Dynamic Traffic Simulation for Traffic Congestion Problem Using an Enhanced Algorithm

Wong Poh Lee, Mohd. Azam Osman, Abdullah Zawawi Talib, and Ahmad Izani Md. Ismail

Abstract—Traffic congestion has become a major problem in many countries. One of the main causes of traffic congestion is due to road merges. Vehicles tend to move slower when they reach the merging point. In this paper, an enhanced algorithm for traffic simulation based on the fluid-dynamic algorithm and kinematic wave theory is proposed. The enhanced algorithm is used to study traffic congestion at a road merge. This paper also describes the development of a dynamic traffic simulation tool which is used as a scenario planning and to forecast traffic congestion level in a certain time based on defined parameter values. The tool incorporates the enhanced algorithm as well as the two original algorithms. Output from the three above mentioned algorithms are measured in terms of traffic queue length, travel time and the total number of vehicles passing through the merging point. This paper also suggests an efficient way of reducing traffic congestion at a road merge by analyzing the traffic queue length and travel time.

Keywords—Dynamic, fluid-dynamic, kinematic wave theory, simulation, traffic congestion.

I. INTRODUCTION

TRAFFIC congestion can be characterized by the decrease in speed, the increase in travel time and the increase of vehicle's queue on the road. In addition, traffic congestion happens when the road demand exceeds the road capacity. When congestion happens, increased in travel time, air pollution and fuel consumption occurs [1]-[2]. At the same time, drop in land value happens in areas which are prone to traffic jam [3].

Dynamic traffic simulation has become the research agenda for a growing community of researchers and industries in recent years [4]-[5]. The term *dynamic* as in dynamic traffic simulation in this paper refers to the ability to adjust parameter values (i.e. speed limit, vehicle type) while the simulation application is running.

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Traffic congestion normally happens when merging points are met [10]. A merging point is a situation where several lanes start to converge into fewer lanes. When this occurs, vehicles need to compete with other vehicles to keep to their respective lanes in order to reach a destination. Therefore, some vehicles need to reduce in speed to give way for other vehicles to make lane-changing which resulted in long traffic queues on the road.

In our work, an enhanced algorithm is developed based on the two existing algorithms namely the fluid-dynamic algorithm [6]-[7] and the kinematic wave theory [8]-[9].

A road merge after the toll plaza at Penang Bridge is taken as a scenario for our study. Penang Bridge is a bridge which connects the island of Penang and the mainland of Peninsular Malaysia. This area often encounters traffic congestion especially during peak hours. In this paper, the proposed enhanced algorithm together with the two original algorithms is used to study the road merge at the bridge. A simulation tool is also developed for the study using standalone application which adopts object-oriented approach and JAVA as the main application programming interface (API). Based on the study using the tool, some suggestions on handling traffic congestion problem at a road merge are discussed.

The rest of the paper is organized as follows: The next section describes a brief background and related work which consist of issues on traffic congestion, merges in traffic environment, merge bottlenecks and dynamic simulation approach. Section III presents the algorithms for traffic congestion which are the fluid dynamic algorithm and the kinematic wave theory. In section IV, a brief methodology which covers a discussion on the observation of traffic activity at a road merge on Penang Bridge and an enhanced algorithm based on fluid-dynamic algorithm and kinematic wave theory is discussed. Section V presents the system architecture of the dynamic traffic simulation tool. Section VI discusses the results based on the original algorithms and the enhanced algorithm. Section VII concludes the paper.

II. BACKGROUND AND RELATED WORK

A. Issues on Traffic Congestion

Generally, traffic congestion occurs when traffic demand is greater than the capacity of the road. Traffic congestion is

considered to be at extreme level when vehicles are fully stationary for long periods of time. Besides, traffic congestion can be characterized based on three factors [11]:

1) Slower speed of vehicles
2) Longer travel times
3) Increased queuing

Federal Highway Administration (FHWA) [12] have classified seven main causes of traffic congestion which are physical bottlenecks/ capacity, traffic incidents, work zones, weather, traffic control devices, special events and fluctuation in normal traffic.

B. Merges in Traffic Environment

A merge is produced if there are *n* number of lanes turning into *m* number of lanes where *n* and *m* are integer values and *m* must be smaller than *n* and *n* must be at least 1. Merges are not the opposite of diverge because a diverge means splitting and normally maintaining the number of lanes. When it comes to merges, drivers will try to switch to the lane where vehicles are moving fast on the lane or when a shorter traffic queue is observed. Therefore, merges normally carry a high risk of accidents if there is no consideration given or proper regulations are not complied.

