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MACRO-SIMULATION OF RAMP METERING USING SIMUL8

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Abstract: In this paper we investigate about the benefits and the drawback of ramp metering as a mechanism to control the traffic congestion in the highway system. A model is developed using SIMUL8 to simulate two conditions for entry of vehicles into highway namely, with metering and without metering. For the metering condition, traffic responsive ramp meter is modelled. Due to the software limitations, the level of simulation that can be developed is to the macroscopic level. The metering effectiveness is studied by investigating some parameters such as average total travel time, total throughput and ramp delay. The model is calibrated, verified and validated before analysis. The outcomes of the study show that SIMUL8 could produce results which are close to the findings by other studies as well as actual field data.

Key Words: SIMUL8, Ramp metering, Traffic simulation, Urban highways, Congestion.

1. INTRODUCTION

The dynamics of urban development and increased size of metropolitan conglomerations present increasingly challenging and demanding problems to local authorities. Malaysia, a fast developing country is also suffering from the same problem. A typical example is the Federal Highway located in Kuala Lumpur, which serves as the main highway between residential areas and town areas. It is observed that, when the highway is nearly congested or at the congested condition, the platoon of vehicles entering from the ramp would lead to the total breakdown of highway traffic flow. Therefore, ramp control, which aims to regulate the flow of vehicles entering the highway, is needed in order to balance the highway demand and capacity. By controlling the entry of the vehicles at ramp, it is expected that the bottleneck at the highway-ramp junction could be eliminated. Ramp metering is an application of control devices such as traffic signals, signing and gates to regulate the number of vehicles entering or leaving the highway. There are three types of control for this operation, which are demand-capacity control, occupancy control and gap acceptance control.

Traffic simulation models can be categorized according to the levels of detail they represent the system to be studied. A macroscopic model describes entities and their activities and interactions at a low level of detail. For example, the traffic stream may be represented in some aggregate manner such as a statistical histogram or scalar values of flow rate, speed and density. SIMUL8 is general-purpose simulation software. Due to the software limitations, it can be used to simulate traffic engineering problems to the macroscopic level. A SIMUL8 model can be easily built by selecting the icons from the tool bar and arranging them on the screen, adding and changing links as necessary. Arrival rates, activity times, travel times, queuing, priority and batching rules can all be changed in the appropriate dialogue box. Attributes, for distinguishing between different types of work items, can be added. Other system defaults such as the unit of time, the warm up period and run times can all be changed from the program toolbar. In addition, it also completes with extensive library of graphics icon. Results and performance measures, such as throughput rates and queue statistics are collected automatically as the model runs. Besides, SIMUL8 is complemented with a built-in programming language, Visual Logic, which allows a more dynamic model to be developed.

The main objective of this study is to develop a model using SIMUL8 that simulates two traffic control situations for highway entry ramp, which are non-metering and with metering condition. The non-metering condition serves as a bench mark so that comparison can be made with the metering condition. The measures of effectiveness (MOE) chosen for the evaluation purpose are average total travel time, freeway total throughput and average ramp delay. The model is calibrated, verified and validated before testing on actual field data. The outcomes of the study show that proposed model could produce results which are close to the findings by other studies as well as actual field data.

2. LITERATURE REVIEW

There is an extensive research carried out to study the effectiveness of ramp metering. Several types of simulation packages had been used to develop the model. In a research using INTEGRATION as the simulation tool, Hellinga and Van Aerde (1995) found out that there was a slight reduction (0.39%) in total network travel time under the absence of the diversion of the vehicles. Another simulation study done by Matson and Daniel (1998) used CORSIM, a microscopic simulator, to evaluate a fixed time ramp meter on the northbound corridor in the Atlanta metropolitan area. A simulation model was developed using CORSIM by Sanhita *et.al.* (2002). They estimated the speed improvements when a simple ramp metering was applied at the on-ramp junctions. A dynamic display of the actual traffic operations of the simulation model was shown by TRAFVU, which came together with CORSIM. Chen *et.al.* (1997) used MITSIMLab for evaluation of the effectiveness of ramp metering operation. They compared the performance of an area wide control of ramp metering and a bilateral control. Nsour *et.al*. (1992) used INTRAS as the simulation tool to evaluate the effects of ramp metering. They found that the restrictive ramp metering significantly improved freeway flow but adversely affected the overall system performance because overflowing queues at ramps blocked street traffic and create a severe disturbance on feeder streets. In addition, they found out that there was a 10.5% reduction in system delay and 4.1% increment in average speed with ramp metering. In a simulation study using AIMSUN as the simulation tool (Panos and Hourdakis 2001), it was found that ramp metering reduced the total travel time about 6-16% while increased the average mainline speeds by 13-26%. Besides, ramp metering reduced the number of acceleration-deceleration cycles and smoothed traffic flow. Artificial Neural Network (ANN) is also used in the ramp metering simulation. Zhang and Stephen (1997) used ANN to design the local traffic responsive ramp control. The control problem was formulated as a nonlinear feedback control problem. One of the conclusions in the study was that local ramp control might not be sufficient to mainline traffic flow at its operating capacity when the freeway demand is high. Another researcher, Chien (2001) also used ANN to develop a mesoscopic model that could incorporate several types of ramp metering control. He proposed the spatiotemporal ANN that posed great potential for solving the metering control problems. In addition, few more simulation packages which need mention are PARAMICS (Chu et.al., 2001), MITSIM (Hasan 1999, 2000), METANET (Papageorgiou *et.al.*, 1990,1991) and fuzzy logic (Amy, 2000).

