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RESEARCH ARTICLE - SYSTEMS ENGINEERING

Use of Microscopic Traffic Simulation Software to Determine Heavy-Vehicle Influence on Queue Lengths at Toll Plazas

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Abstract

Highways and expressways provide support for the local, regional, and national transportation of services and goods. Moreover, they are indispensable to economic activities as modern lifestyle would be impossible without them. Activities related to work, education, shopping, tourism, and social are generating a demand for trips. Furthermore, the presence of toll plazas at expressways slows down traffic, thus creating traffic congestion during rush hour. Malaysian toll plazas are considered conventional toll collection, which is manual and the most common toll collection method. Manual toll collection is usually the cause of congestion related to the delay experienced by drivers, toll collection procedure, and operators at the manual toll lanes. This paper aims to examine the effect of the percentage of heavy vehicles on the performance of toll plazas in terms of the queue length using the microscopic traffic simulation model called VISSIM. The findings indicate that the percentage of heavy vehicles in traffic flow significantly affects queue lengths at toll plazas.

Keywords Heavy vehicle · Toll plaza performance · Queue length · Traffic simulation model · VISSIM

1 Introduction

The increased use of tollways and their associated toll plazas is a continuing trend in Malaysia because of the expanding number of vehicles going through airports, entrances of major ports, federal routes, and the growing population in towns and major cities. The manual toll collection implemented at toll gates is one of the main causes of traffic congestion along expressways [1]. Every vehicle that passes through a toll plaza experiences certain delays depending on the type of payment, and queues start to build up when traffic volume for one payment type exceeds the capacity of the plaza for one or all of the payment types [2].

Recently, the examination of toll plazas by employing microscopic simulation software has drawn attention because of the intricacy in analyzing the procedure of toll plaza operations. Microscopic simulation software is commonly adopted as a complementary or alternative instrument in diagnostic procedures and methods for road traffic services and for forecasting future performance according to calculated or expected adjustments in probable operational plans or patterns of vehicle travel demand [3,4]. Thus, traffic simulation models should address the important characteristics of the traffic flow dynamics [5].

Microscopic models with 3D visualization are powerful tools for helping planners and traffic engineers solve specific traffic problems. Through 3D visualization, users are provided with virtual and real-world viewpoints (i.e., helicopter, traffic camera, and vehicle) and allowed to view the simulated area in a rich virtual environment, which contains structures representative of the real world [6]. Assessing the performance of toll plazas and the traffic volume effects under different traffic characteristics and toll plaza configurations is always required. Moreover, visualizing and examining the present and forthcoming traffic procedures at toll plazas is critical.

Toll plazas in the Malaysian expressways system are an interesting subject for two reasons. First, traffic along the expressway is heterogeneous with mixed vehicles composed of cars, small lorries, trucks, trailers, and buses. Second, the toll collection system involves both manual and electronic toll collection, and thus payment time and operation vary according to vehicle class. Furthermore, as the automatic

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vehicle identification (AVI) system has yet to be adopted in Malaysia, heavy vehicles (trucks, trailers, and buses) are prohibited from using electronic toll lanes. This paper addresses the question of how heavy vehicles in a heterogeneous traffic flow affect toll plaza performance and queue lengths in Malaysia.

2 Literature Review

Microscopic traffic simulation is a useful instrument to simulate traffic flow in roadways under homogeneous and heterogeneous conditions [7]. It has been used as an efficient tool for studying traffic problems [8]. Generally, microscopic traffic simulation models can materialize the intricacies of traffic demand and vehicular flow to enhance the understanding of operational performance in toll plazas [9]. Nonetheless, these models are usually not equipped with built-in toll plaza simulations [10]. Accordingly, researchers have attempted to develop their own simulation models for examining toll plaza performance.

Ito examined the traffic congestion in toll plazas in Kochi I.C., Japan, and offered the results of the process simulation [1]. The developed model considers the redesign of the layout of toll plazas and approximates suitable time in combination gates for gate change to achieve enhanced performance. Astarita [11] and Kuang [12] examined mixed toll stations that operate using various systems of toll collection. The developed model of the car-following model can reveal the toll system performance and uphold its ideal design as a traffic condition function. Moreover, the simulation model is an effective tool to analyze traffic in highway stations. Poon and Dia developed a microscopic traffic simulation model called AIMSUN [13], which can assess the performance of toll booths in the current gateway toll plaza design. The model is employed to quantify and examine the effects of different scenarios to increase efficiency in toll areas. These scenarios include increasing the number of heavy vehicles using the toll booths. According to the study, increasing the usage of toll lanes that adopt fully electronic toll collection (ETC) can greatly improve the system's overall efficiency. Drivers who switch from automatic and manual toll payment methods to the ETC method can experience section times five and ten times faster, respectively, then before. Another research [14] developed and calibrated two different simulation models, namely SHAKER and VISSIM. Both the SHAKER and VISSIM models are potential tools for estimating the maximum throughput and capacity of toll plazas. Therefore, planners and engineers can better develop traffic plans for toll plazas and provide valuable processing time and demand data, which can be used to establish capacities based on lane type, payment type, payment amount, and vehicle type. On the basis of users' perception of service quality at toll plazas, Obelheiro developed a method to examine levels of service at toll plazas [15]. The evaluation of model sensitivity shows that "Mean Queue Length at booths" mostly affects the quality perceived at toll plazas. When queue lengths at booths are increased, users' perception of quality is significantly reduced. Moreover, "Percentage of Trucks" significantly affects service quality perception.

This literature review clearly indicates that many research works are available for evaluating toll plazas using different traffic simulation models. However, studies have not been conducted yet on heavy-vehicle influence on the overall performance of toll plazas in terms of queue length at toll plazas in Malaysia.

3 Methodology

In this paper, a simulation model is developed to assess the implementation of mixed mode (cash/ticket and ETC) toll booth collection. In Malaysia, heavy vehicles (trucks, trailers, and buses) should use the mixed mode lanes even when they can use ETC payment. The model seeks to reflect the effect of different factors on payment time at toll booths. To develop the model and obtain results, data were collected from the case study, the service time process was estimated, the model was constructed and calibrated, and different scenarios were run according to different input parameters.

3.1 Microscopic Simulation Model VISSIM

A variety of traffic simulation packages are available for studying traffic operations at toll plazas. Each of these simulation packages has pros and cons for simulating the toll plaza operation. Previous literature research studied specific simulation packages in terms of capabilities of modeling the traffic facilities [16].

The capabilities of these simulation packages differ widely, and selection of the most appropriate model for a given case depends on several factors such as the requirements and characteristics of the site/toll plaza, cost, objectives of the study, and simulation model capabilities for achieving the objectives.

In this study, VISSIM was chosen to simulate the operations at the Juru toll plazas. It was proved that VISSIM was a very well-suited tool to simulate the traffic operations at toll plazas and its performance based on the requirements and the objectives of this study, and also based on various previous studies conducted around the world [2,17–21].

3.2 Data Collection

The paper was interested in simulating the heavy-vehicle influence within traffic flow condition during maximum weekday peak hours. Figure 1 shows that Friday has the maximum traffic flow in weekdays for both entry and exit directions. The collected field data of the Juru toll plaza were separated by morning peak hour and direction because they differed in terms of number of lanes, lane configuration, toll base fee, traffic volume, vehicle composition, and number of approach lanes for each direction. For entry direction (southbound), the morning peak hour was at 11:00–12:00 and had three approach lanes to the plaza. For exit (northbound), the morning peak hour was at 7:00–8:00 and had two approach lanes as shown in Fig. 2.

To simulate the traffic operation at toll plazas, microscopic field data were needed for each individual vehicle arriving and completing the transaction at the toll plaza. The video recording approach was used to collect field data. Thus, CCTV cameras were needed to be installed at the site to record the traffic operations at the Juru toll plazas. The study required to install CCTV systems at both entry and exit directions. The vehicle composition and service time for mixed mode toll lanes are extracted from CCTV recordings during morning peak hour, as part of the efforts to build the simulation model for Juru toll plaza. Six cameras were used to capture the upstream and downstream traffic flow and the operations at the toll plaza. All six cameras were simultaneously started, and each one captured a different situation. Three of the six cameras were used to capture one direction, and the other three were simultaneously capturing the opposite direction. The following data collections were the requirements for the creation of the Juru toll plaza model.

