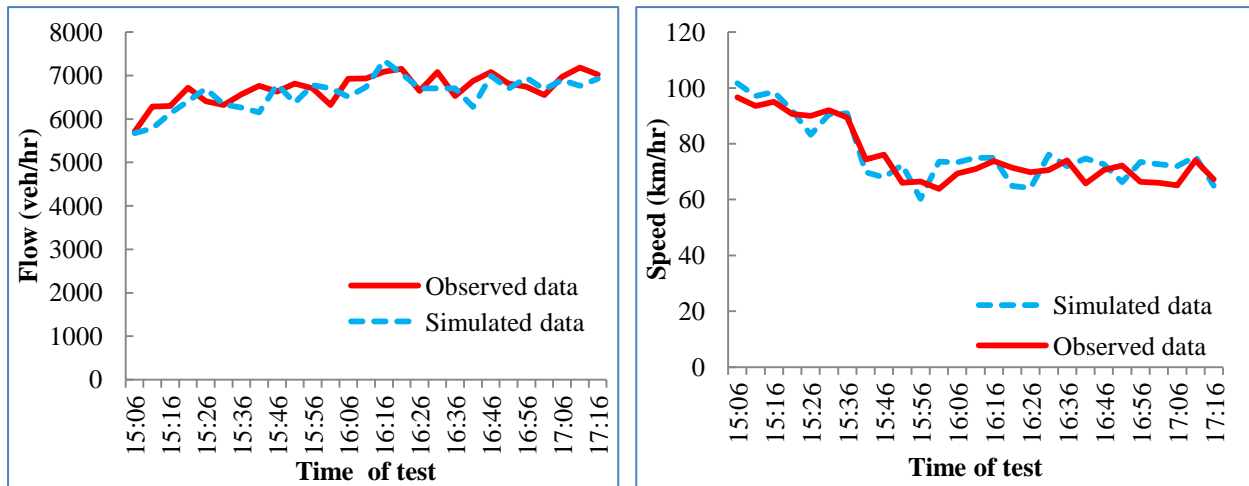


Fig.4. Data collected from different loop detectors for the M60 J2 weaving section.

For this weaving section, there are three loop detectors, as follows:

- the upstream detector (M609034B) at 200m from the entrance point,
- the merging detector (M609030B) at 200m after the entrance point, and
- the diverging detector (M609026B) at 90m after the exit point.

To select the optimum parameters for Equations 1 and 2, it was found that ($\beta_3=0.3$ and $\beta_4=0.4$). Fig.5 shows the comparison between observed and simulated data, whereas Table 3 demonstrates the statistical tests for this comparison. The tests used here are the coefficient of correlation (r), root mean square percent (RMSP), Theil's inequality coefficient (U), Theil's mean difference (U_m) and Theil's standard deviation (U_s). These tests have been used in different traffic simulation models, for example, Hourdakos *et al.* (2003) and Wang (2006). The results of the comparison show that these values are within acceptable limits. Therefore, the developed model reasonable represents the reality as shown in Table 3.



A. Observed and simulated flow (veh/hr)

B. Observed and simulated speed (km/hr)

Fig.5. Comparison between field and simulated data: (A) Flow and (B) Speed.

Another set of field data from the M60 - J2 was used to validate the developed model as indicated in Table 4. The results also show good agreement with field data since they are within acceptable limits.

Table 3 Comparison between simulated and observed data-M60-J2 on 29-10-2010

<i>Loop location</i>	<i>After merging section</i>		<i>After diverging section</i>	
<i>Parameters</i>	<i>Flow</i>	<i>speed</i>	<i>Flow</i>	<i>Speed</i>
<i>R</i>	0.88	0.91	0.88	0.83
<i>U</i>	0.017	0.034	0.0169	0.034
<i>Um</i>	0.276	0.039	0.299	0.409
<i>Us</i>	0.029	0.0081	0.0463	0.09
<i>RMSP%</i>	3.5	1.51	3.6	7.0