It is evident that most of the simulation studies are microscopic models developed using the special purpose simulation tool. Therefore, it is worth trying to simulate the ramp metering by general purpose simulation software, SIMUL8 done in present study. This is because most of the microscopic tools are developed by the western countries. Thus, the tool is calibrated using the traffic condition in the entire countries which might not reflect the local traffic conditions. By using general purpose simulation software, we would have higher degree of freedom to create and develop our model. We can input the traffic equations which reflect local condition into our own model. Although the special purpose simulation software such as Paramics has the ability to allow us to override its original setting, however, its degree of freedom is not as high as the general purpose software. Nevertheless, the price that we have to pay for this freedom is to have a lower level model while the accuracy of the outcome is preserved and competitive to those microscopic models.

3. METHODOLOGY

A model using SIMUL8 is developed to simulate two conditions for entry of vehicles into highway namely, with metering and without metering. In order to study the effectiveness of ramp meter, comparison is made with non-metering condition. The non-metering condition serves as a bench mark for comparison. The metering feature in non-metering model is turned off. Thus, it always allows the ramp vehicles to join the highway. For the metering condition, the metering system is activated when the traffic flow achieves certain pre-specified criteria. The downstream capacity is preset with a limiting value. When the upstream flow rate, which is the total flow rate of highway mainline and ramp volume, is higher than capacity value, a signal is sent to the ramp meter to stop the ramp vehicles from entering to the highway and vice versa. However, to maintain a good level of service and to avoid long queue at the ramp from spilling over to the arterial roads, a queue override system is set in the model. That is, when the queue length or the number of vehicles at the ramp is more than allowed, the vehicles at the ramp are released to the highway regardless of the highway condition. Nevertheless, the mainline vehicles are given the priority to move through the section without being controlled by any traffic devices. The concept of the ramp metering embedded in the proposed model is summarized in Figure 1. Some traffic flow equations have to be used as an input into the system in order to generate the traffic condition. The most common parameter used in describing the traffic condition is the vehicle speed. One of the limitations in SIMUL8 is the difficulty in specifying the distance between two components on the screen. Therefore, it is difficult to set the vehicle speed directly. However, SIMUL8 provides the *travel time* tab in return. Thus, the only way to specify the speed of the vehicles is through specifying their travel time between components. It is assumed that the total length of the highway segment is 100m while the ramp located 50m away from the mainline entrance. The ramp length is 200meter. The travel distance on the highway segment is chosen purposely to be 100m. This is because the equipment (video camera with wider lenses and tripod stand) used to record the field data for calibration and validation is unable to record data more than 100m. In addition, wider point of view is difficult to obtain as the site chosen are restricted by the buildings at the roadside. Moreover, it is chosen to be short so that the assumptions made in this model are held. Thus, the model is calibrated for this short distance.

In addition, Arcelik speed-flow model (Singh, 1999) is used for speed calculation. However, the equation needed some modifications so that the link travel time calculated represented seconds per 100 meters for mainline and seconds per 200 meters for ramp. Thus, the equations become:

$$225t = t_o/225 + [0.25T\ \{(x-1) + (x-1)^2 + (8J_a x/QT)\}^{0.5}] \qquad \text{for mainline} \qquad (1)$$

$$450t = t_o/450 + [0.25T\ \{(x-1) + (x-1)^2 + (8J_a x/QT)\}^{0.5}] \qquad \text{for ramp} \qquad (2)$$

where,

t = average travel time per unit distance (hours/mile)

t_o= free-flow travel time per unit distance (hours/mile)

T = flow period i.e. the time interval in hours, during which an average arrival (demand) flow rate, v, persists.

Q = capacity; x = the degree of saturation i.e. v/Q

J_a = the delay parameter (freeway ramps=0.167; metered ramps=0.4; freeways=0.1)

The service time for both highway and the ramp has to be set. It is known that the service time is the inverse of flow rate. For the mainline, the forced flow equation of the Federal Highway is used (Sivasankar, 1997).

$$Q = (2.5 \times 10^5\ V)^{0.5631} \qquad (3)$$

where:

Q = flow rate (veh/hr)

V = speed of vehicles (km/hr).

The value from the above equation has to be divided by three before it is used in the model. This is because the equation is developed for three-lane road while only one lane is being modelled in the present research. For the ramp, the Siegloch formula (Brilon *et. al*, 1999) is used to calculate the entrance capacity for the ramp.