3.3 Toll Plaza Configuration and Payment Type

The model presented in this paper is based on data collected from a closed toll system Juru toll plaza in Bukit Mertajam, Malaysia. Juru toll plaza is a barrier toll plaza at the North–South Expressway. This kind of toll plaza configuration impedes traffic flow on the expressway, especially during peak hours. Figure 3 shows the configuration for Juru toll which has twenty-three toll lanes. Seven toll lanes are allocated for entry direction (enter the expressway) and sixteen toll booths are allocated for exit direction (exit the expressway).

The lanes in the Malaysian toll plazas are mainly divided into two types: First is the single-class lane (specified only for class 1; these lanes are Smart TAG and Touch ’n Go lanes), and the second is the multiclass lane (specified for all

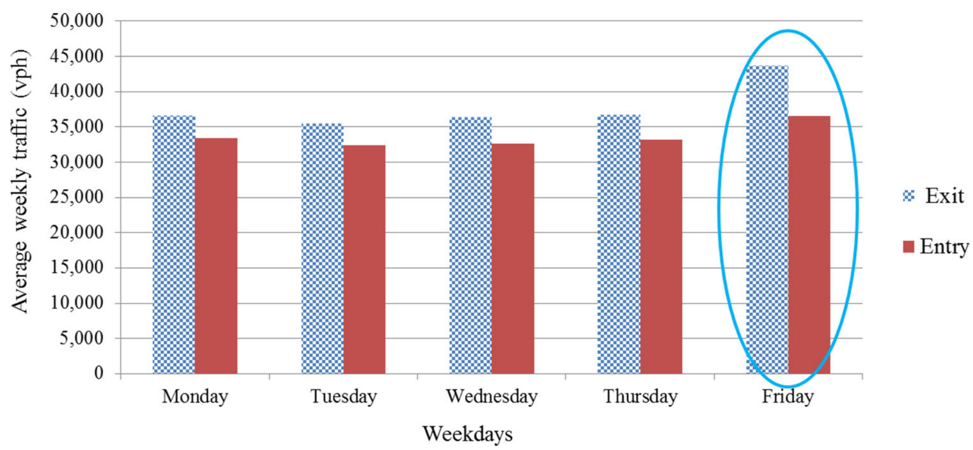


Fig. 1 Average weekly traffic at Juru toll plaza

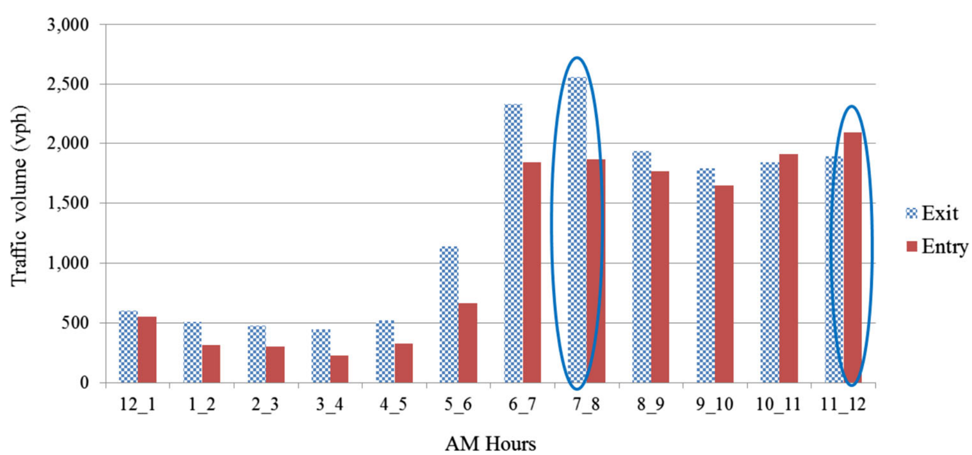
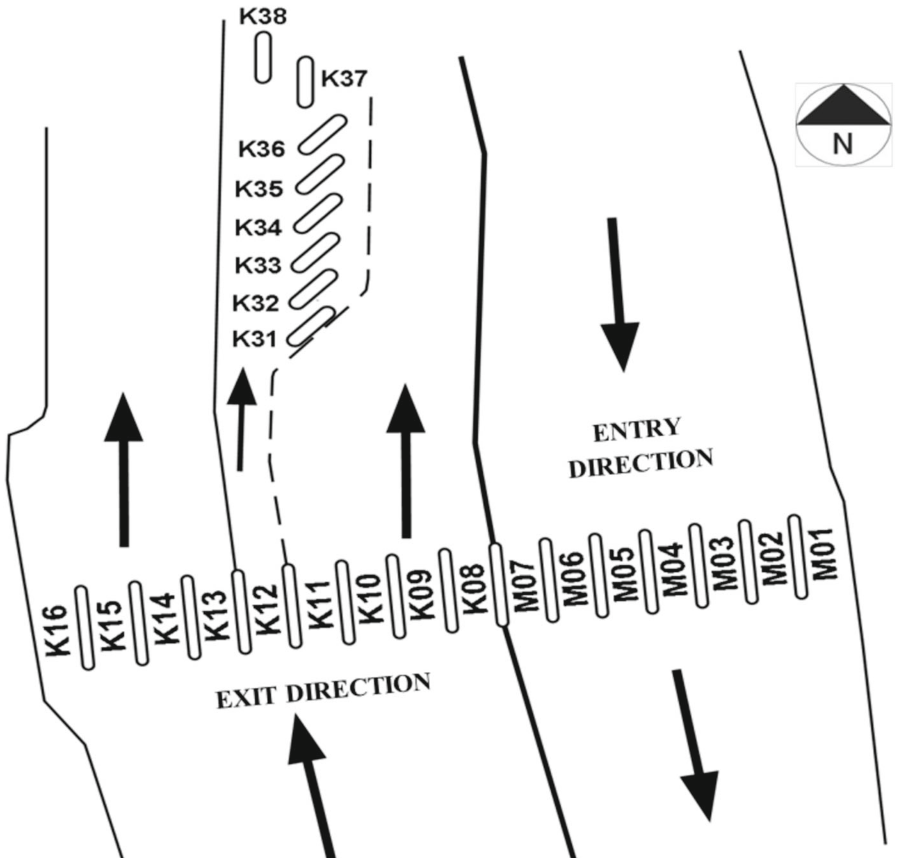


Fig. 2 Friday traffic at AM hours by direction

Fig. 3 Juru toll plaza configuration



EXIT DIRECTION	
Booth No.	Payment Type
K08 – K09	Smart TAG
K10 – K11	Touch n Go
K13 – K16	Mixed Mode
K31 – K38	Staggered Booths Mixed Mode

ENTRY DIRECTION	
Booth No.	Payment Type
M01 – M03	Mixed Mode
M04 – M05	Touch n Go
M06 – M07	Smart TAG

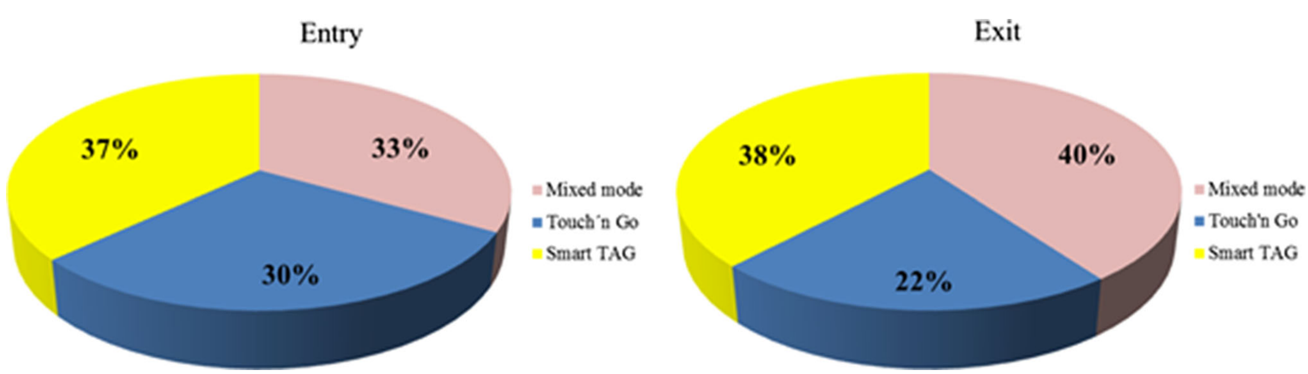


Fig. 4 Percentages of payment type at entry and exit of Juru toll plaza

(a)

