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CALIBRATION AND VALIDATION OF VISSIM MICROSCOPIC MODEL OF CONTRAFLOW OPERATION SYSTEM OF SILK HIGHWAY, MALAYSIA

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Abstract

The understanding of heterogenous driving conditions can be furthered through microscopic simulation model calibration. This study focused on the calibration of six (6) driving behaviour parameters (standstill distance, look-ahead distance, headway time, following variation, diamond-shape queuing, and look-back distance) for control and simulation of driving behaviour in VISSIM for the prediction of heterogeneous traffic when operating a contra-lane. Driving behaviour simulation at a contraflow operation system is more complicated than mainstream traffic simulation due to the heterogeneous traffic condition at peak hour. The calibrated results in this study were validated and compared to field results using Mean Absolute Percent Error (MAPE) and paired t-test analysis at 95% level of confidence. The validation process showed no observable difference at 98.5% confidence level. Furthermore, standstill distance, headway time, and following variation were found to govern driving behaviour variations. The look-ahead & look-back distances allow smooth and realistic driving manoeuvres in merging & diverging scenarios. Microscopic driving behaviour model enhancement in VISSIM at heterogeneous Asian highway has its benefits in terms of predicting various scenarios as an alternative solution in such traffic.

Keywords: Calibration, Contraflow, Driving behaviour parameters, Microscopic simulation, VISSIM.

1. Introduction

Contraflow operations are basically operated using a median crossover for sole aim of traffic redirection from the inbound lanes into the normal outbound lanes [1]. It is generally assumed that contraflow operation results in perfect execution of emergency evacuations [2-5]. When designing a contraflow operation, the enforcement issues and geometric conditions at the local level must be considered [6]. There is currently no standard guideline for both general and emergency contraflow design.

The relevance of traffic micro-simulation models keeps increasing in transport studies owing to their research and industrial potentials. Traffic simulation models (TSM) are more significant in capturing the dynamic attribute of transport systems in a way that is not possible with some classic methods. However, micro-simulation users are mainly faced with the problem of appropriate calibration of the utilized software; this problem is a serious one as inappropriate software calibration could produce misleading results which could cause serious problems and irreparable losses [7, 8].

According to Jie et al. [9], it is important to ensure a match between the need for microscopic traffic model calibration and the reason for using such model. For instance, if the intent is to use the model for crash risk prediction, the driver model's validity in terms of acceleration and detailed speed levels is enough [10]. Similarly, remote sensing-sourced trajectory data can serve as the input parameter for the model calibration based on many drivers at a given location. It is expected that such data would be enough for ensuring the validity of the simulation program for emissions estimation.

Siddharth and Ramadurai [11] noted that efficient vehicular traffic modelling is still a contentious issue, especially when considering the driving condition in East Asian countries. Traffic situations in most East Asian countries, including Malaysia are considered heterogenous; however, rigorous calibration efforts are still needed before micro-simulation software can be reliably used for estimating such flows. Microscopic traffic stream estimation, such as roadway capacity, average speed, & average travel time is usually performed using traffic simulation software programs; hence, the current practice usually involves a systematic alteration of the model input parameters to achieve a good match between the expected output of the microscopic model and the experimental data.

VISSIM uses a psycho-physical car-following model that is based on the model developed by Leutzbach and Wiedemann [12]; this model defines the driver perception thresholds and their associated formed regimes. Furthermore, there are close similarities between the "Wiedemann 99 car-following model" used in VISSIM and the "Wiedemann 74 car-following model"; however, some of the 99-model thresholds sometimes defined in a way that supports building of accurate freeway traffic models. Most of the other thresholds in the 99-model can also be modified. Car following model for freeway modelling consists of ten different Calibration Components (CC) parameters which can be adjusted by the user [13]. Those are: "$CC0$ (Standstill distance), $CC1$ (Headway time), $CC2$ (Following variation), $CC3$ (Threshold for entering Following), $CC4$ and $CC5$ (Following thresholds), $CC6$ (Speed dependency of oscillation), $CC7$ (Oscillation acceleration), $CC8$ (Standstill acceleration), $CC9$ (Acceleration at 80 km/h)". in addition to Lane Change behavior parameter and Min. Headway (front/rear).