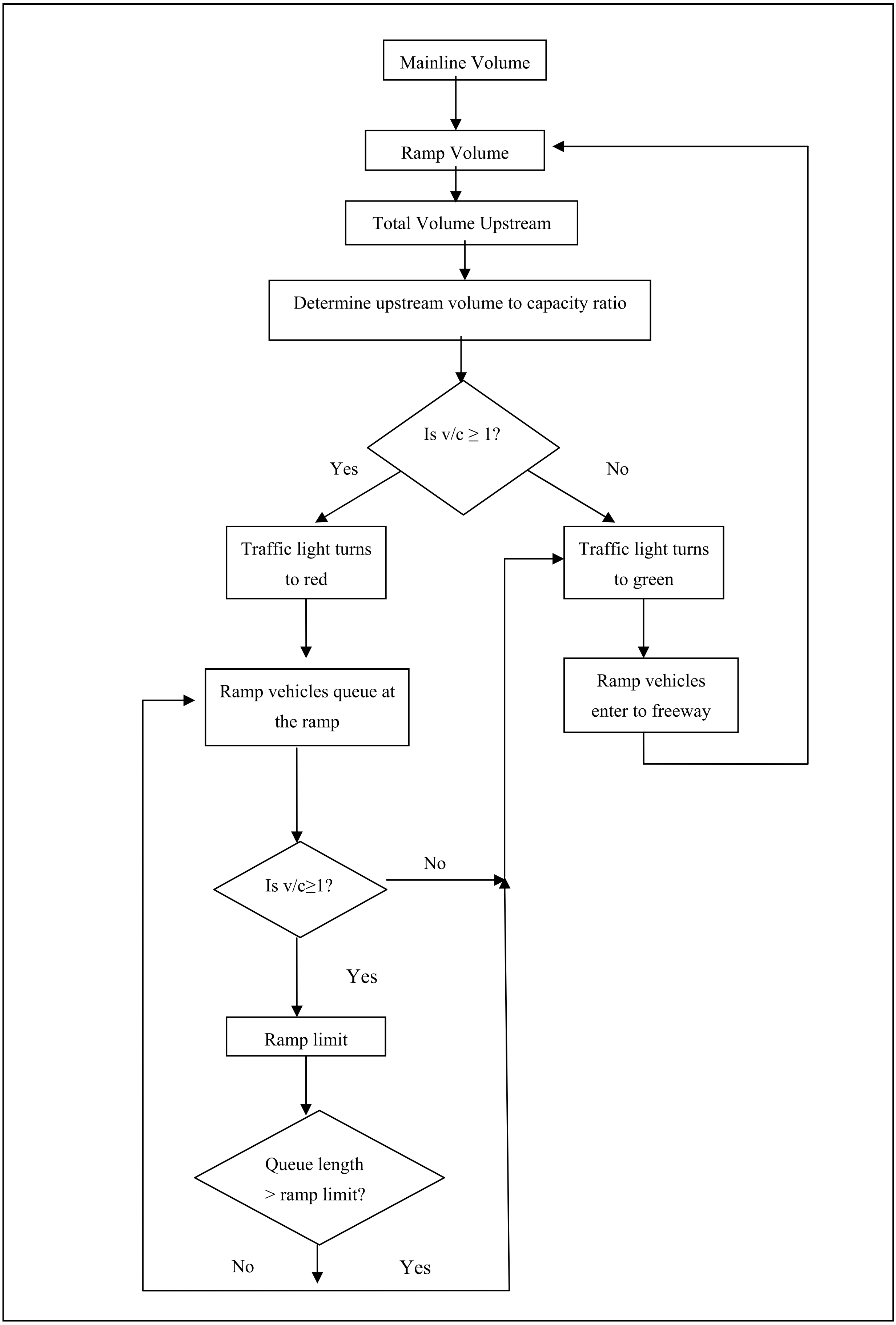

Figure 1. Ramp metering and queue override system modelling concept

$$C = \frac{1}{t_f} e^{-q_p \cdot t_0} \tag{4}$$

where:
C= entrance capacity (veh/s); q_p = flow on mainline (veh/s)
t_f = follow up time = 2.9s; $t_0 = t_c - t_f/2$ with t_c = critical gap = 6.25s

Following assumptions have been made for model development due to the software limitations.

- The driver behaviour such as lane changing is not modelled.
- The vehicles maintain constant speed (according to the speed specified) when they entered the system until they exit.
- The ramp drivers accelerate to the same speed as the vehicle at mainline after they merge into the freeway.
- The ramp drivers encounter all the delay due to the merging process. The mainline driver encounters no delay.
- The flow of traffic is free of road surface characteristics and weather conditions.

Calibration that introduces the input parameters of the model is an important step in simulation model. The input for the model are mainline capacity, mainline and ramp arrival rate, ramp limit, freeway and ramp vehicle free flow speed, mainline and ramp service time distribution. The sources from where the default values are obtained are summarized in Table 1. This table also shows the parameter values and ranges selected for calibration of proposed model.