Vehicle Classification - PLUS			
No	Vehicle class	Icon	Description
1	Class 1		Vehicles with 2 axles and 3 or 4 wheels excluding taxis
2	Class 2		Vehicles with 2 axles and 5 or 6 wheels excluding buses.
3	Class 3		Vehicles with 3 or more axles.
4	Class 4		Taxis
5	Class 5		Buses

(b)

Vehicle type - Simulation model			
No	Vehicle type	Icon	Description
1	Type 1		Car and Taxi
2	Type 2		Small lorry (2 axles and 6 wheels)
3	Type 3		Truck (3 or more axles. With length 8.5-13.0 m)
4	Type 4		Trailer (3 or more axles. With length more than 13.0 m)
5	Type 5		Bus

Fig. 5 Vehicle classifications; **a** vehicle classification adopted by PLUS, **b** vehicle type used in the simulation model

types of vehicles including heavy vehicles; these lanes are for mixed mode toll collection). Methods of toll payment at toll plazas in Malaysia can be divided into three types. The first and most common method of payment is by cash/ticket in which a toll collector/ attendant is required at the toll booth to collect the cash, dispense the change (if any), and issue the ticket to the patron (upon request). The second method of payment is using the Touch ’n Go card which uses contactless smart card technology (electronic toll collection ETC). Both methods for cash/ticket and Touch ’n Go vehicles need to stop to make the payment. The last method of toll payment is by using Smart TAG which is a nonstop automatic payment system for toll network. The system can make the payment transaction within 20 km/h maximum speed for passing vehicles. Furthermore, Smart TAG and Touch ’n Go toll lanes can be used only by cars, mixed mode toll booths allowable for all vehicles class including the heavy vehicles that use the manual or ETC methods.

Figure 4 shows the percentage of average payment types for Fridays morning peak hour in Juru toll plaza for both directions. At entry direction, mixed mode lanes processed 33% of traffic, Touch ’n Go lanes processed 30%, and Smart TAG lanes processed 37% of the traffic. At the exit direction, the traffic was different where mixed mode lanes processed 40%, Touch ’n Go lanes processed 22%, and Smart TAG lanes processed 38% of the traffic. The study will focus on mixed mode because it presents the traffic composition which contains the heavy vehicles.

3.4 Vehicle Type

Vehicles in the Malaysian expressways (closed system) are divided into five classes according to the vehicle classification adopted by PLUS based on the toll fare and the number of axles and wheels. However, due to reason of passenger cars and taxis having the same vehicle characteristics and thus behaving in the same manner, they were grouped in the same vehicle type in the simulation model. Also, based on field data, huge variations were observed in terms of vehicle length for trailer even though they are classified as vehicles having three or more axles.

The variation in vehicle length for trailers impacts the toll operation. Therefore, vehicles in this class are divided into trucks (heavy vehicles having three or more axles with a vehicle length of between 8.5 and 13.0 m) and trailers (having three or more axles with a vehicle length of more than 13.0 m).

Figure 5a shows the vehicle classification adopted by PLUS, while Fig. 5b shows the vehicle type used in the simulation model.

In VISSIM, vehicles are assigned to certain types and combined with vehicle classes. However, vehicle types needed to be assigned to vehicle categories first. Vehicle categories, by default, contain categories of vehicles with similar traffic interaction. A vehicle type allows the user to form a group of vehicles with the same technical driving characteristics.

Table 1 Vehicle classes that are used in the Juru toll plaza model

No.	Class name		Payment type	Lane type
	Entry	Exit		
1	Car STAG	Car STAG	Smart TAG	Single-class lanes
2	Car TNG	Car TNG	Touch ’n Go	Single-class lanes
3	Entry car ticket	–	Ticket	Multiclass lanes
4	Entry car Tng	–	Touch ’n Go	Multiclass lanes
5	–	Exit car cash	Cash	Multiclass lanes
6	–	Exit car Tng	Touch ’n Go	Multiclass lanes
7	Entry small lorry ticket	–	Ticket	Multiclass lanes
8	Entry Small lorry Tng	–	Touch ’n Go	Multiclass lanes
9	–	Exit small lorry ticket	Cash	Multiclass lanes
10	–	Exit small lorry Tng	Touch ’n Go	Multiclass lanes
11	Entry truck ticket	–	Ticket	Multiclass lanes
12	Entry truck Tng	–	Touch ’n Go	Multiclass lanes
13	–	Exit truck cash	Cash	Multiclass lanes
14	–	Exit truck Tng	Touch ’n Go	Multiclass lanes
15	Entry trailer ticket	–	Ticket	Multiclass lanes
16	Entry trailer Tng	–	Touch ’n Go	Multiclass lanes
17	–	Exit trailer cash	Cash	Multiclass lanes
18	–	Exit trailer Tng	Touch ’n Go	Multiclass lanes
19	Entry bus ticket	–	Ticket	Multiclass lanes
20	Entry bus Tng	–	Touch ’n Go	Multiclass lanes
21	–	Exit bus cash	Cash	Multiclass lanes
22	–	Exit bus Tng	Touch ’n Go	Multiclass lanes

In this step in developing the VISSIM toll plaza model, the traffic composition was created to differentiate different vehicle behaviors in the simulated model. The traffic composition in VISSIM allows the user to insert the relative flows of each link and the desired speed for each vehicle class. In this study, the traffic composition consists of five vehicle classes using three methods of payment.

The difficulty in this stage of the simulation of toll plaza operations was on how to simulate the real vehicle classes in the Juru toll plazas. As previously mentioned, the vehicles at the toll plazas are classified into five classes: cars, small lorries, trucks, trailers, and buses. These classes used three types of payment, namely mixed mode, Touch ’n Go, and Smart TAG. The mixed mode payment in the entry direction is different from the exit direction in terms of procedure, payment type, and service time.

To solve this complexity, the vehicles are classified into two types at the toll plaza according to the toll lane selection: vehicles that select single-class lanes and vehicles that select multiclass lanes. The vehicles that select single-class lanes were cars that used the Touch ’n Go payment and the cars that used Smart TAG payment. Both these two classes are used in the entry and exit directions. The vehicles that selected the multiclass lanes were the vehicles that used the mixed mode payment.

As a result, twenty-two classes of vehicles in the VISSIM model needed to be created to represent the real traffic operation at the toll plazas. Table 1 shows the created vehicle classes in the toll plaza model for the Juru toll plaza.

3.5 Traffic Composition

Traffic composition represents the proportions of different vehicle types in the traffic flow. This is useful to control the way vehicles behave and react in the toll plaza and to incorporate the differences in terms of their operational performance in the simulation model. Traffic compositions are important because vehicle travel routes are assigned for specific vehicle types [22]. In addition, the service time of the mixed mode lane depends upon the arrival pattern of vehicles. Moreover, the traffic composition in the toll plaza modeling concepts is not only focused on the proportions of different vehicle types in the traffic flow but also on the proportion of the traffic flow based on the toll lane types (payment methods).