In an observation on traffic activity, it is found that congestion on highways is often caused by merges. A long stretch of vehicles cannot merge if there are no gaps which are big enough for a vehicle to fit in. If drivers are able to create large spaces between each vehicle throughout the way, lane-changing by vehicles can happen easily.

C. Merge Bottlenecks

The basic theory of merge bottlenecks comes from a maximum sustainable flow downstream of merge when downstream conditions are uncongested or known as capacity. This theory states that if the total entering vehicles in certain duration of time go beyond the merge capacity, then the downstream flow reduces the capacity level and causes a queue. The queue continues to grow as more vehicles approach the merge [13].

M. Cassidy and R. Bertini [10] stated that in some places, there are considerable empirical evidence of roadway vehicles that discharge from a merge bottleneck at a nearly constant maximum rate. In their study, they observed the upstream and downstream of a roadway bottleneck to diagnose the traffic conditions.

In another paper by Daganzo [14], three assumptions were made on merge bottlenecks based on his obtained results. He assumed that if a merge is congested, the merging vehicles will "force" gaps and move slowly into the roadway in a given ratio with roadway vehicles. Secondly, vehicles will maintain on the roadway until they get to a certain place and thirdly, when a vehicle is on the roadway, it occupies some space that depends on the flow. Daganzo also noted that there are three possible reasons which cause congestion. His three reasons are stated as follows [14]:

1) Some roadway exits cannot provide enough space and

will end up with slow-moving queues.

2) The roadway has a bottleneck which forms queues naturally.
3) There is too much inflow along the roadway which makes it a constraint to the vehicles.

D. Dynamic Simulation Approach

Dynamic approaches to traffic simulation have been widely used in traffic environment to monitor the traffic systems. Dynamic refers to the ability to allow users to change or tune parameter values while the tool is still in the execution process. Changing of parameter values in traffic simulation may result in different outcomes. For instance, if speed limit on a certain highway is increased, the probability of longer queue length formed when red lights are met is higher.

Through some observations on some vehicles on the road, different vehicles apply different speed on the road. It is not possible to assume all vehicles to move at the same speed every time they are on the road. This limitation brings to further analysis where constraints need to be defined. In an observation by Martin Treiber [15], adjusting speed limits can be useful only if there is a heavy traffic or there is a bottleneck. Decreasing speed limit also leads to different breakdowns.

III. ALGORITHMS FOR TRAFFIC SIMULATION

Two algorithms considered are the fluid-dynamic algorithm and the kinematic wave theory. These algorithms are chosen because the fluid-dynamic algorithm handles well in traffic flow while the kinematic wave theory optimizes the lane-changing effect on vehicles.

A. The Fluid-Dynamic Algorithm

R. Natalini, G. Bretti and B. Piccoli [6] discuss a simulation algorithm based on a fluid-dynamic model. In the algorithm, numerical approximations were considered and a brief discussion of boundary conditions and conditions at junctions is also included.

The basic fluid-dynamic algorithm can be represented by:

$$\textit{traffic flow} = \textit{traffic density} \text{ x } \textit{mean velocity} \qquad (1)$$

where the *traffic flow* represents the average number of vehicles passing per time unit and the *traffic density* represents the number of vehicles per distance unit. *Mean velocity* represents the average velocity of cars in a distance unit. If the velocity reached its maximum value, this means that no other cars are on the highway and the vehicle is able to move at the highest speed. Velocity value of 0 shows that the vehicle is not on the move or in other words, it is a bumper to bumper traffic.

B. The Kinematic Wave Theory

Lighthill and Whitham [8] studied the kinematic wave theory in relation to flood movement. The wave property with regards to the flow and concentration are described as *kinematic*. They use the technique of kinematic waves to

analyze flood movement in long rivers which could further be related to traffic systems.

Wen-Long Jin [9] proposed a kinematic wave theory of lane-changing vehicular traffic where different lanes share the same traffic conditions. The frequency of lane-changes among vehicles in highway merging, diverging and weaving require a great study because bottlenecks and accidents frequently happen in such area. A lane-changing traffic dynamics based on the kinematic wave theories is modeled as follows:

$$(p + V(1+e))=0 \qquad (2)$$

where p represents the density / number of vehicles per unit distance and e represents the lane-changing effect parameter. This model applies when traffic conditions and lane-changing effects are almost constant. V represents the velocity and e represents the value of the lane-changing effect parameter, that is the difference in traffic queue length between two specified lanes.