Table 4 Comparison between simulated and field data from the M60-J2 on 8-10-2010

<i>Location</i>	<i>After merging section</i>		<i>After diverging section</i>	
<i>Parameters</i>	<i>Flow</i>	<i>Speed</i>	<i>Flow</i>	<i>Speed</i>
<i>RMSP%</i>	4.9	0.11	2.6	1.7
<i>R</i>	0.93	0.89	0.975	0.90
<i>U</i>	0.029	0.046	0.048	0.038
<i>Um</i>	0.086	0.007	0.826	0.009
<i>Us</i>	0.0116	0.0045	0.006	0.193

5. The applications of the developed model

After the calibration and validation processes which show reasonable results, the developed model was used to investigate different impacts of some characteristics such as the percentage of heavy goods vehicles (HGVs), the volume ratio (VR) and the length of weaving section.

5.1. Impact of HGVs

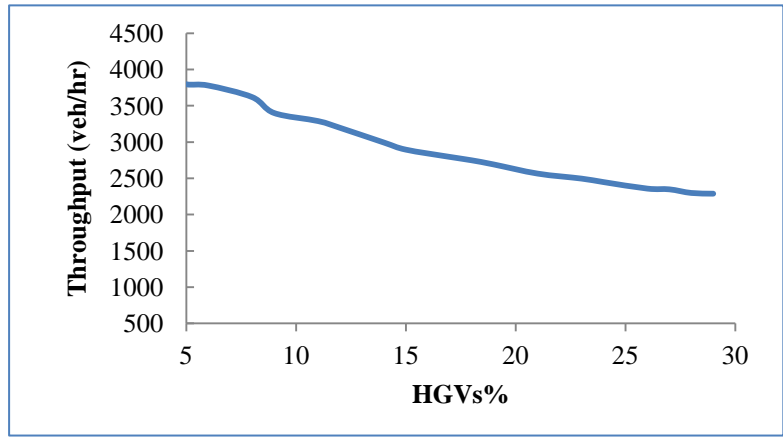
The effect of HGVs was investigated using the developed model. In order to test the effect of varying the percentages of HGVs, other parameters were fixed in the model. These parameters include the length of weaving section (300m), the VR (0.25), R (0.4). Three types of weaving sections were used in this test: two-lane, three-lane and four-lane sections.

Figure 6-a shows the effect of different percentages of HGVs on the throughput for a two-lane weaving section. As the percentage of HGVs increases, the throughput decreases from approximately 3800 veh/hr to less than 2300 veh/hr.

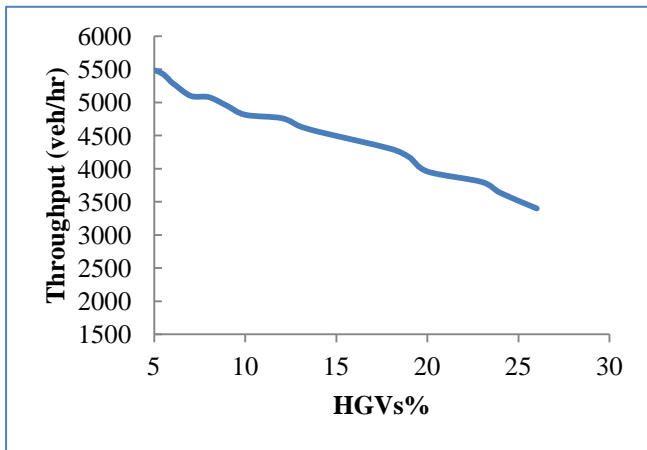
For a three-lane weaving section, the effect of the percentage of the HGVs has also been investigated as shown in Figure 6-b. As the percentage of the HGVs increases, the throughput decreases from approximately 5500 veh/hr to 3400 veh/hr. This reduction in the throughput is higher than that for the two-lane weaving section. On other hand, the effect of the HGVs for the weaving section with four lanes has also been investigated as shown in Figure 6-c. The

reduction in the throughput reaches up to 2200 veh/hr due to the effect of increasing the percentage of HGVs.