Figure 6 shows the traffic composition for the entry to the lanes with a traffic volume of 2501 vph, which consists of 85.5% cars, 7.7% small lorries, 1.8% trucks, 3.5% trailers, and 1.6% buses, while the traffic composition at the exit lane with a traffic volume of 2920 vph, which consists of 83.9% cars, 8.5% small lorries, 2.6% trucks, 4.2% trail-

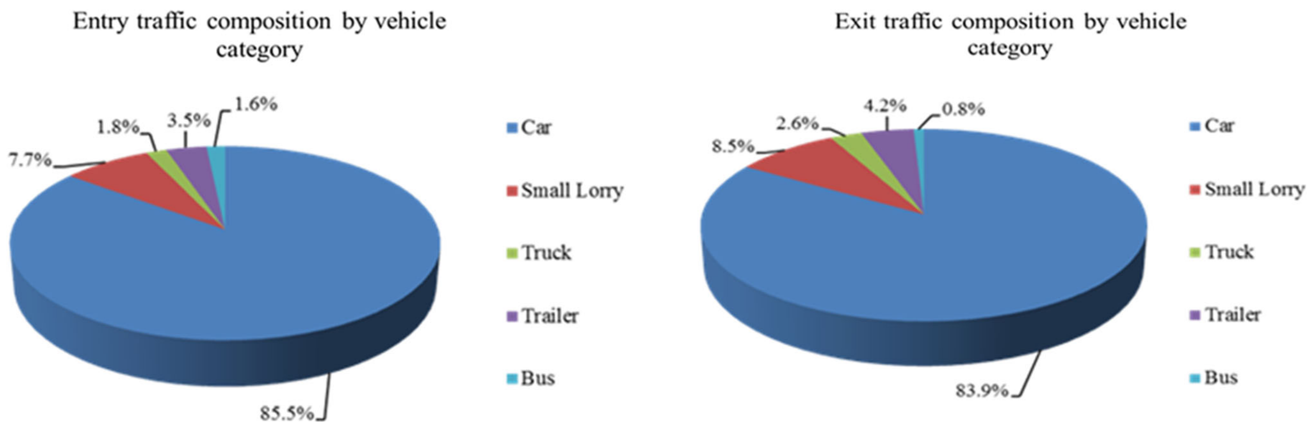


Fig. 6 Traffic composition percentages at Juru toll plaza for entry and exit

ers, and 0.8% buses. The percentage for the heavy vehicle (HGV = Truck + Trailer + Bus) in entry direction is 6.9% and that for the exit direction is 7.6%.

3.6 Desired Speed Distribution

The desired speed distribution is an estimation of the upstream speed of the approaching vehicle toward the toll plaza. The distribution function of the desired speeds is a particularly important parameter because it impacts the link capacity and the queuing at the tollbooths and, thereby, the operation of the toll plazas.

A driver will travel at his desired speed if not hindered by other vehicles or network objects. A driver, whose desired speed is higher than his current speed, will check whether he can overtake other vehicles without endangering anyone. The more the speed of the drivers differs, the more the platoons are created.

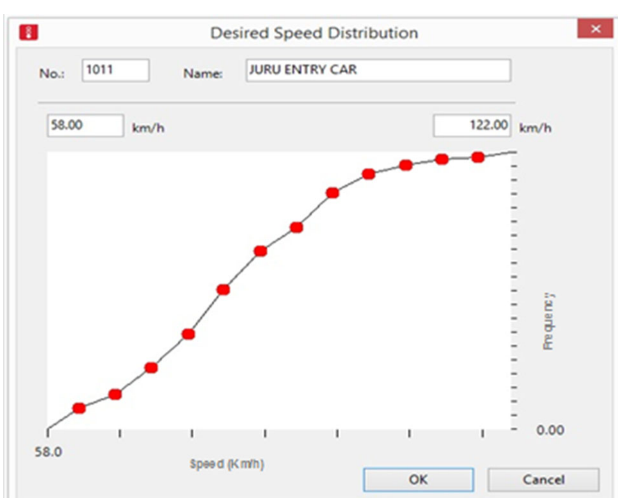


Fig. 7 Desired speed distribution of vehicle class in VISSIM toll plaza model—example

In VISSIM, the desired speed distributions are defined depending on vehicle class, which are used for the command of vehicle compositions. The desired speeds at toll plazas varied according to the toll plaza type, toll plaza location, approach direction, and vehicle class. Thus, the observed speeds from the Juru toll plaza were classified into five categories for both entry and exit directions to meet the needs of the VISSIM toll plaza model. The use of distributions of the values of the desired speeds rather than the average speeds makes the created model more accurate in representing the real traffic operations of toll plaza.

The speed data observations were collected from the Juru toll plazas using a laser speed gun on March 2015. Figure 7 shows an example of the desired speed distribution for the vehicle type in the VISSIM toll plaza model.

3.7 Service Time

Service time, in its general definition, is the time interval between time when the wheels of a vehicle stop rolling at the tollbooth and the time when they start rolling again. In other words, service time is the time a vehicle spends to complete a transaction at the tollbooth; it does not include the delay time in the queue before entering the tollbooth [23,24].

Service time is an important parameter for the evaluation of the operational performance of a toll plaza. Several factors influence the actual service time in electronic toll collection (ETC) and manual toll collection (MTC), such as the type of vehicle making the payment [25–28], the fee value [28], the traffic composition [29,30], the processing efficiency of the electronic toll collection (ETC) technology, and the efficiency of the tollbooth attendant [24]. These factors are helpful in understanding questions such as why cars have different service times from trucks, or why the vehicles of the same class have different service times for same direction of the travel.

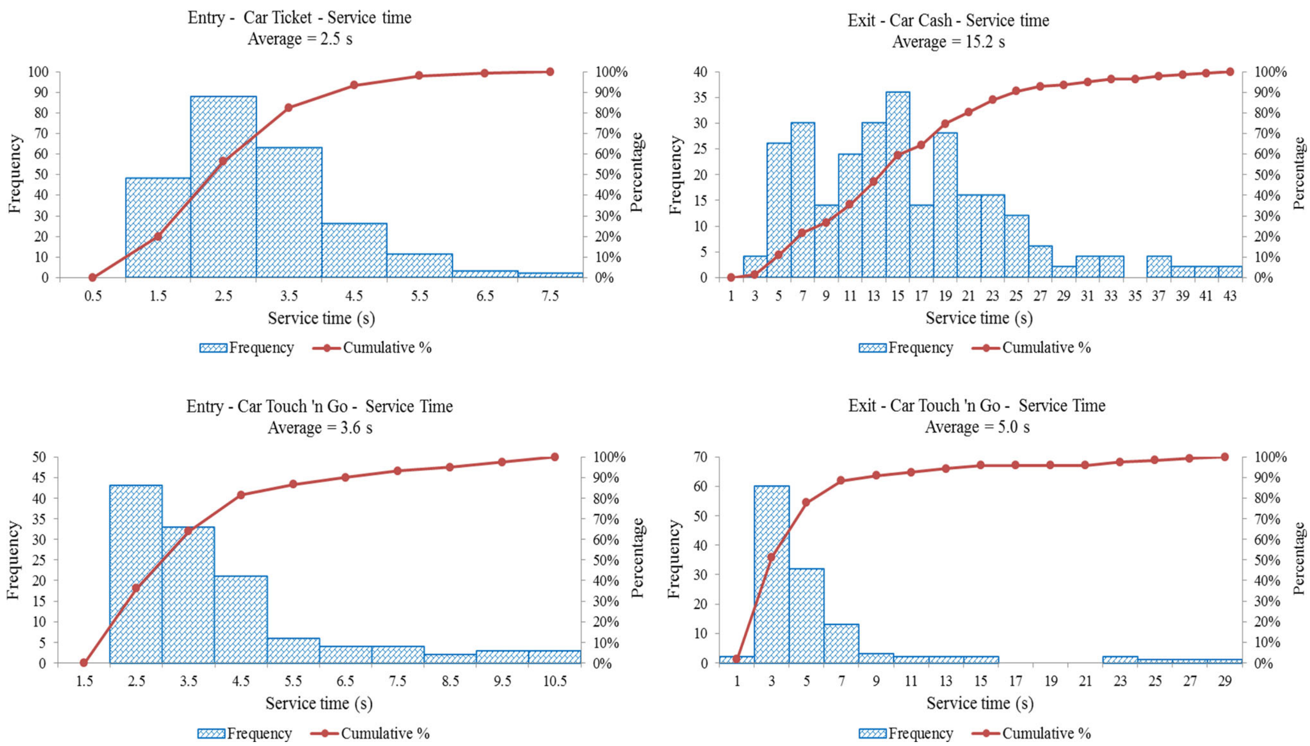


Fig. 8 Frequencies and cumulative curves of service time for car at Juru toll plaza; **a** Entry—ticket and Touch ’n Go, **b** exit—cash and Touch ’n Go