IV. METHODOLOGY

In the first instance, a study of traffic parameters on road merges is carried out. The outcome of this study includes a list of parameters related to road merges. These parameters are used to determine traffic congestion level in a traffic environment.

After the parameters are studied, an observation of the traffic activity at a road merge on Penang Bridge is carried out to accumulate data on travel time at a certain distance, vehicle type and speed limit. These data are measured for a certain duration of time and are later used to forecast the Penang Bridge traffic using a dynamic traffic simulation tool.

When the observation is done, the next step is to review and compare the fluid-dynamic algorithm and the kinematic wave theory. These two algorithms are studied to obtain an enhanced algorithm which will be used to suggest an efficient way of reducing traffic congestion in a road merge.

Then, a dynamic simulation tool on lane-merging is developed. The dynamic simulation tool consists of an input, a process and an output. The input denotes a selection of parameter values and these values are computed in the process phase while the outputs from the tool include the time duration, travel time of each vehicle, traffic queue length and the total vehicles which pass through the merging point. This tool is then integrated with the enhanced algorithm and another version without the enhanced algorithm. The tool without the enhanced algorithm uses a simple algorithm which computes the outputs by setting a set of parameter values based on the observation carried out in a road merge on Penang Bridge.

The final step of the methodology includes experiments using the dynamic simulation tool to forecast the traffic activity at a road merge on Penang Bridge based on the accumulated data and to suggest an efficient way of reducing traffic congestion at a road merge based on the enhanced algorithm.

A. Observation of Traffic Activity at a Road Merge on Penang Bridge

In order to obtain a detail traffic information, time recording and observation is carried out. Several criteria such as vehicle type (light vehicles and heavy vehicles) and travel time are considered. Fig. 1 shows the points where observers will be located in order to obtain the travel time.
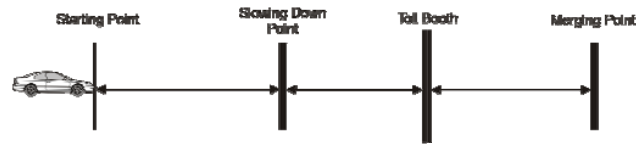

Fig. 1 Observation Points on the Penang Bridge

Travel time is acquired in the measurement unit of seconds. The data with regards to the travel time are accumulated beginning from the starting point and way down to the slowing down point. From the slowing down point till the toll booth, the time is taken again. This value is to be subtracted with the value from the starting point to the slowing down point. At the same time, the travel time for vehicles to move from toll booth to the merging point will be recorded.

Besides, the total number of lanes which formed the roads are observed and analysed for the development of the environment in the dynamic traffic simulation tool.

The velocity of every vehicle is calculated as an average. A formula is used to obtain a single value of velocity of cars and trucks based on the observations data collected at the Penang Bridge.

Besides, a ratio of heavy vehicles over the light vehicles in the real traffic system is taken into account. For every 10 minute interval, the number of heavy vehicles and light vehicles are noted and the average value is calculated from the acquired data.

B. An Enhanced Algorithm based on the Fluid-Dynamic Algorithm and the Kinematic Wave Theory

Fluid-dynamic algorithm and the kinematic wave theory are evaluated to get an efficient way of reducing traffic congestion in terms of queue length and travel time. As a result, the fluid-dynamic algorithm and the kinematic wave theory are combined to produce an enhanced algorithm. The combination process consists of verifying and analyzing the similar variables.

In the fluid-dynamic algorithm in [7], the traffic variables are velocity, density and traffic flow. In the kinematic wave theory [9], the traffic variables are density, velocity and lane-changing effects. Therefore, a combination is performed by applying the density variable of the fluid-dynamic theory to the density variable of the kinematic wave theory. The step-by-step combination to obtain the enhanced algorithm is as follows:

1) From [7], the formula for a basic fluid-dynamic algorithm is as follows:

traffic flow = traffic density x *mean velocity*

2) The *mean velocity* from the above formula is brought over to the left which resulted in

traffic flow / mean velocity = traffic density

or

traffic density = traffic flow / mean velocity

3) From [10], the formula for the kinematic wave theory based on lane-changing is obtained.

$(p + V(1+e))=0$

where p represents the density, V is the velocity and e represents the value the lane-changing effect parameter where it is presented by the subtraction of two traffic queue length in two lanes where merging is concerned.