Most of the previous studies have focused either on freeway calibration, arterial or intersection operations. Contrarily, serious attention must be given to the optimization of methodologies and selection techniques of the calibration parameters and the calibration process itself. The differences and similarities in the calibration methodologies have been summarized, comprising of approximately the calibration components (CC) parameters (either of the optimization technique, the procedure, fitness, objective function, or the subjected test bed. A categorization of different studies in this review based on categories clearly showed their common points as related to the technique optimization method used. The Genetic Algorithm (GA) is a commonly used heuristic for calibration purposes. The major difference is the number of parameters required to calculate the difference to prescribe the agreement between the field data and the simulated data. There are two parameter calibration method- single and multi-parameter calibration methods. There are also parametric and nonparametric statistical calibration methods. Systematization based on the optimization method as a major category is shown in Table 1.

Table 1. VISSIM calibration and validation parameters - State of the Art.

Authors	**Optimization Method**	**Measure of Performance**	**Analysis Method**	**Network Type**
Lownes and Machemehl [14]	Sensitivity Analysis	Capacity	ANOVA	Freeway
Park et al. [15]	Monte Carlo	Travel Time and Queue Length	*T*-Test	Arterial
Rakha and Gao [16]	-	Free low Speed Steady State Conditions	root-mean-squared-percentage-error (RMSPE)	Intersection
Manjunatha et al. [17]	Genetic Algorithm	Delay Measurement	ANOVA	Intersections
Aghabayk et al. [7]	Particle Swarm Optimization	Error minimization of field parameter	-	-
Ge and Menendez [18]	Elementary Effect	Variation of Travel time and Speed	-	Freeway
Tettamanti et al. [19]	Genetic Algorithm	Speed Flow	-	Freeway
Buck et al. [20]	Sensitivity Analysis	Delay Measurement	RMSPE	Intersection
Jayasooriya and Bandara [21]	Sensitivity Analysis	Queue length	RMSPE	Intersection
Current study	**Sensitivity Analysis**	**Volume, Speed and Travel Time**	***T*-Test**	**Highway contraflow**

2. Methodology

To evaluate the contraflow operation system, microsimulation modelling has been constructed. The microscopic computer traffic simulation software package VISSIM 9.0 was used to simulate and assess contraflow network model. The flowchart, as shown in Fig. 1, illustrates the procedure of microsimulation modelling of contraflow operation system.

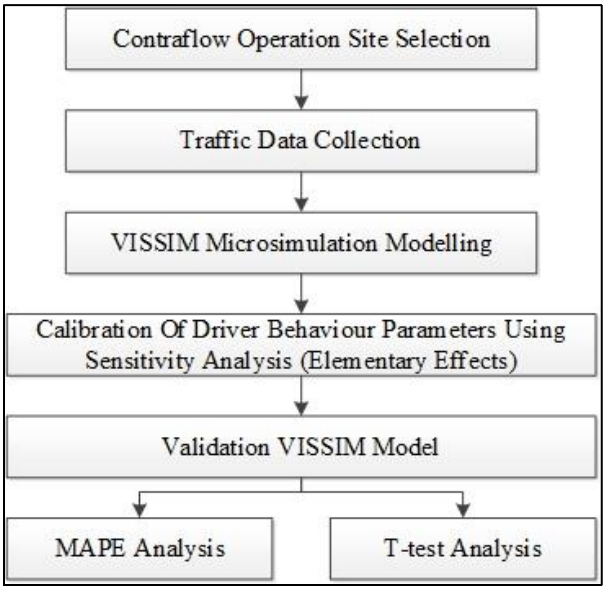


Fig. 1. Flow chart of the study.

2.1. Data collection

One of the challenging issues of contraflow operation system is finding ideal lane network reconfiguration that optimizes the given directions with Current contraflow lane reversal programs traditionally focus on evacuation flow [22, 23]. Therefore, SILK highway contraflow operation system is selected in this study as typical Malaysian contraflow operation system.