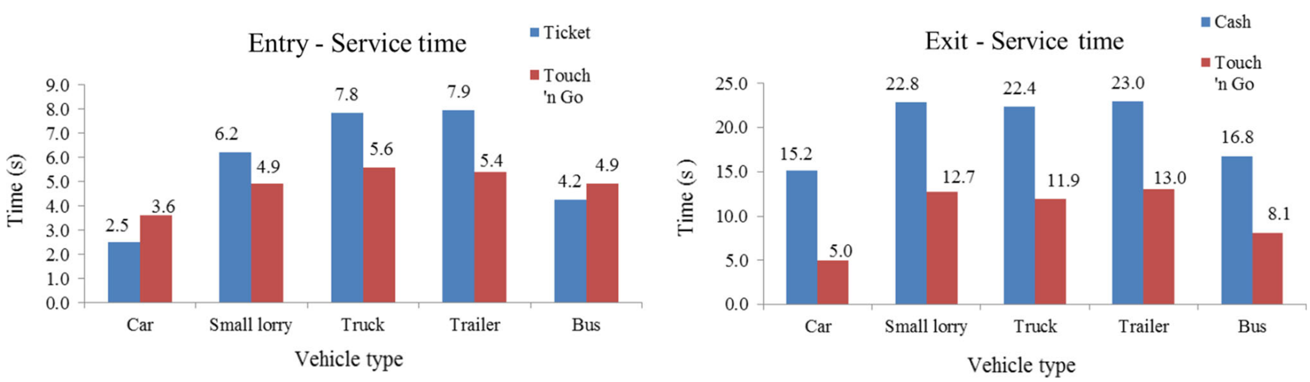


Fig. 9 Service times at Juru toll plaza of mixed mode lanes for ticket and Touch ’n Go based on vehicle type—entry and exit

In a conventional tollbooth, service time is measured from the time the vehicle stops at the tollbooth until it starts moving. For nonstop ETC lanes, the vehicle must decelerate within the speed limit while passing through the toll plaza. Given that the ETC vehicle transacts without stopping at the tollbooth, the service time for the nonstop ETC vehicle in this case is equal to zero [21].

Service time is one of the main input parameters in the toll plaza model, which most significantly influences the performance of toll operation and, thus, the overall toll plaza capacity.

The service time in the mixed mode lanes is the time in seconds that a vehicle spends at a tollbooth to pay a toll until it starts moving. This principle gave the procedure for the observation and extraction of data of the vehicle service time from video recordings for each individual vehicle when it stopped at the tollbooth to make payment.

The determination of the service time at this type of toll plaza (conventional toll plaza) becomes too complex, especially at the multiclass mixed mode toll lane. The complexity comes from the fact that the multiclass mixed mode toll lanes have five types of vehicles, with each type having its own service time. Furthermore, the service time is different, whether at entry or exit, for a particular vehicle type.

According to the VISSIM model requirements, service times need to be represented as cumulative curves. Therefore, Fig. 8 shows an example of the frequencies and cumulative

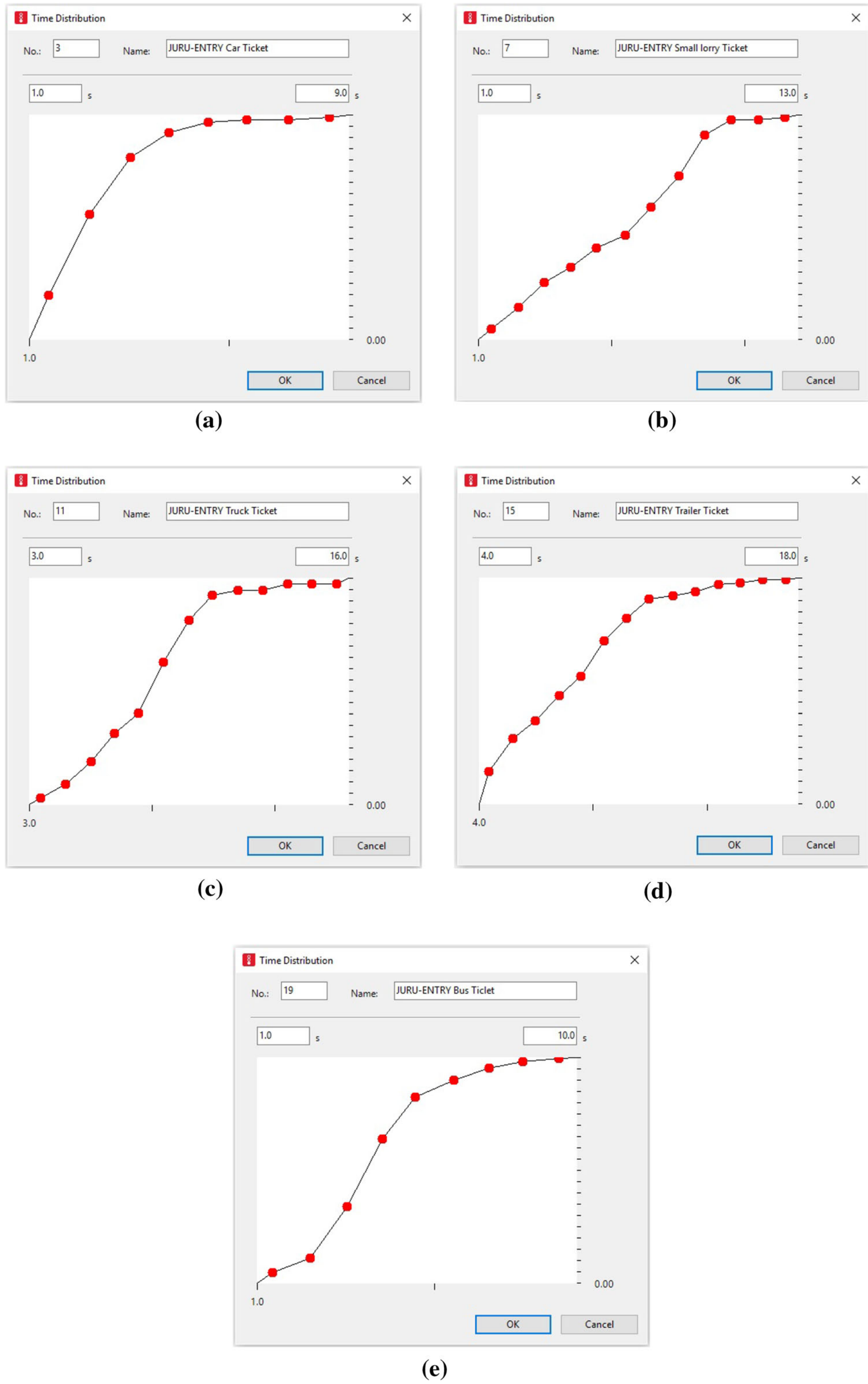


Fig. 10 Dwell time distribution for vehicle types at multiclass lane—Juru toll plaza—entry—ticket; **a** car, **b** small lorry, **c** truck, **d** trailer, **e** bus