4) Therefore, the traffic density from the fluid-dynamic algorithm is applied to p in the kinematic wave theory as follows:

$(traffic\ flow\ /\ mean\ velocity) + V(1+e)=0$ (3)

The above formula (3) shows the enhanced algorithm based on the combination of the fluid-dynamic algorithm and the kinematic wave theory.

Based on the enhanced algorithm, the values are adjusted accordingly depending on the execution of the simulation tool. If the addition of the variable values does not add up to zero, adjustment will be made to suit the requirements of the algorithm.

V. SYSTEM ARCHITECTURE OF THE DYNAMIC TRAFFIC SIMULATION TOOL

The development process involves the use of JCreator LE as an IDE to develop the simulation tool. The simulation is compiled as an applet, which enables multi-platforms support.

The dynamic simulation tool is built from a base which is divided into two main components, the content development and the parameter controls as shown in Fig. 2. The content development is a task where objects such as vehicles, lanes and others are developed while the parameter controls include speed limit, generation of vehicles, vehicle ratio and time warp.

Graphical User Interface (GUI)								
Cars	Trucks	Lanes	N	Speed Limit	Vehicle Generation	Vehicle Ratio	Time Warp	N
Content Development				Parameter Controls				
Dynamic Traffic Simulation								

Fig. 2 Dynamic Traffic Simulation Framework

The development of cars, trucks and lanes are grouped as a category of objects in the content development module. *N* represents additional objects that can be further added in future. The development of the contents comprise of a graphical user interface (GUI) that enables interactivity and a better presentation of the simulation.

Parameter controls component is the ability to calibrate values when the simulation tool is running. This includes the adjustment of speed, generation of vehicles, vehicle ratio and

time warp. *N* represents additional parameter controls to be added in future. This feature allows a dynamic environment of a traffic system while the dynamic simulation tool is in the process of running.

A. The Implementation Flow

The implementation flow consists of four important phases as shown in Fig. 3. The process of developing the system consists of parameters, vehicles and road designs, algorithm integration and the verification of the dynamic simulation tool.
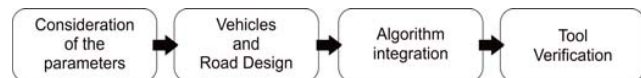

Fig. 3 Implementation Flow

The first stage which takes the parameters into consideration involves identifying valid parameters and appropriate parameter values to be used. Then, the vehicles and road design are constructed. Algorithm integration is a process of integrating the enhanced algorithm into the dynamic simulation tool for analysis. Final stage is the tool verification which confirms that the dynamic simulation tool is working in a correct and accurate manner.

There are several assumptions to be considered in the dynamic simulation tool such as limitations and assignments of the vehicles and roads. The following shows the assumptions used with regard to the implementation of the dynamic simulation tool:

1) Each vehicle is represented by rectangles. Red rectangles represent cars while black rectangles represent trucks. The length of trucks (5 x 2 pixels) is longer than the length of cars (3 x 2 pixels).

2) Road width for each vehicle to fit in a lane is constant along the way which means no two vehicles are allowed to be in the position side by side on the same lane.

3) Vehicle characteristics are integrated throughout the execution of the simulation tool.

4) Vehicles will find the shortest traffic queue to proceed to their destination. For example, if multiple lanes are used, vehicles will proceed to the lane with the shortest queue length.

5) Each car generated behaves the same in terms of acceleration, deceleration and velocity value. Similar characteristics apply for trucks.

Four parameters are taken into consideration that consists of the main inflow, heavy vehicle percentage, imposed speed limit and time warp factor. These parameters offer changes to the distinctiveness of the vehicles during the execution of the simulation tool.

B. The Components of Dynamic Traffic Simulation Tool

The components of a dynamic traffic simulation tool include the design of vehicles (cars and trucks) and the environment of the traffic flow.

The vehicle is implemented as a driver model which

includes several aspects such as the desired velocity, maximum acceleration, desired deceleration, jam distance and safe time headway. These values are set to represent a specific type of vehicle. In the dynamic traffic simulation, cars and trucks are used.

The desired velocity for a car is set to 120.0 because in the real world, the majority of cars would essentially be able to increase its velocity to a desired value of 120km/h on a highway. The maximum acceleration value is set to 0.3 m/s^2 and the maximum deceleration value is set to 3.0 m/s^2 because low values will improve the formation of the ongoing traffic flow. Jam distance represent the minimum gap of each vehicles, which is 2.0 meters to keep a certain distance between each vehicles in queues. The safe time headway for cars is set to 1.5 seconds, which is the desired value for cars when following other vehicles in a queue.