The evaluation of VISSIM simulation model in terms of operation in any contra-lane demands observation and analysis of the method of performance (MOP) of a currently operational contra-lane. Six-lane SILK highway contraflow section as shown in Fig. 2 opened on weekdays from 7.00 am to 9.00 am where the initiation point is located just after Sungai Ramal (B) Toll Plaza (KM 24.1) and ends at the termination point at (KM 28.3) near the grade separated intersection at UNITEN & Serdang Hospital. During the evening peak hours, the contraflow is open on weekdays from 4.30 pm to 6.30 pm from (KM 28.3) to (KM 24.1) which is about 4.2 km in total implementation length. Contraflow operation system operates on highway with three lanes in each direction. To perform this operation, the inbound lane is increased by 33% through the reversal of one lane of the outbound lanes. Figure 2 depicts the contra-lane route; the figure also showed the cross-sectional view of the area for traffic data collection for the reversed outbound lane to the additional inbound lane at SILK highway.

Fig. 2. VISSIM layout map for SILK highway contraflow operation system.

Manual traffic volume data from video camcorder above a pedestrian bridge facing the highway was used to capture traffic movements (traffic volume per lane, lane change, turning vehicle movement) for SILK highway contraflow section. Video camcorder feed data includes traffic volume (number of vehicles passing the camcorder lens) and vehicles class (motorcycle, light vehicle, and heavy vehicles) in 30 fps (frame per seconds) resolution was stored in hard drive. Traffic volumes data were recorded for a period of four hours for all the presence time of contraflow (6:30 - 8:30) am and (4:30 - 6:30) pm at SILK highway contraflow section. While a minimum of random 50 speed measurements for each lane (left, middle, right, and contra) were collected for all type of travelling vehicles (motorcycle, light vehicles, and heavy vehicles) on the contraflow and normal lane during peak hours.

2.2. Calibration of VISSIM model by using sensitivity analysis

To create realistic simulation models, model calibration and validation must be conducted. Model calibration is the process by which the individual components of the simulation model are adjusted or tuned, such that the model accurately represents measured or observed traffic conditions [24].

Calibration is accomplished based on traffic flow and vehicular speed aggregated per highway lane. First, all 12 VISSIM driving behaviour parameters for the car following model and lane-change model are explained in PTV-VISSIM user manual [25]. Several of them found to have the most influence after comprehensive calibration efforts in term of sensitivity analysis by using the Elementary Effects (EE) method which was developed by Morris in 1991 [26]. Elementary effects (EE) are a stochastic and qualitative screening approach for most of the important parameters of complex models [27]. It is mainly used in mathematical models that are computationally costly or models with several inputs where it is costly to apply other sensitivity measures. The EE concept adopts the One-At-a-Time (OAT) method where only one model input parameter is increased or decreased in each step of the analysis with a specific value while fixing the values of the other parameters at a given level. Assume a model Y that has k number of independent variables [$X1$, $X2$, ..., Xk], then, the model's output will be $Y(X1, X2, ..., Xk)$. Changes in the ith parameter Xi by a specific value Δ (fixing the k-1 parameters) will change the output of the model to $Y(X1, X2, ..., Xi\text{-}1, Xi + \Delta, Xi{+}1, ..., Xk)$. Then, EE of the parameter Xi, written as EEi, will then be given as:

$$EE_i = \frac{Y(X_1,\ldots,X_{i-1},X_i+\Delta,X_{i+1},\ldots,X_k)-Y(X_1,\ldots,X_{i-1},X_{i+1},\ldots,X_k)}{\Delta} \tag{1}$$

The *EEs* of Xi can only be estimated using the above equation through a random generation of a specific number (i.e., m) of permutations of $X1$ to Xk from the input space while varying Xi with Δ. Then, the mean μ, standard deviation σ, and absolute mean μ^* of the derived m EEs for Xi can respectively be estimated. These 3 indicators are considered the parameters' sensitivity indexes and can be used later for the parameters ranking with respect to their impact on the model output. For example, a non-influential parameter presents low values of both μ and σ [28]. Elementary Effects (EE) method was done to find which parameters affect VISSIM driving behaviour in a significant way. The parameters which were chosen for sensitivity analysis are 9 cars following behaviour parameters and three-lane change behaviour parameters as shown in Table 2.

Table 2. Sensitivity analysis results for VISSIM driving behaviour parameters by using Elementary Effects (EE).