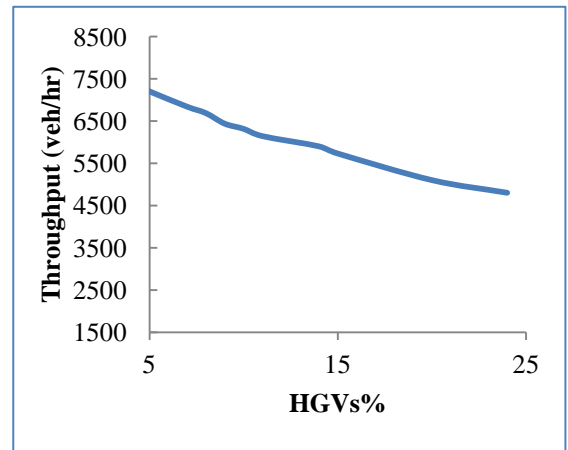
In light of the above, the percentage of HGVs has a strong effect in reduction the throughput from weaving sections. However, this effect differs according to the number of lanes in the weaving section.



a. Two-lane section.



b. Three-lane section.



c. Four-lane section.

Fig.6. Impact of HGVs on the capacity of weaving section

5.2. Impact of weaving length

As discussed in the previous sections, other characteristics of weaving section have been fixed such as the percentage of HGVs (15%), the ratio of VR (0.3) and R (0.4). Here, the weaving length has been changed from 100m to 700m to study its effect on the capacity of weaving section.

The impact of the weaving length on throughput for two, three and four lane sections is as shown in Figure 7. For all sections, the effect of the first 300m has large influence on the throughput of weaving section. Beyond this 300m, there is no significant effect. For example, the as the weaving length increases from 100m to 300m, the throughput increases from

approximately 5800 to 6700 veh/hr for the four lane section. Similarly, for the two and three lane sections, the increase is from 2200 to 3100 veh/hr and 3800 to 4700 veh/hr, respectively.

In the light of the above, the effect of weaving length differs according to the geometric design of a weaving section. The effect of a two lane section is higher than the others. This could be attributed to the direct effect of weaving vehicles on the non-weaving vehicles due to restriction in the geometric design. In another words, the non-weaving vehicles have to follow the weaving vehicles. Therefore, the four lane weaving section has less effect than the three-lane and the later is less than the two lane section because of possibility of non-weaving vehicles to select other options such as cooperative lane changes