As for trucks, this type of vehicle normally moves slower than cars. The reason is trucks are characterized as heavy vehicles and more time is needed to accelerate from a lower speed to a higher speed compared to cars. Besides, the weight of trucks is definitely heavier compared to cars, which resulted in a more time-consuming manner for the increase of velocity and acceleration.

The desired velocity for trucks is set to 80.0 because in the real world, the majority of trucks would essentially be able to increase its velocity to a desired value of 80km/h on a highway. The maximum acceleration value is set to 0.3 m/s^2 and the maximum deceleration value is set to 4.0 m/s^2 because low values will improve the formation of the ongoing traffic flow. Jam distance represent the minimum gap of each vehicles, which is 2.0 meters to keep a certain distance between each vehicles in queues. The safe time headway for trucks is set to 1.7 seconds, which is the desired value for trucks when following other vehicles.

The environment of the traffic flow as represented in the dynamic simulation tool is shown in Fig. 4. Starting from the beginning where the vehicles arrive up to the merging point, a total of 470 pixels are used to represent a road length 320 meters. This means that a pixel represents about 0.68 meters in the real world traffic system.
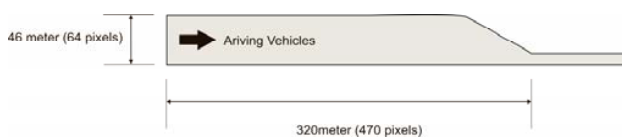

Fig. 4 The Representation of the Dynamic Simulation Tool Towards the Real World

C. Gathering Results by Observing Real Traffic at Penang Bridge

The results are gathered based on the outputs from the dynamic traffic simulation tool. Speed limit, traffic queue length, travel time for every vehicle and the total number of vehicles which passes through the merging point are gathered from the simulation tool.

The *speed limit* is obtained at every 2 minute interval to observe the changes towards the traffic activity. During this instance, speed limit is adjusted on the run prior to the integration of the existing algorithms and the enhanced algorithm. Initial speed limit is set to 80km/h and the value changes depending on the algorithms.

Traffic queue length is measured by calculating the pixels of the longest queue till the merging point as shown in Fig. 5. The traffic queue length is measured by taking the coordinate of the merging point till the back of the last vehicle of the longest traffic queue.
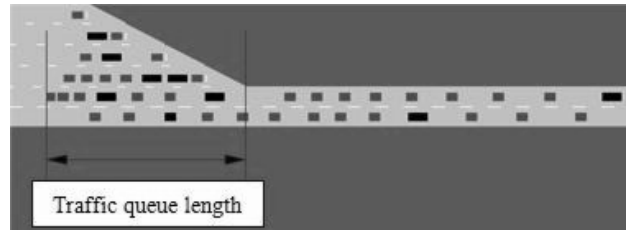

Fig. 5 Measurement of Traffic Queue Length

Travel time represents the time where the vehicles starts to enter a starting point until it reaches the merging point. The starting point for the travel time to be measured is the point where the vehicles are generated. Each vehicle will be integrated with variables to detect the travel time. The steps to obtain the travel time are as follows:

1) When a vehicle is generated, current time (*time1*) which includes hour, minutes and seconds is obtained.
2) When a vehicle reaches the coordinate of the merging point, current time(*time2*) is obtained.
3) The travel time is obtained as follows:

$$\text{Travel time} = time2 - time1 \tag{4}$$

The *total number of vehicles which passes through the merging point* is observed so that a comparison between the existing algorithms and the enhanced algorithm can be carried out. This output value is counted as soon as the head of the vehicle touches the merging point of the road. Every vehicle which manages to pass through the point will be counted as 1.

VI. RESULTS AND DISCUSSION

Real world as well as calculated values based on the fluid-dynamic algorithm, the kinematic wave theory and the enhanced algorithm are examined and discussed in this section.

The simulation results of the dynamic traffic simulation tool are evaluated based on the followings:

1) Simulation outputs based on the real observation at Penang Bridge.
2) Simulation outputs based on the fluid-dynamic algorithm.
3) Simulation outputs based on the kinematic wave theory.
4) Simulation outputs based on the enhanced algorithm based on the fluid dynamics algorithm and the kinematic wave theory.
5) Analysis of traffic congestion levels based on current and enhanced algorithms.