Table 1. Input parameters in the model

No.	Input parameters	Sources	Default value/ranges	Value chosen
1	Mainline capacity	Highway Capacity Manual	2000vph	2000vph
2	Mainline arrival rate		1000-3000vph	1800, 2000, 2200vph
3	Ramp arrival rate	Federal Highway Administration, 2000	240-900vph	350-750vph
4	Ramp limit	Texas Department of Transportation, 2001		Table 2
5	Mainline free flow speed	Local authority	80km/h	80km/h
6	Ramp free flow speed	Field Data	20-50km/h	35km/h

Besides, the type of distribution chosen for the inter-arrival time is exponential distribution (Karl, 1999). This is because the vehicle arrival pattern is well represented by Poisson distribution where the arrival is random and independent of time (Nicholas and Lester, 1996). Table 2 shows the relationship between ramp volume and number of vehicles adopted by Texas Department of Transportation (2001).

To verify that the codes are correctly and logically executed by the program, verification has been carried out. The verification of the model is done by two methods, which are animation and sensitivity analysis. By animation, we can make sure that the simulation correctly executes the program. It is observed in animation that the mainline queue is forming when the v/c ratio more

Table 2. Relationship between ramp volume and number of vehicles

Volume (vph)	Number of vehicles
350	16
400	18
450	20
500	21
550	23
600	25
650	26
700	28
750	29

than one. The traffic light at entry ramp in the model also shows red sign. The ramp vehicles are stopped from entering to the freeway. When the queue override system is activated, the vehicles at the ramp are allowed to join even though the v/c ratio is more than one and the queue length is long at mainline. For the non-metering condition the ramp vehicles are always allowed to merge into the highway regardless of the highway condition. Besides, it is important to determine the factors that affect the measure of performances of the model. In sensitivity analysis, the factors investigated are the choice of distribution for the vehicles arrival rate and the service time at mainline and ramp. For the single lane ramp, the arrival rate must less than 900vph (Texas DoT, 2001). The mainline arrival rate has the limit of 3000veh/hr/lane. If the value is higher than 3000veh/hr, the model would have error in executing the codes. This has been found after conducting some number of trials to find limiting values for the model. Besides, when the mainline arrival rate increases, the total throughput decreases. This is logical because when the highway is more congested, the service time of the vehicle would be longer and thus within the one hour period, fewer vehicles can pass through the system. For this reason, the average total travel time and the delay at the ramp increases. From the analysis too, it is observed that the model is credible. The outputs are consistent if the service time distribution is changed from the exponential distribution to the fixed distribution, and the average distribution. For model validation purposes data is collected at some on-ramp junctions along the Federal Highway, Kuala Lumpur.

4. TESTING AND RESULTS

To test the proposed model four ramps are selected for data collection along the Federal Highway, Kuala Lumpur, Malaysia. The first one is in front of the University Hospital, Kuala Lumpur where the ramp junction connects University Road to the Federal Highway. The second one is the ramp junction in front of the Sungai Way Primary School at Petaling Jaya. Third one is the ramp junction, which caters the traffic flow from Syed Putra Road into the Federal

Highway. The last site is at Cheras, near Wenworth Hotel. All these sites share the similar characteristics where they consist of a highway mainline and an on-ramp junction connected to the highway. Two digital cameras were set up at the site and recorded the data for 90 minutes continuously. One of the cameras was used to record the traffic flow at the highway while the other was used to record the traffic flow from the ramp. The highway chosen consisted of 2 or 3 lanes, but only the left lane which interacts with the ramp is recorded. Whenever the mainline is refered in this paper, it refers to the left lane of the mainline highway. The middle and right lanes are ignored so that this is consistent with our model. Then, the recorded tapes were playback for analysis in the traffic laboratory. The traffic characteristics such as vehicle headway, speed and travel time was collected from the highway mainline and the ramp. The headway was used to calculate the arrival rate and traffic volume. A 15-minute interval was used for analysis. The headway data was entered into the Stat:Fit software to find the suitable distribution type for the data. Stat:Fit is statistics software, which is part of SIMUL8. Then, the data is used as inputs to the model. After running a trial, which consisted of 100 runs, the total volume served is recorded together with the 95% confidence interval produced. The values produced by the model are compared to the field data. Other parameters selected for validation purposes is mainline average travel time.

Figure 2 shows comparison between the model value and the field data for the mainline volume served. From statistics point of view, the 95% confident interval is interpreted as the mentioned interval had 95% of chance to include the true value. From Figure 2, 5 points out of 6 points are within the interval range. The confidence interval produced by the model is acceptable (Ronald and Fred, 2001). For the ramp, the volume served comparison is shown in Figure 3. All of the observed values from the site are within 95% interval range produced by the model.