VISSIM Parameters	Range	Default	(*P*-value)			Elementary Effects (EE)		
			Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
*CC*0	0.5-6.0 m	1.5 m	0.01	0.008	0.005	159.34	184.21	189.25
*CC*1	0.5-2.0 s	0.9 s	2E-03	3E-04	4E-5	142.01	156.39	178.84
*CC*2	0-10 m	3.5 m	0.001	4E-03	2E-03	112.35	132.54	157.90
*CC*3	-100-0 s	-8 s	0.36	0.33	0.30	4.3	7.5	11.45
*CC*4 & *CC*5	-0.8-0.8 m/s	-0.35 m/s	0.68	0.59	0.52	1.2	3.4	6.2
*CC*6	0-100 1/m.s	11.44 1/m.s	0.23	0.19	0.17	0	0	0
*CC*7	0-1 m/s^2	0.82 m/s^2	0.84	0.76	0.52	0	0	0
*CC*8	0-100 m/s^2	11.48 m/s^2	0.96	0.94	0.90	0	0	0
*CC*9	0-100 m/s^2	4.92 m/s^2	0.68	0.53	0.38	0	0	0
Diamond shape	Enable - Disable	Disabled	0.20	0.18	0.11	178.65	196.32	202.65
Look ahead	0-500 m	0-250 m	0.04	0.02	0.009	178.21	179.69	193.11
Look Back	0-500 m	0-150 m	0.08	0.05	0.01	168.47	178.21	184.55

Sensitivity analysis is usually performed using Quasi-optimised Trajectory in EE. During the analysis, 10 quasi-optimized trajectories were generated from 500 trajectories based on the distribution of the trajectories. Each trajectory is comprised of A point that refers to one value for each of 12 parameters set. The simulation process using the VISSIM model was performed for 5 random seeds each for the 10 trajectories. Three trials were conducted for each parameter and the basic effects for each parameter are tabulated in Table 2. The table shows that *CC*0, *CC*1, *CC*2, look-ahead & look-back distances, as well as diamond-shape are parameters that showed high level of elementary effect based on the outcome of the three trials. They presented p-values of less than 0.2 [11]. Hence, these 6 parameters were considered sensitive. After comprehensive calibration efforts in term of sensitivity analysis are done on a model used in this research, values in the column titled 'calibrated value' are found to replicate the field conditions in a best manner in Table 3.

Table 3. Default and calibrated values for car following and lane-change model parameters.

Model parameters	Range	Default value	Calibrated value
$CC0$	0.5-6.0 m	1.5 m	1.0 m
$CC1$	0.5 - 2.0 s	0.9 s	0.7 s
$CC2$	0 - 10 m	4.00 m	2 m
Diamond shape queuing	Enable - Disable	Disabled	Enabled
Look ahead distance (observed vehicles)	0 - 500 m (0-10)	0-250 m (2)	0-50 m (4)
Look back distance	0 - 500 m	0-150 m	0-30 m

3. Results of Calibration and Validation of Model

3.1. Calibration results of VISSIM model

Calibration was conducted with 15-minute sets, results are shown for Silk highway section for morning rush hour (7:00 - 9:00) am. From Tables 4 and 5 which are representing each lane's (outer, centre, inner, and contra) traffic flow of field data against default and modified data for VISSIM model for two hours (7:00 - 9:00) am 15-minute sets time interval with values of modified error in percentage. It is evident that $CC0$ and $CC1$ decreased while Traffic flow increased in the model. Since $CC0$ defines stopped distance between stopped cars, as this distance decrease, more vehicles can be traced per freeway length. As the drivers pay more attention to the traffic conditions on the road (decrease of $CC1$ value), speed reduces due to safety concern of the drivers.

Table 4. Calibrated vs. default values vs. field values for outer and centre traffic flow lanes.

Time Interval	Outer lane Flow (veh/15min/ln)				Centre lane Flow (veh/15min/ln)			
	Field	Default	Modified	Modified Error %	Field	Default	Modified	Modified Error %
7:00 - 7:15	282	221	293	3.90	390	285	347	-11.03
7:15 - 7:30	283	135	223	-21.20	332	207	380	14.46
7:30 - 7:45	321	140	274	-14.64	315	208	281	-10.79
7:45 - 8:00	324	133	382	17.90	323	222	360	11.46
8:00 - 8:15	335	139	385	14.93	352	206	324	-7.95
8:15 - 8:30	226	151	257	13.72	262	212	257	-1.91
8:30 - 8:45	146	133	123	-15.75	310	193	286	-7.74
8:45 - 9:00	140	137	190	35.71	244	222	242	-0.82