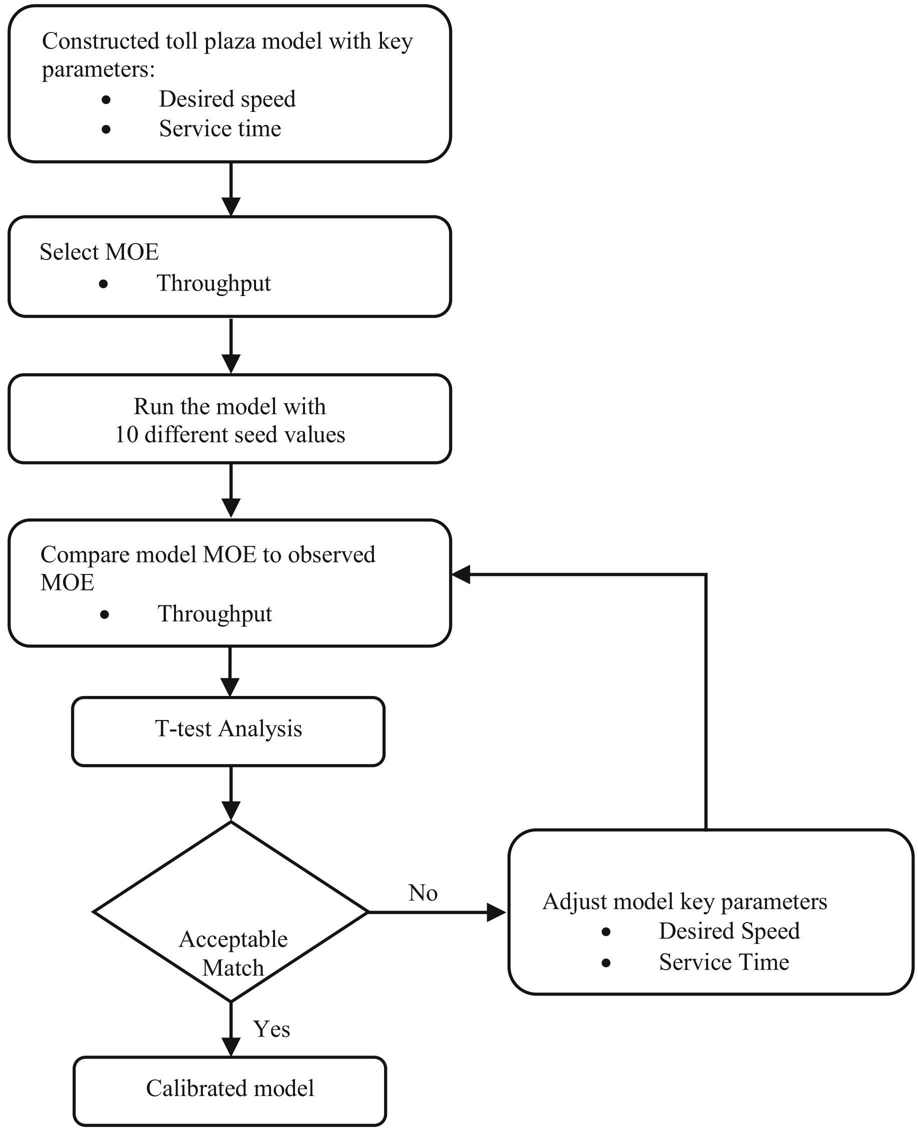


Fig. 11 Flowchart of the calibration process of the simulation

curves of the measured service time for cars in mixed mode lanes.

Figure 9 shows the summary of the service times at entry and exit of mixed mode lanes for ticket and Touch 'n Go based on vehicle type in Juru toll plaza. For entry, the maximum service times for ticket and Touch 'n Go for truck and trailer were (7.8 and 7.9) s and (5.6 and 5.4) s, respectively. For exit, the maximum service times for cash and Touch 'n Go for small lorry, truck, and trailer were (22.8, 22.4, and 23.0) s and (12.7, 11.9, and 13.0) s, respectively.

4 Development of Toll Plaza Models

Once the requirements of the basic features used to build the toll plaza models were completed, the base models of the Juru toll plaza were created with the necessary inputs related to the real toll plazas. The necessary inputs are:

1. The satellite image is used to match the information on the number of lanes in the toll plaza and the geometry of toll plaza area. Additionally, the configurations of the toll plaza are represented by the number of the toll lanes dedicated for each type of payment.
2. The desired speed distribution, which is a particularly important parameter, impacts the link capacity and the queuing at the tollbooths and thereby the operation of the toll plaza.
3. The service time is the distribution for each vehicle type needing to stop to make a payment in the toll lane of the toll plaza. For Juru toll plaza model in this paper, there are twenty service time distributions. For each direction in the mixed mode lanes, there are five types of vehicles

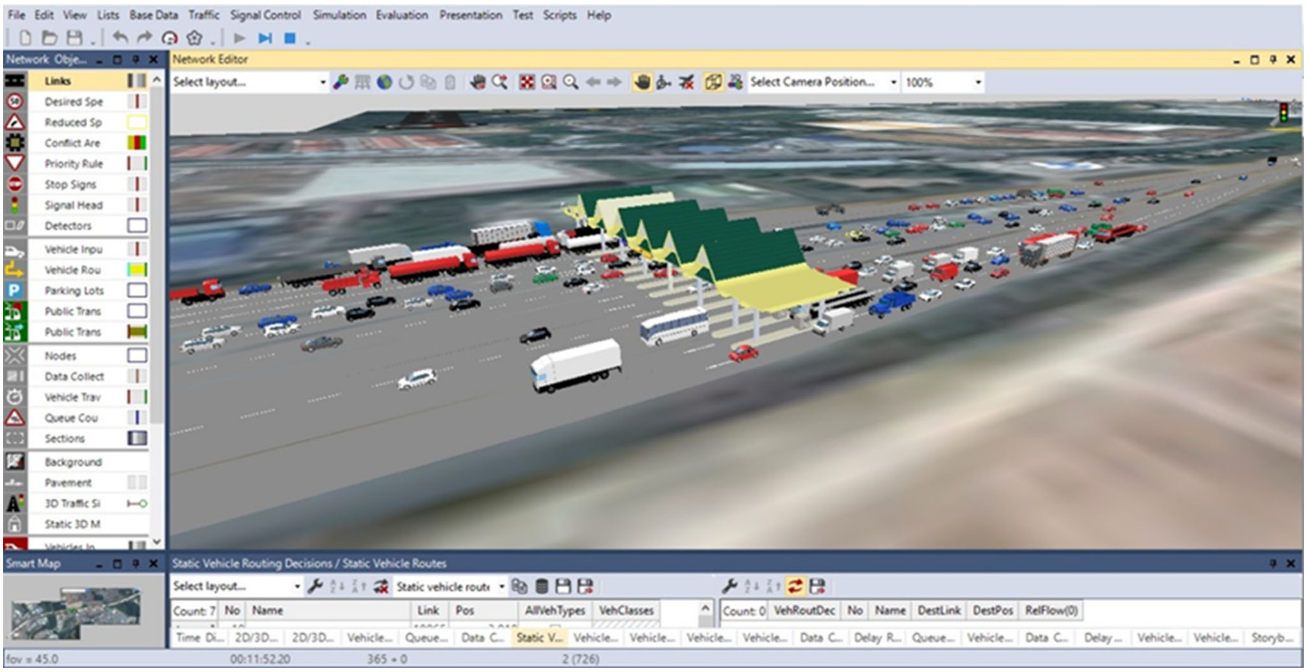


Fig. 12 Screen-captured image of the calibrated model for Juru toll plaza

with two payment types: 10 service time distributions for entry and 10 service time distributions for exit. Figure 10 shows an example of the dwell time distributions (service time) input for vehicle types in the VISSIM model of Juru toll plaza at entry.

5 Calibration of the Model

Calibration is a process of adjusting the model's parameters to improve the model's ability to accurately reproduce traffic operation characteristics [31]. Calibration is performed on various components to replicate observed data to a sufficient level to satisfy the objectives of the model [7].

Calibration is necessary because no single model is equally accurate for all possible traffic conditions. Even the most detailed microsimulation model still contains only a portion of all of the variables that affect real-world traffic conditions. Therefore, every model must be adapted to local conditions [32].

The procedure of the toll plaza model calibration was divided into several steps. The first step was to select the measure of effectiveness MOE (throughput) [33] as the index of comparison between the simulated and observed values. Second, the simulation models for 10 different values were run and the outputs of the selected MOE were obtained [7,13,31]. Then, the statistical paired two-sample t test analysis with 95% level of confidence was used to compare the observed MOE values with the outputs from the simulation results [31].

If the value of the calculated MOE T test was less than the t critical value (from the table), the simulation outputs show a statistical significance of similarity to the observed MOE, and thus, the model of the Juru toll plaza was calibrated. However, when the value of the calculated MOE T test was greater than the t critical value (from the table), a significant difference is seen between the simulated and observed values of the MOE; thus, the model's key parameters need more adjustments depending on the field observation and the simulation reruns for 10 different values. A multiple of 10 simulation runs with different values of the key parameters were done until the calibration was completed.

Figure 11 shows the flowchart of the calibration process, while Figure 12 shows the screen capture of the calibrated model for the Juru toll plaza.