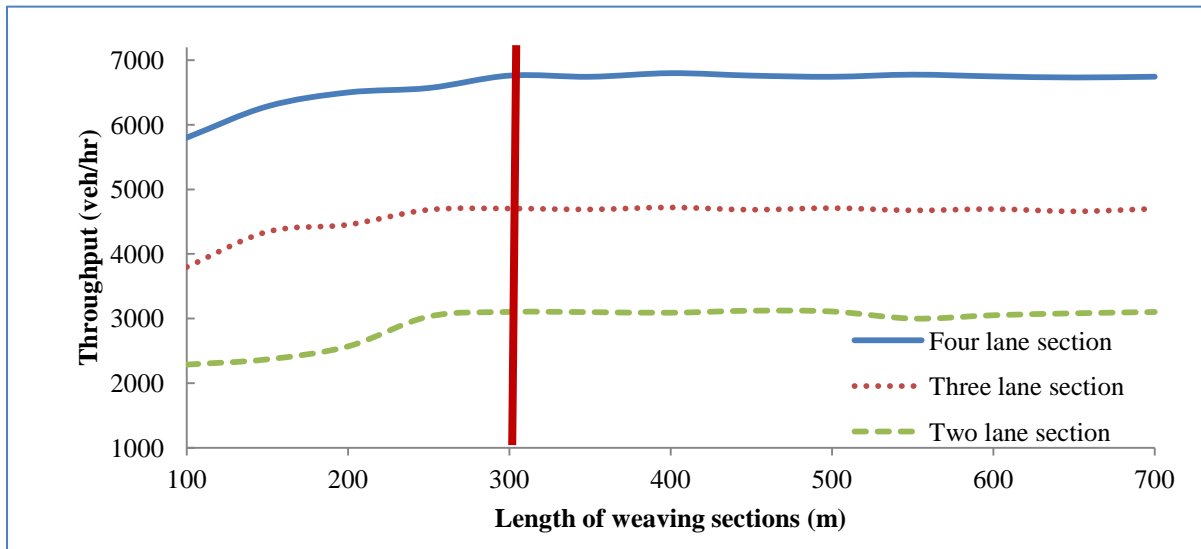


Fig.7. Effect of weaving length on throughput for two, three and four lanes weaving sections

5.3. Impact of VR

The effect of VR, which is the ratio of weaving vehicles to the total vehicles entering a weaving section, was investigated as shown in Figure 8. The conditions used here are similar to the ones used by the HCM and the INTEGRATION simulation package as reported by Zhang and Rakha (2005) to allow comparison.

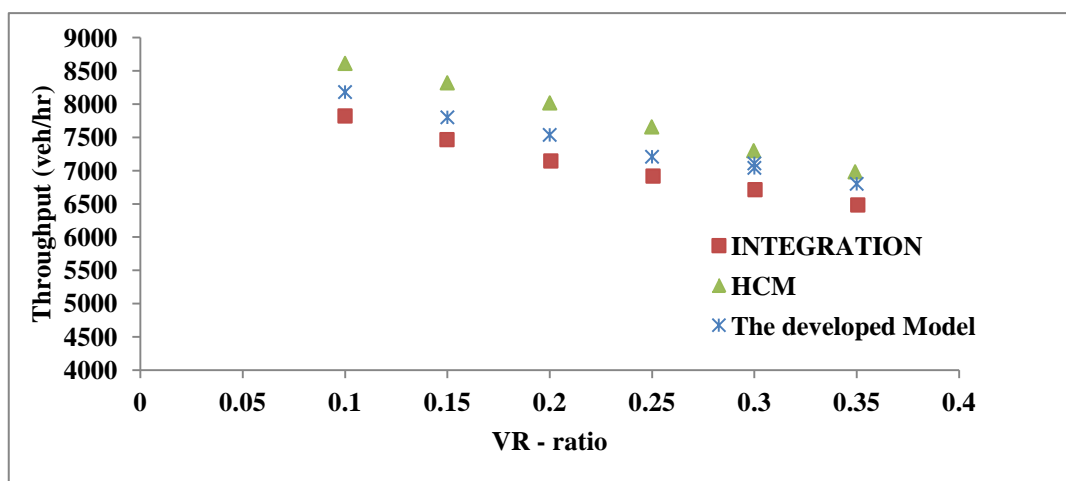


Fig.8. Comparison the developed model with HCM and INTEGRATION

The figure demonstrates that the developed model is slightly higher than the predicted values from the INTEGRATION model under different values of VR. However, it is lower than the HCM predicted values up to 0.25 and then they become approximately the same.

6. Conclusions

The main points of this study can be summarised as follows:

- The developed model has proved to be better than other simulation models such as Paramics, AIMSUN and VISSIM in terms of car-following behaviour. In addition, its lane changing behaviour shows reasonable representation of the observed data.
- The developed model shows good fit with field data used in the calibration and validation processes both graphically and statistically.
- Effects on throughput of HGVs, VR and weaving lengths were investigated using the developed model. It was found that the effect of HGVs was higher than the effect of other factors such as VR and weaving length on the maximum throughput of weaving sections.
- The effect of weaving length on throughput is up to a certain limit of weaving length, namely “effective length”. In this study, beyond 300m there is no influence of weaving length on throughput for two, three and four lane weaving sections.
- When testing the effect of VR on throughput, the developed model gave similar trend to those obtained from the INTEGRATION and the HCM (2000). However, the throughput was higher than that from the INTEGRATION and lower than the HCM (2000).

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