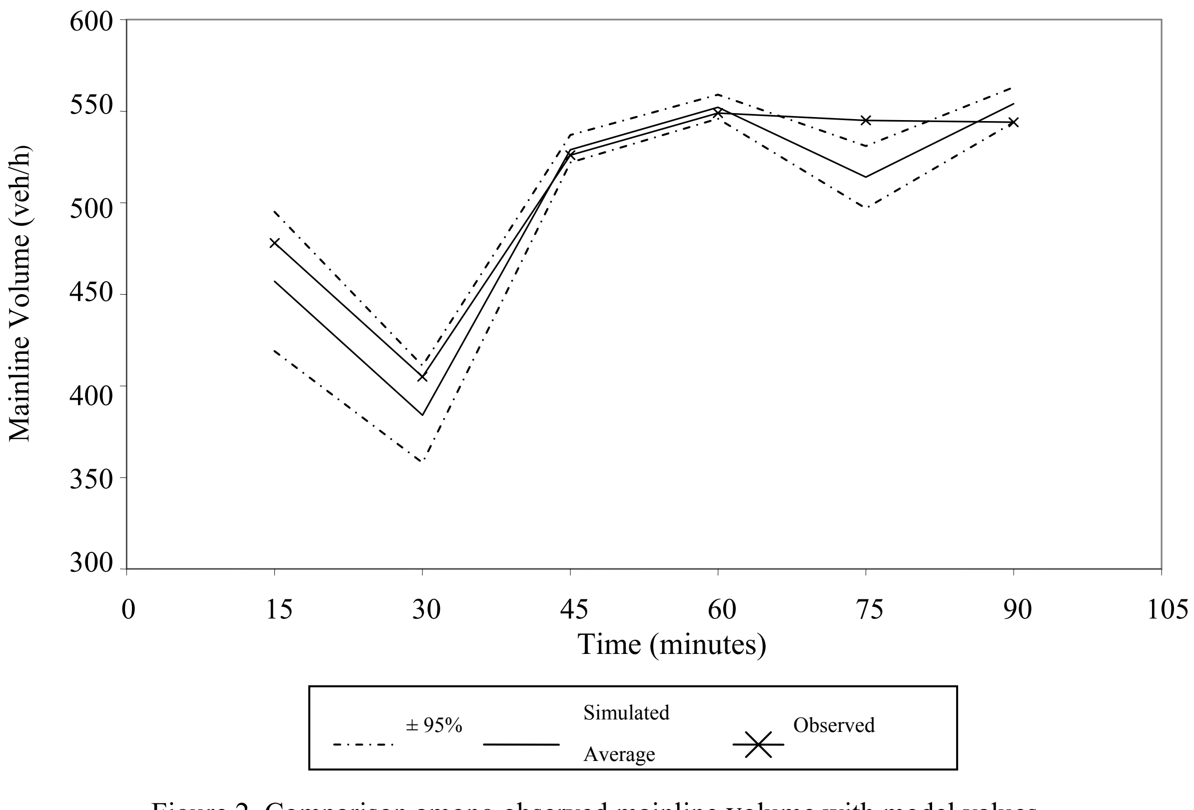

Figure 2. Comparison among observed mainline volume with model values

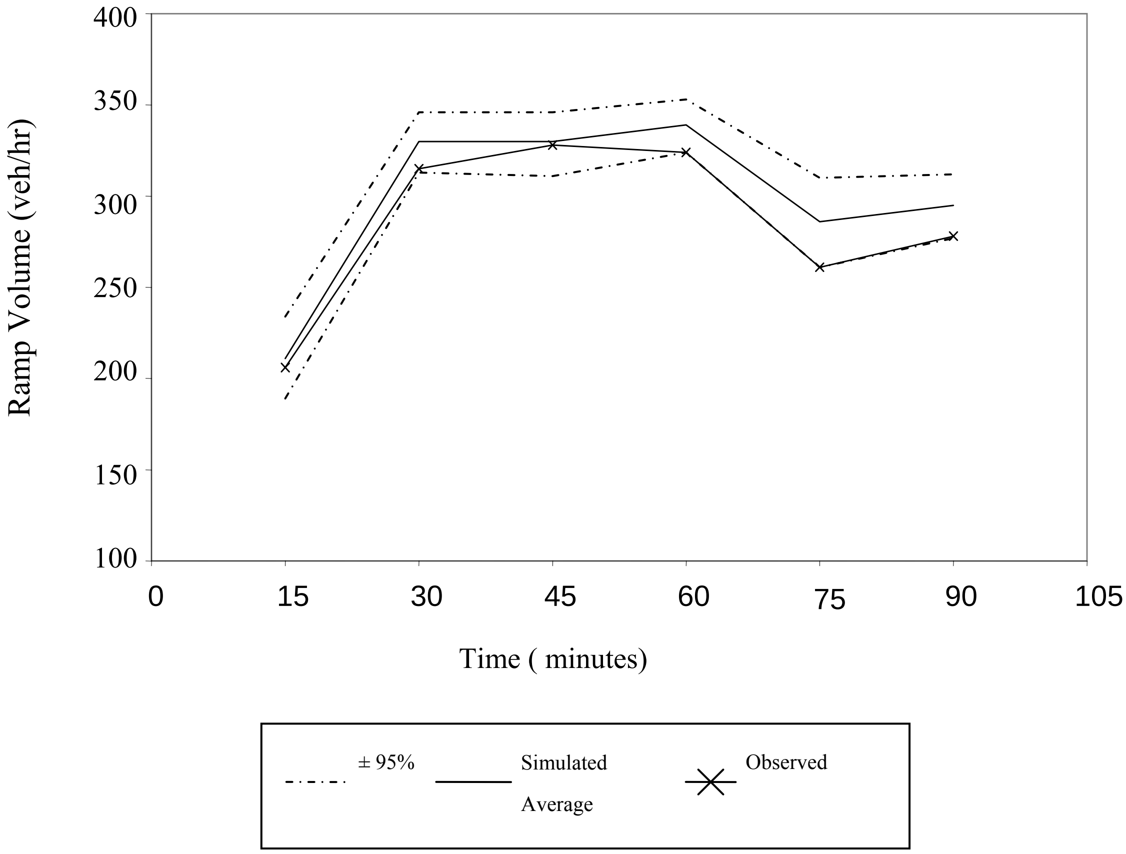

Figure 3. Comparison among observed ramp volume with model values

Another parameter used for validation purposes is the mainline average travel time. Two lines which are separated by 100m (the location of the lines is marked on the site using delineator cones) are drawn on the screen and the time where the vehicles pass through the lines is recorded. The travel time is the time difference between two lines. The observed travel time is then averaged. Figure 4 shows that 4 points out of 6 points are within the interval range. It is shown that the observed values are within 2 standard deviations or 95% confident interval. The observed values are within the acceptable range produced by the model, hence the model is reasonably validated (Ronald and Fred 2001). The travel time at time 90 minutes is the congestion that occur because of an incident occurs in the highway when the recording is done.