6 Examination of Effect of Heavy Vehicles on Queue Lengths at Juru Toll Plaza

This study aims to construct traffic simulation models of the Juru toll plaza based on the calibration model. Firstly, the newly proposed models are used as scenarios to represent different traffic conditions at the toll plaza, from which the impact of heavy-vehicle percentages on queue lengths along the mixed mode toll lanes is tested. Secondly, the influence of heavy-vehicle percentages on queue lengths along other toll lane types is determined. Finally, the influence of payment types and vehicle types on queue lengths is examined.

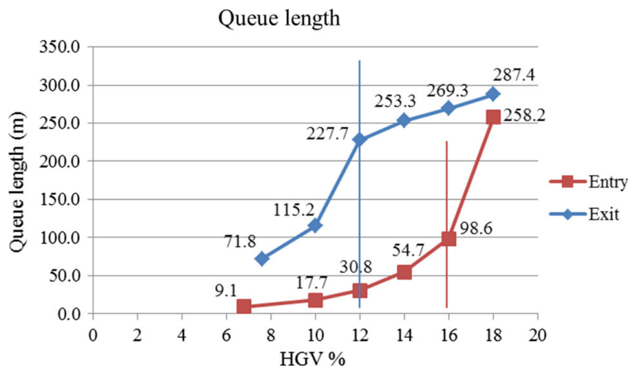


Fig. 13 Impact of heavy-vehicle percentage on queue length along mixed mode lanes of Juru toll plaza

Six scenarios have been identified and simulated to determine the traffic operations of the toll lanes.

1. Scenario 1: base scenario (normal traffic flow)

   Entry: 2501 vph with 6.8% of vehicles are heavy vehicles
   Exit: 2920 vph with 7.6% of vehicles are heavy vehicles

2. Scenario 2: the same traffic volume as in Scenario 1, but heavy-vehicle percentage is increased to 10%, 12%, 14%, 16%, and 18%.

The results obtained in Scenarios 1 and 2 are used to investigate the impact of heavy vehicles on toll plaza operations in terms of queue lengths.

Figure 13 shows the impact of heavy vehicles on queue lengths. Queue length is measured at the end of a 1-h simulation period. At the entry direction (see plotted graphs in Fig. 13), queue length is gradually increased to 16% with increments of heavy-vehicle percentage, after which this queue length is rapidly increased from 98.6 to 258.2 m for 16% and 18% of heavy vehicles, respectively. However, the opposite is observed at the exit direction, in which the queue length is rapidly increased from 71.8 to 227.7 m for 7.6% and 12% of heavy vehicles, respectively, and then the queue length is gradually increased to 287.4 m for 18% of heavy vehicles.

The influence of heavy-vehicle percentage on queue length for other toll lane types is also examined. Figure 14 shows the mixed mode queue lengths for the Touch 'n Go and Smart TAG lanes at the entry and exit directions.

On the basis of the graphs plotted in Fig. 14, heavy-vehicle percentage has no significant influence on other toll lane types at the entry and exit directions.

Figure 15 shows the screen-captured image of the 3D simulation model of the Juru toll plaza, in which the scenario of 18% of heavy vehicles is considered.

With regard to the influence of payment types on queue length with increments of heavy-vehicle percentage, the same case as those of Scenarios 1 and 2 has been adopted, i.e., heavy-vehicle percentages of 6.8%, 10%, 12%, 14%, 16%, and 18% at the entry direction and 7.6%, 10%, 12%, 14%, 16%, and 18% at the exit directions. However, this third case differs in terms of payment type for each vehicle type, particularly for the ticket and Touch 'n Go scheme at entry and the cash and Touch 'n Go scheme at exit. Therefore, new scenarios can be considered. Scenario 1 represents the equality between payment types and vehicle types, that is, the number of vehicles that pay with tickets is equal to the number of vehicles that use Touch 'n Go at entry, and the procedure is the same between cash and Touch 'n Go payment types at exit. In Scenario 2, all vehicle types use Touch 'n Go at entry and exit. In Scenario 3, all vehicle types pay with tickets at entry and cash at exit.

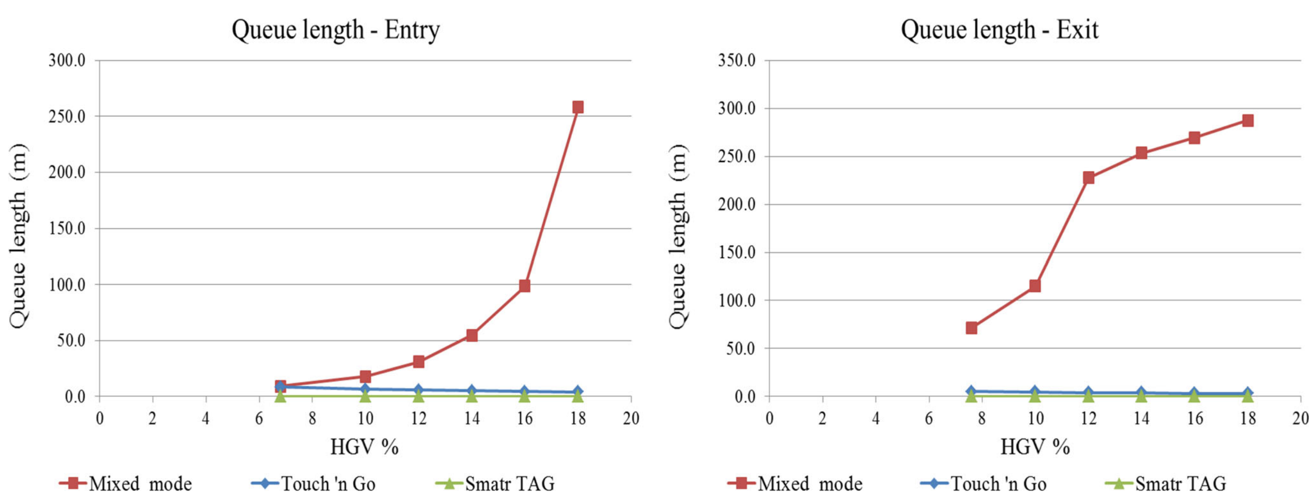


Fig. 14 Queue length results of the Juru toll plaza model at entry and exit directions