**Table 5. Calibrated vs. default values vs.
field values for outer and centre traffic flow lanes.**

Time Interval	Inner lane Flow (veh/15min/ln)				Contra lane Flow (veh/15min/ln)			
	Field	Default	Modified	Modified Error %	Field	Default	Modified	Modified Error %
7:00 - 7:15	501	278	449	-10.38	450	451	445	-1.11
7:15 - 7:30	397	207	349	-12.09	411	455	458	11.44
7:30 - 7:45	375	201	412	9.87	415	420	416	0.24
7:45 - 8:00	365	220	323	-11.51	419	461	468	11.69
8:00 - 8:15	356	223	324	-8.99	406	455	457	12.56
8:15 - 8:30	332	218	318	-4.22	426	437	473	11.03
8:30 - 8:45	396	221	422	6.57	460	407	473	2.83
8:45 - 9:00	386	210	337	-12.69	403	408	449	11.41

Figure 3 represents the speed variation results for all type of vehicles (heavy vehicles, light vehicles, and motorcycles) for highway's three lanes (left, middle, and right) in (km/hr) for field, default, and modified data at Silk highway. From the results, it is evident that speed variation in vehicles classes for default VISSIM model are far from reality as presented in field data. While modified results for speed for all vehicle classes at highway's three lanes (left, middle, and right) showed a better resemblance with field data.

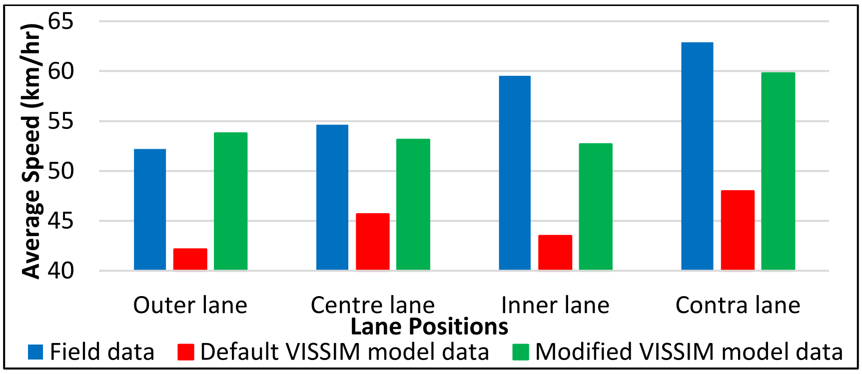


Fig. 3. Average speed variation of all lane positions for field, default VISSIM model, Modified VISSIM model data.

As the major three fundamental relations of traffic flow: flow rate (Q) in (veh/hr), density (K) in (veh/km), and space mean speed (U) in (km/hr), have been defined according to Fundamental relations of traffic flow by Mathew and Rao (2006) [29]. The fundamental equation of traffic flow is shown in equation below.

$$Q\left(\frac{veh}{\text{hr}}\right) = K\left(\frac{veh}{km}\right) * U\left(\frac{km}{hr}\right) \qquad (2)$$

The three fundamental diagrams have been shown in figures below, where Fig. 4 shows the relationship between flow rate and density; speed and density; speed and flow rate for VISSIM output for ten iterations simulation runs. The results show typical representation of fundamental curves in red color where can be interpreted as good representation of traffic flow of VISSIM.