There are several assumptions when obtaining the simulation results. The assumptions are as follows:

1) The simulation starts from time 0 when there are totally no cars on the road. As soon as the simulation starts, vehicles are generated.
2) A time duration of 60 minutes is observed for each simulation run. The results are taken in every 2 minute interval to enable an average value to be obtained.
3) The calculation to obtain the parameter values to forecast the Penang Bridge traffic system is based on several observations.

Results are gathered in a 2 minute interval to enable observation of the average changes to the traffic activity generated by the dynamic traffic simulation tool.

A. Simulation Outputs based on the Real Observation at Penang Bridge

Traffic congestion for every test case is measured by adjusting different parameter values and obtaining the traffic queue length, travel time and total number of vehicles passing through the merging point at every 2 minute interval. As for the first simulation outputs based on the real observation at Penang Bridge, calculation on the main inflow, vehicle type percentage and speed limit from the observation is carried out and used as the parameter for the dynamic traffic simulation tool.

The simulation outputs based on the real system at Penang Bridge is observed in terms of speed limit and vehicle type to be applied into the dynamic traffic simulation tool. These values are calculated as an average value to be applied in the dynamic simulation tool for analysis. The calculation to obtain the data for the dynamic traffic simulation tool is shown in Table I.

TABLE I
CALCULATION OF PARAMETER VALUES BASED ON THE OBSERVATION AT PENANG BRIDGE

Parameters	Calculation[a]	Value[b]
Main Inflow	103 vehicles in 10 mins Therefore, 103 x 6 = 618 vehicles	618
Speed Limit	80km/h	80
Heavy Vehicle Percentage	(26/103)x100 : (77/103)x100 = 25.24 : 74.76 = 25:75	25%

[a] mins = minutes, km/h = kilometer per hour.
[b] % = percent.

B. Analysis of Traffic Congestion Levels based on the Current and Enhanced Algorithms

The analysis is carried out on four simulation outputs which consist of the number of vehicles passing through the merging point, traffic queue length, speed limit and travel time. These outputs are analyzed in detail based on charts and comparison of results.

From Table II, it is noticed that the fluid-dynamic algorithm is capable of providing the most vehicles to pass through the merging point which is 591 vehicles. The reason is that fluid-dynamic algorithm optimizes the traffic flow on the road. The kinematic wave theory is only capable of providing 498 vehicles to pass through the merging point due to the lane-changing effect which reduces the traffic queue length as its main objective. The enhanced algorithm produces a better result than the kinematic wave theory but slightly lower than the fluid-dynamic algorithm by 45 vehicles.

TABLE II
TOTAL VEHICLES BASED ON SIMULATION OUTPUTS

Algorithm	Total Vehicles
Observation At Penang Bridge	570 vehicles
Fluid-Dynamic Algorithm	591 vehicles
Kinematic Wave Theory	498 vehicles
Enhanced Algorithm	546 vehicles

As shown in Fig. 6, different algorithms exhibit different patterns of traffic flow. Based on the observation at Penang Bridge, the result shows the highest traffic queue length. The fluid dynamic algorithm provides less traffic congestion problems during long run compared to the observation at Penang Bridge. However, the enhanced algorithm provides better result compared to the fluid dynamic algorithm. Kinematic wave theory could manage traffic congestion better because the kinematic wave theory is based on lane-changing vehicular traffic. Therefore, the queue length is well managed when this algorithm is applied. As for the enhanced algorithm, the traffic queue length sits in between the fluid-dynamic algorithm and the kinematic wave theory.
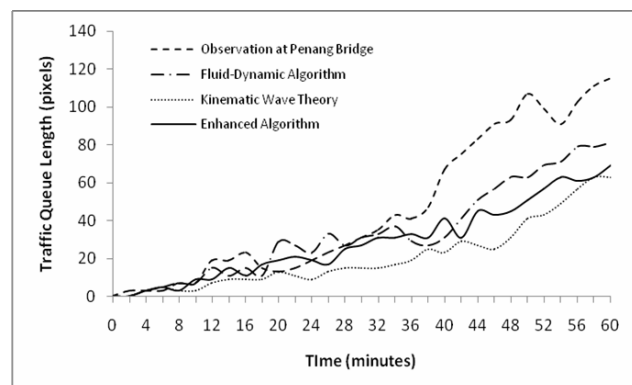