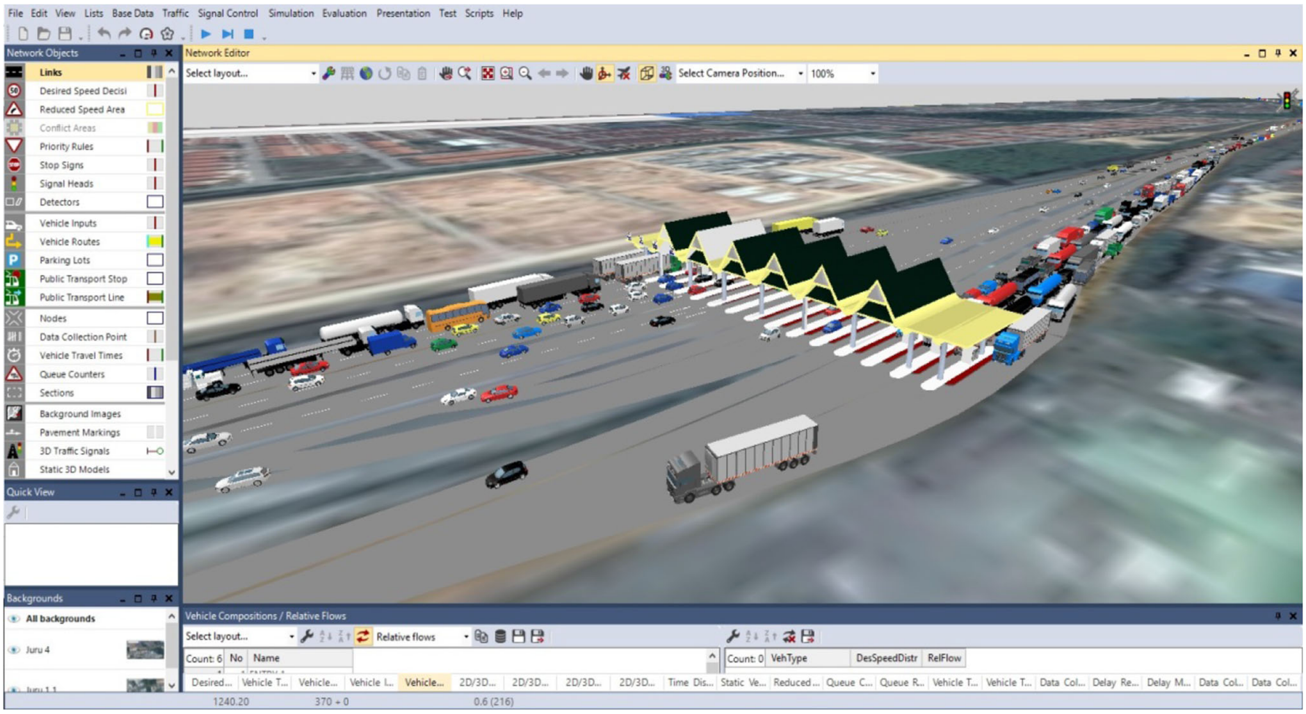


Fig. 15 Screen-captured image of the 3D simulation model of Juru toll plaza

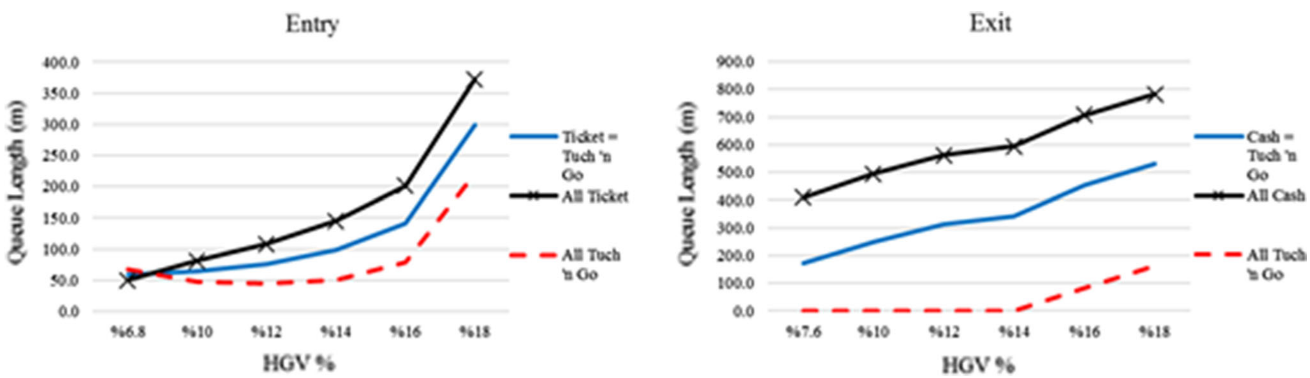


Fig. 16 Influence of payment types on queue length at the entry and exit directions of the Juru toll plaza model

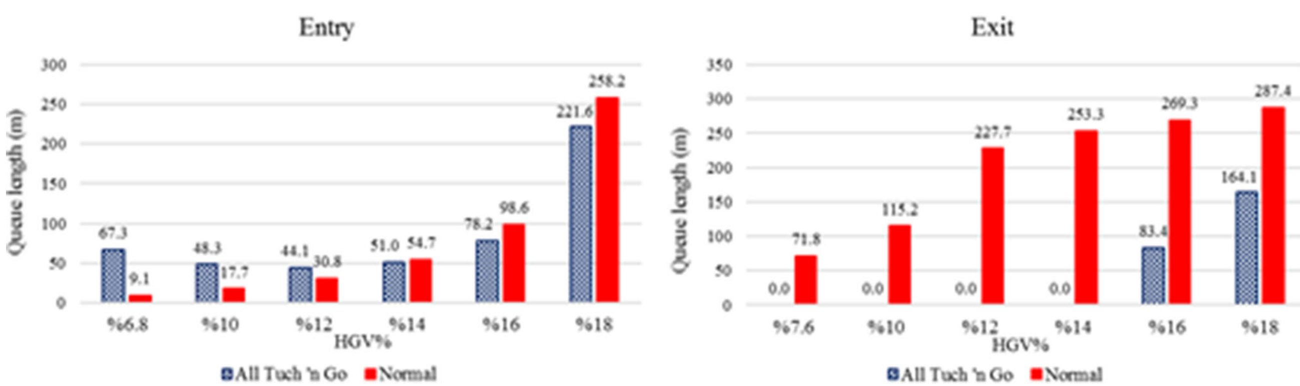


Fig. 17 Comparison between queue lengths after increments of heavy-vehicle percentages and after all vehicles use Touch 'n Go at the entry and exit directions of the Juru toll plaza model

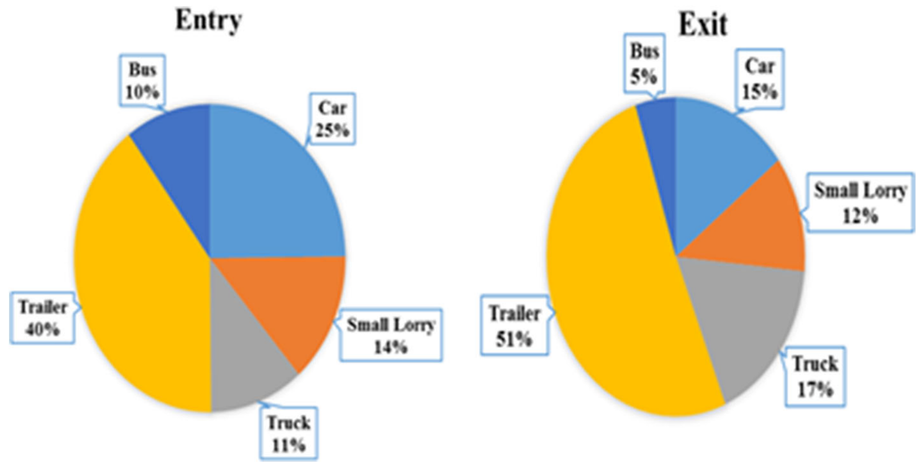


Fig. 18 Influence of vehicle types on queue length at the entry and exit directions of the Juru toll plaza model

As shown in Fig. 16, the best case of queue lengths at the entry and exit directions can be realized when all vehicles use the Touch ’n Go payment type, which is depicted by Scenario 3. Figure 17 shows the comparison between queue lengths in two cases, namely after increments of heavy-vehicle percentage and after all vehicles change to the Touch ’n Go payment type. The results show that the queue lengths after increments of heavy-vehicle percentage can be improved by approximately 80% when all vehicles use Touch ’n Go at exit. However, at the entry directions, the improvement in queue length can be achieved only when heavy-vehicle percentages exceed 14%; in this case, the improvement rate is 17%.

To further determine the influence of vehicle types on queue length with increments of heavy-vehicle percentage, a scenario the same as that of Scenario 1 (i.e., equality between payment types for all vehicle types) has been adopted. In particular, the number of vehicles that correspond to a certain queue length is calculated, and the percentages of all types of queued vehicles are determined. The reason for selecting Scenario 1 is to neglect the impact of payment types on the results. Figure 18 shows that most queue lengths at the entry direction comprise 40% of trailers, 25% of cars, and 14% of small lorries, whereas most queue lengths at the exit direction comprise 51% of trailers, 17% of trucks, and 15% of cars.

7 Conclusions

The main goal of this study is to examine the impact of percentage of heavy vehicles in the Malaysian expressway system on the performance of Juru toll plaza in terms of vehicle queue length. The microscopic simulation software called VISSIM was used to construct the Juru toll plaza model and investigate toll operations. The results of the calibration prove that VISSIM is a suitable tool for simulating heterogeneous traffic flow and can accurately replicate the real-world operations of the toll plaza. Moreover, the results show that the percentage of heavy vehicles in traffic flow has a significant impact on queue length at the Juru toll plaza. The significant impact of heavy-vehicle percentages starts from 16% and 7.6% at the entry and exit directions, respectively. The results also show that heavy-vehicle percentage has no influence on ETC lanes at entry and exit. Most queue lengths have been caused by trailers that represent 40% and 51% of the total queue length at entry and exit, respectively. The best procedure for improving queue length at the entry and exit directions at the Juru toll plaza is by changing the payment type to Touch ’n Go for all vehicle types.

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