Each of the figures is obtained using independent set of data. The number of runs for each set of data is 100 runs with different and unique random number stream sets. It is conducted by running a trial which consisted of 100 runs. The warm up period is one minute and the simulation length is one hour.

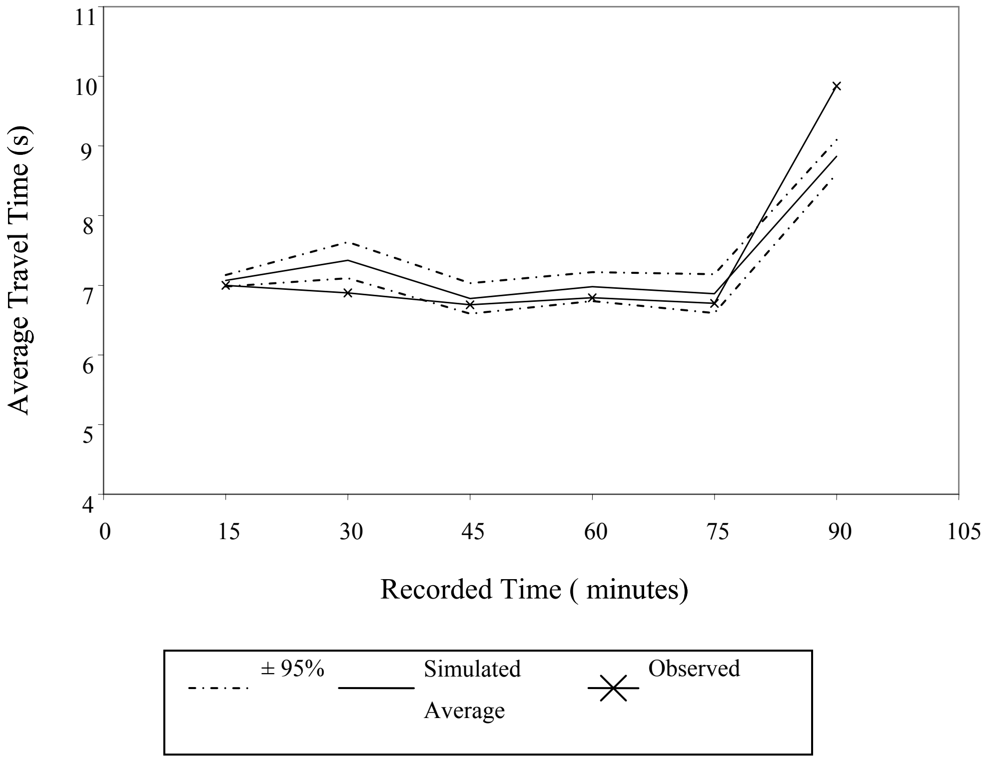

Figure 4. Observed and model mainline average travel time

For the analysis of results, the comparing means (SIMUL8 Corporation, 2000) technique is used. The mean value produced by SIMUL8 is an estimated value of the true mean. Therefore, in order to report convinced results, the findings from the model should be within 95% confidence interval. It is very important that the difference (either improvement or deterioration) between the suggested method and the base method is significant before the decision can be made. This could be done by comparing the confidence interval between the alternatives. If the confidence interval for both alternatives overlaps, there is no significant difference between both alternatives and vice versa. The results are summarised as follows:

I. When the ramp meter is applied, we observe that it reduces the average total travel time for the overall system. However, the percentage of decrement is variable and depends on the traffic conditions. Figure 5 shows the percentage decrement when the ramp is applied. It shows that the decrement is about 19% to 16% when the mainline arrival rate is under the capacity value and the ramp arrival rate is within 600veh/hr to 700veh/hr. When the ramp arrival rate is less than 550veh/hr, the difference for these two conditions is not significant. This means that under such circumstances, the implementation of ramp meter would not bring any benefit to the system. When the mainline arrival rate is at capacity value, for ramp arrival rate 450veh/hr to 700veh/hr, there is about 14% to 10.6% reduction in total average travel time. For the mainline arrival rate above the capacity value, the difference is significant for all ramp arrival rates. But, the decrement is little, which is less than 10%. It is observed that, in such situation, the ramp meter could not prevent the traffic congestion from occurring, but it could at least reduce the impact of the congestion. However, the effectiveness of the ramp metering reduces when the total demand volume increases.

II. The total throughput increases when the ramp meter is applied. For the mainline arrival rate under the capacity value, there is significant difference in throughput increment when the ramp arrival is more than 500veh/hr. The percentage of increment is around 5% to 2.7%. For the mainline arrival rate at capacity, the increment of the throughput is significant when the ramp arrival is from 350veh/hr to 700veh/hr. The increment is around 4%. For mainline arrival more than 2200veh/hr, the increment is significant when the ramp arrival is under 500veh/hr. However, the increment is just around 3%. The improvement is not significant when the ramp volume is more than 550veh/h. Figure 6 shows the results.

III. The ramp meter is found to have an adverse effect on the system. The drawback of the ramp meter is it increased the waiting time for the ramp vehicles. The average waiting time for the ramp vehicle with control is longer than the non-metering model. The ramp delay is the measure of the differences in average waiting time between two conditions. The average delay for mainline volume of 1800veh/h, 2000veh/h and 2200veh/h are 1.45 minutes/vehicle, 1.71 minutes/vehicle and 2.6 minutes/vehicle respectively.