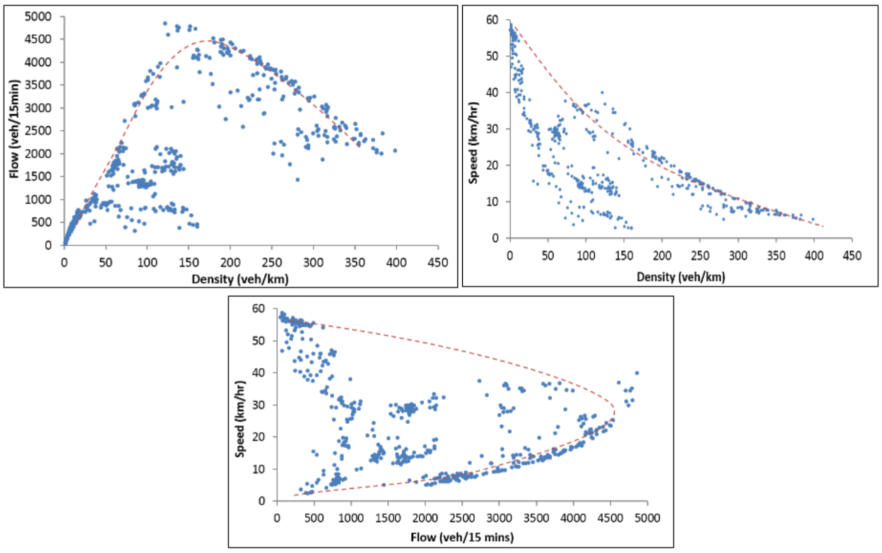


Fig. 4. Speed-flow-density relationships for morning rush-hour at Silk highway for 10 iterations simulation runs

These diagrams also contain information about the relation between intensity and travel time; this is used in traffic assignment. Often the fundamental diagrams are basic elements of more comprehensive models that describe the traffic operation on a network or describe assignment and traffic operation in combination. Red lines are shown in all figures as trend line for each relationship. VISSIM simulation results represent a typical relationship as additional proof for traffic composition representation.

3.2. Validation results of VISSIM model

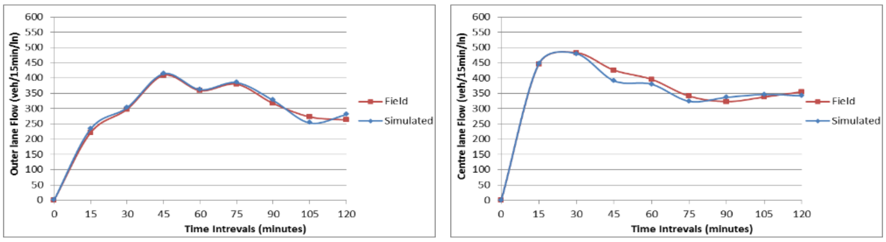
The aim of model validation tests is to test for the model accuracy by benchmarking the predicted traffic flow data with the field data. Validation has a direct reliance on the calibration strategy since the calibration process must be done in a way that will ensure improvement of the capability of the model in replicating the observed traffic flow [24]. Thus, the data generated by the VISSIM model was validated using the one-day-ahead field data. The error associated with the VISSIM model was calculated based on the MAPE which can be calculated using Eq. (3) [30]:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{f_m^i - f_f^i}{f_f^i}\right| \tag{3}$$

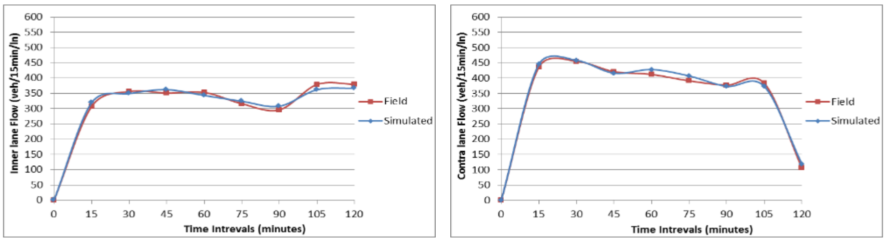
where n = the number of utilized data points during the process, f_m^i = VISSIM model-estimated traffic flow at time i (veh/15 min/ln) and f_f^i = observed flow of traffic at time i (veh/15 min/ln). For all the lanes, the total average MAPE is 0.5% as shown in Table 6; the comparison between the field and simulation data are shown in Fig. 5. The outcome of the validation process was satisfactory as the predicted values differed slightly from the observed field flows; the field values were predicted at an accuracy of 96% [9, 11, 31].

Table 6. Validation of modified VISSIM flow data for all lanes at Silk highway.