Fig. 6 Traffic Queue Length in 60 minutes for the Algorithms

Based on Fig. 7, it is found that the enhanced algorithm and the fluid-dynamic algorithm are capable of increasing the maximum speed. As for the kinematic wave theory, the maximum speed increases but it decreases during some certain time period. The observation at Penang Bridge is a constant speed at 80km/h as imposed by the management of Penang Bridge. This means that the maximum possible speed for vehicles to move is 80km/h. We can conclude that increasing the speed limit will result in better traffic flow and a lower traffic congestion problem.
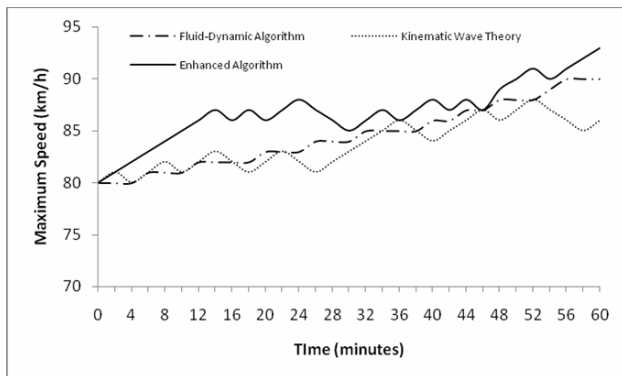

Fig. 7 Traffic Maximum Limit in 60 minutes for the Algorithms

The results in terms of travel time are divided into different time group of 10 seconds. This is to observe the total number of vehicles that takes the longest and shortest time to reach the merging points.

As observed from Fig. 8, the travel time generated from the simulation results clearly shows that the enhanced algorithm has the tendency of reducing travel time. In comparison with the kinematic wave theory and the fluid-dynamic algorithm, the number of vehicles with the travel time of 20.0-29.9 seconds and 30.0-39.9 seconds are higher. This may be due to the increase in speed limit in relation to the enhanced algorithm.
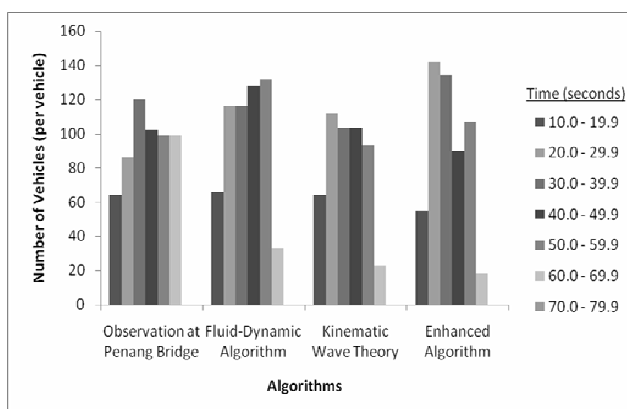

Fig. 8 Travel Time for Each Algorithms in 60 minutes

C. Discussion

The results from the dynamic traffic simulation tool are based on one iteration for every test case. The results are obtained every 2 minutes so that each vehicle's location can be identified and average changes in each result can be achieved.

Based on the analysis, the enhanced algorithm is able to forecast a better traffic output in terms of travel time, traffic queue length and the number of vehicles passing through the merging point compared to the fluid-dynamic algorithm and kinematic wave theory. The aim of this research is to reduce traffic congestion. Therefore, the disadvantage of this enhanced algorithm is that the total number of vehicles which manage to pass through the merging point is slightly lesser.

Based on Table II, the fluid-dynamic algorithm is good at optimizing the number of vehicles passing through the merging point but this leads to a higher level of traffic queue length on the road when it is left running for a longer time. As for the kinematic wave theory, traffic congestion is not as serious as compared to the fluid-dynamic algorithm with regard to traffic queue length. However, the number of vehicles which manage to pass through the merging point is lower for the kinematic wave theory.