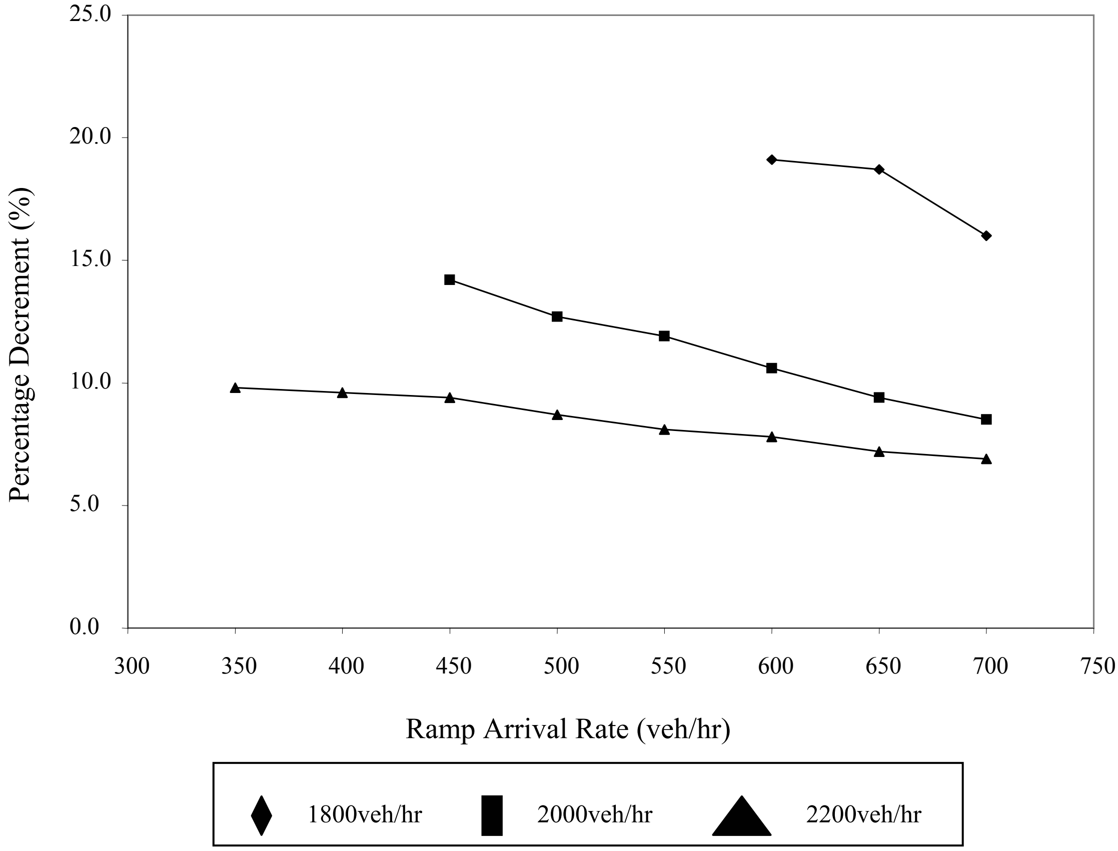

Figure 5. Percentage decrement in average total travel time

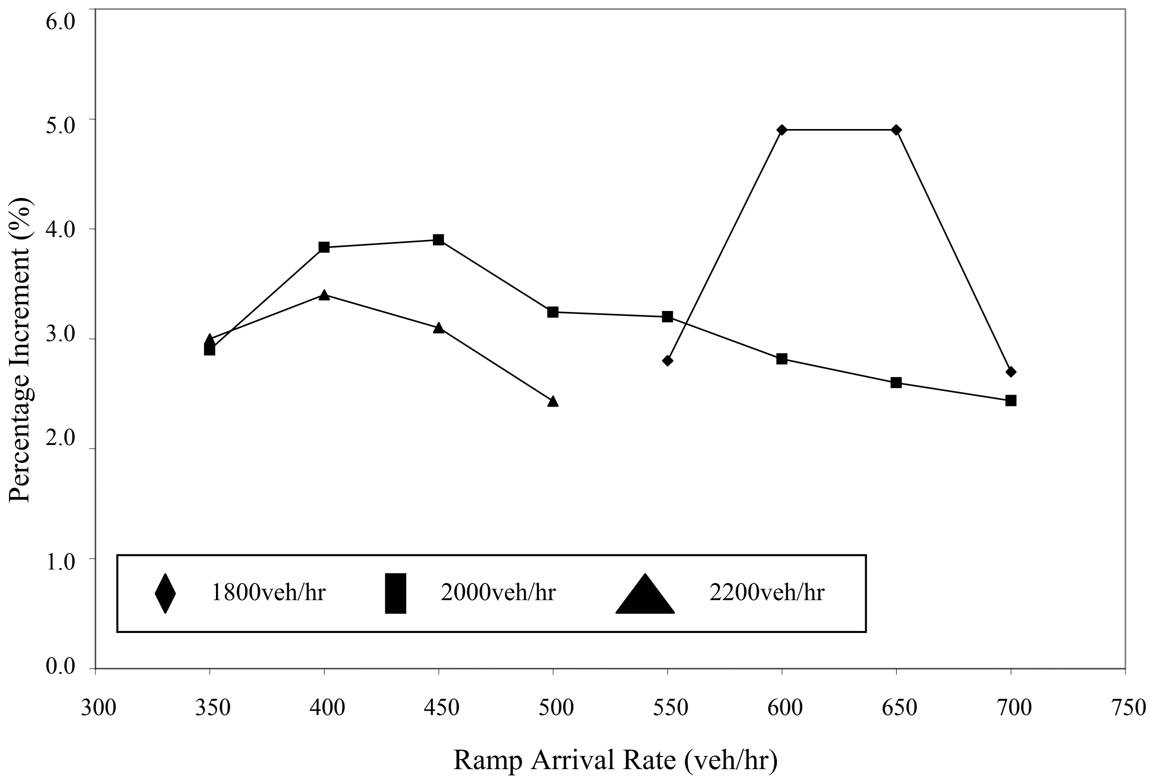

Figure 6. Percentage increment in total throughput

5. CONCLUSION

The findings for this study are acceptable when compare to the previous studies done in western countries. The outcomes of the study are compared to the field study done in Twin Cities, the United States of America and other places (Cambridge Systematic Inc, 2001). They are listed in Table 3. The research findings are very close to the previous studies and therefore they are acceptable.

Table 3. Results comparison

No.	MOEs	Research Findings	Previous Studies
1	Average total travel time	- 7% to -19%	-6% to -20%
2	Total throughput	+2.5% to 4%	+0% to +7%
3	Ramp delay	< 2.6 minutes	< 2.5 minutes

SIMUL8 can be used to solve the traffic problems. Although it has some limitations, it still could be used in traffic simulation. The limitations could be tackled by inserting the traffic engineering formula, which describe the situation into the model. The results produced are reliable and are similar to the previous studies. Ramp metering is a good tool to solve the highway congestion problem. However, its effectiveness is depended on the traffic volume at the highway and ramp. Therefore, we must carefully consider before we make decision to install the ramp meter. In the case of Malaysia, the system is yet to apply in our country. This idea is sparked in our mind after observing the traffic congestion condition on the highway in our country. From the finding, we are sure that this system is applicable to solve the congestion problem in Malaysia. There is not any research being done about this system by other researches in our country. Therefore, this project serves as a basic idea to suggest to our transport authority for the implementation of the system. Thus, future work is encouraged towards eliminating the assumptions in this study to develop a more complete and complex model. Besides, we should look into the metering algorithm in order to eliminate the ramp delay.

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