Time Interval	Outer lane Flow (veh/15min/ln)			Centre lane Flow (veh/15min/ln)			Inner lane Flow (veh/15min/ln)			Contra lane Flow (veh/15min/ln)		
	F.	***S.***	***E.***	***F.***	***S.***	***E.***	***F.***	***S.***	***E.***	***F.***	***S.***	***E.***
7:00 - 7:15	221	233	5.43	446	447	0.22	307	319	3.91	436	445	2.06
7:15 - 7:30	298	303	1.68	483	480	-0.6	356	349	-2.0	455	458	0.66
7:30 - 7:45	409	414	1.22	426	391	-8.2	351	362	3.13	421	416	-1.2
7:45 - 8:00	359	362	0.84	396	380	-4.04	353	343	-2.83	412	428	3.88
8:00 - 8:15	380	385	1.32	341	324	-5.0	316	324	2.53	391	407	4.09
8:15 - 8:30	317	327	3.15	323	337	4.33	296	308	4.05	377	373	-1.1
8:30 - 8:45	273	253	-7.3	338	346	2.37	379	362	-4.5	383	373	-2.6
8:45 - 9:00	263	280	6.46	355	342	-3.66	380	367	-3.4	107	119	11.21
	average MAPE		1.60	average MAPE		-1.83	average MAPE		0.11	average MAPE		2.13
										Total Average MAPE		**0.05**



(a) Outer-lane flow (b) Centre-lane flow



(c) Inner-lane flow (d) Contra-lane flow

Fig. 5. Comparison of validated VISSIM simulation flow with field flow for all lanes at Silk highway.

The next validation process is the statistical analysis of the field & modified flows using paired *t*-test analysis; this is aimed at determining the level of significant difference between the new calibration parameters and VISSIM simulation software which in concur in previous studies [32, 33]. The analysis found a mean traffic flow difference of 0.281 vehicles, and this is taken as minimal, with *P*-value (significance value) = 0.902 as shown in Table 7.

Table 7. Paired samples t-test analysis for field and modified flow values of Silk highway contraflow section.

Field	Modified	Field	Modified	Paired Samples *t*-test analysis	
221	233	307	319	*N*	32
298	303	356	349	Field mean	354.6
409	414	351	362	Modified mean	354.9
359	362	353	343	Mean differences	0.281
380	385	316	324	Hypothesized mean difference	0
317	327	296	308	Correlation	0.984
273	253	379	362	*d.f*	31
263	280	380	367	t stat	-0.122
446	447	436	445	P-value (one tail)	0.451
483	480	455	458	t-value (one tail)	1.695
426	391	421	416	P-value (two tails)	0.902
396	380	412	428	t-value (two tails)	2.039
341	324	391	407	R^2	0.970
323	337	377	373		
338	346	383	373		
355	342	107	119		

4. Conclusions

It has been demonstrated in this study that VISSIM micro-simulation model calibration for driving behaviours is important for achieving accurate driving conditions, especially for countries in East Asian where motorcycles contribute to traffic conditions during rush hours.

Sensitivity analysis was used to calibrate VISSIM model parameters. In this study, six parameters of driving behaviour were altered to ensure realistic simulation of such condition. The vehicle behaviour model was found to be controlled by three VISSIM driving behaviour parameters which are $CC0$, $CC1$ and $CC2$.

Furthermore, forward & backward observation distances were found as the determinant factors for alternating lanes since both distances decreases with increases in vehicular traffic. The circumstance is due to the inability of the driver to track the path of the nearby vehicles in heterogeneous scenarios.

Lastly, motorcycles capacity presents a different shape in a heterogeneous traffic, i.e. a rhombus (diamond) shape rather than rectangle to fit the existing gaps between nearby vehicles in different highway lanes. Hence, manoeuvring would be impossible in most heterogeneous conditions without paying prior attention to the upcoming streams of motorcycle in-between lanes.

The validation process achieved satisfactory results as there was no observable mean difference between the observed and predicted field flows; the field values were predicted at an accuracy of 96%.

Nomenclatures

ANOVA	Analysis of Variance
CC	Calibration Components
EE	Elementary Effects
$d.f$	Degree of Freedom
f_f^i	Field Traffic Flow
f_m^i	Simulated Traffic Flow
GA	Genetic Algorithm
K	Density
Q	flow rate
MAPE	Mean Absolute Percent Error
MOP	Method of Performance
N	Number of observations
OAT	One-At-a-Time
R^2	Proportion of the variance for a dependent variable
RMSPE	Root-Mean-Squared-Percentage-Error
TSM	Traffic simulation models
U	space mean speed
Xi, Yi	Independent Parameters

Greek Symbols

Δ	Changes in the ith parameter
μ	Mean
$\mu*$	Absolute mean
σ	Standard deviation

Abbreviations

UNITEN	Universiti Tenaga Nasional
VISSIM	Verkehr In Städten-SIMulationsmodell

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