In addition, we found out that 87km/h is a suitable speed limit for the Penang Bridge. This value is obtained as an average value from the enhanced algorithm as shown in Fig. 9.
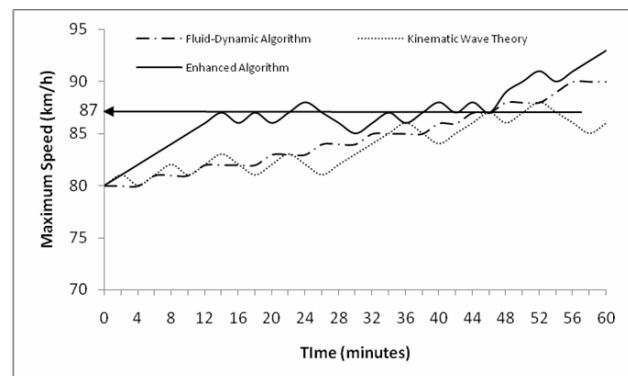

Fig. 9 Average Speed Limit based on the Enhanced Algorithm

The increase in speed limit would enable vehicles to move faster after the merging point which allows more vehicles to pass through. From the observation of the simulation results, if vehicles move faster after the merging point, vehicles behind the merging point do not have to reduce much in speed and this may improve in the traffic flow of vehicles.

VII. Conclusion

A dynamic traffic simulation model for traffic congestion has been developed for the purpose of forecasting traffic congestion level at a merging point. Furthermore, each vehicle's characteristics in terms of lane-changing and

vehicle's movement are used to synthesize the properties of a vehicle model in situation such as merges.

An enhanced algorithm has been provided to suit this special environment. Two main algorithms are studied which are the fluid-dynamic algorithm and the kinematic wave theory. A combination of these two algorithms makes up the proposed enhanced algorithm which provides better solution in reducing traffic congestion while maintaining the traffic flow.

Based on the results from the dynamic traffic simulation tool with the integration of the enhanced algorithm, 87km/h is suggested for the Penang Bridge traffic. By increasing the speed limit, vehicles manage to move faster after the merging point which allows more room for vehicles to pass through. From the analysis of the simulation results, if vehicles move faster after the merging point, vehicles before the merging point do not have to reduce much in speed. However, other considerations need to be carried out such as road obstacles and road conditions. These may also affect the vehicle lane-changing effect and the vehicle traffic flow on the road.

REFERENCES

[1] The Columbia Electronic Encyclopedia, 6th ed. Copyright © 2007, Columbia University Press. "Effects on Health and the Environment", Available: http://www.infoplease.com/ce6/sci/A0856526.html

[2] Richard Reese ,"Oil And The Future" [Online], Available: http://www.eco-action.org/dt/oilfut.html

[3] BBC News, "Heavy traffic bad for your heart", Available: http://news.bbc.co.uk/1/hi/health/3761012.stm. [Accessed 21st October, 2004].

[4] R. Shreckengost, "Dynamic Simulation Models: How Valid Are They", 'Book Dynamic Simulation Models: How Valid Are They', 1985.

[5] Edward Lieberman, A.K.R., "Traffic Simulation", 'Book Traffic Simulation' (edn.), pp. Chapter 10, 11-23.

[6] G. Bretti, R. Natalini, and B. Piccoli, "Numerical algorithms for simulations of a traffic model on road networks", J. Comput. Appl. Math., 2007, 210, (1-2), pp. 71-77

[7] Gabriella Bretti, "A Fluid-dynamic Model for Traffic Flow on a Road Network", Istituto per le Applicazioni del Calcolo, M. Picone (IAC), March 2005.

[8] M. J. Lighthill, G. B. Whitham: "On Kinematic Waves. I. Flood Movement in Long Rivers", Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, Vol. 229, No. 1178, pp. 281-316

[9] Wen-Long Jin, "A Kinematic Wave Theory of Lane-changing Vehicular Traffic", Institude id transportation Studies, University of California, February 2008.

[10] R. L. Bertini and M. J. Cassidy,"Some observed queue discharge features at a freeway bottleneck downstream of a merge." Transportation Research A, 36 (8), 2002, 683-697.

[11] Wikipedia, "Traffic Congestion", Available: http://en.wikipedia.org/wiki/Traffic_congestion. [Accessed March 28, 2008]

[12] U.S. Federal Highway Administration, "Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation." Sept. 2005.

[13] A. Carlos F. Daganzo, "Remarks on Traffic Flow Modelling and Its Applications" Proc. Traffic and Mobility Simulation, Economics and Environment Conference, 105-115, Aachen, Germany, Springer-Verlag, New York, N.Y., 1999.

[14] Jean-Baptiste Lesort, "Transportation and Traffic Theory", International Symposium on Transport & Traffic Theory, Lyon France, 1996.

[15] Martin Treiber, "Microsimulation of road traffic", Available: http://vwitme011.vkw.tu-dresden.de/~treiber/MicroApplet/. [Accessed 25th July 2005].