THE EFFECTIVENESS OF USING VARIABLE SPEED LIMIT ON THE PERFORMANCE OF AN INTERRUPTED SPEED FLOW

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ABSTRACT
The urban traffic congestion is getting worse with ever increasing urban population and vehicle ownership. The long queues at intersections and blockage of traffic on urban arterial roads become routine during the peak hours. Interrupted traffic flow through signalised intersections and arterial roads have badly been affected by these occurrences. Thus this paper examines the possibility of employing variable speed limit (VSL) for upstream traffic during the peak period to improve the traffic performance through signalised intersections as well as in urban arterials. The micro simulation software VISSIM was used to examine a hypothetical road network under VSL application. An expected traffic flow near capacity condition was simulated several times to see the effectiveness. Results show that for a reasonable period of time, the VSL application to the upstream traffic improve the traffic performance at immediate downstream intersections in terms of vehicle delay (16%), average queue length (18%) and average number of stops per vehicles (16%), while intersections located far from the VSL application has no or little effect. Similarly, the arterial performances have also been improved for a short period of time on the immediate downstream link in terms of density (13%), space mean speed (10%) and traffic flow (2%), the effective is negligible on the links located far. In addition a slight improvement was noticed to the total journey time on the immediate link.

KEY WORDS
Interrupted Traffic Flow, Variable Speed Limit, VISSIM, Traffic Simulation

1. Introduction
The traffic congestion usually occurs when traffic demand is close to or exceeds the available capacity of the network. This phenomenon frequently emerges in some city centres and motorways. Traffic demand is not constant but in a broad sense it would changes with season, day of the week, and the time of day. On the other hand, the capacity is not constant because it can be changed due to bad weather, work zones, traffic incidents and other events. Therefore the increasing demand or decreasing capacity of the any road system will lead to problems for both car users and society. The problem associated with the traffic congestion influence the quality of peoples’ life and environment, and effects can be noticeable from increased travel time, delay, fuel consumption, air and noise pollution and from deduced road safety. As a result the traffic congestion related problems are making monetary losses in many major cities all over the world[1].

In 1950’s the problem in traffic flow for the general public is seen to be easy to tackle by building new roads or lane widening of existing roads. Later, experts found that constructing new road infrastructure is sometime considered as an expensive way to mitigate traffic congestion for several reasons [3 & 4]. In conclusion, increased road capacity in congested zones may make the congestion condition worse.

Many theories and empirical evidence have been imposed to increase the capacity in congested areas [2]. To suppress traffic congestion in cities, many travel demand management strategies have been proposed by researchers, as an efficiency way to reduce the cost and time of its implementation. Variable speed limits (VSLs) are commonly used to regulate traffic flow speeds on motorway or freeways by using appropriate variable message signs (VMS). The original VSL was aimed to improve traffic safety, by increasing driver compliance that subsequently leads to decreasing the potential of end collisions [5].

Hegi, Schutter and Hellendoorn (2005) have carried out a study to investigate the influence of shock waves on a freeway when traffic flow conditions change suddenly. The study further explained that the ability of using dynamic speed limits to omit or reduce the impact of creating shock waves. Further is shows that coordination of the variable speed limit is necessary to prevent the occurrence of new shock waves or detrimental effects on the traffic flows in other locations [6]. The effect of variable speed limits was investigated on the performance of a German autobahn[7]. It was revealed a strong correlation between prior warning of traffic congestion and effective management of traffic load. Moreover, the
reduction in the speed limit to control the dense traffic resulted in the congested area being able to maintain flow at 30 – 40 km/h.

Papamichail et al (2008) studied the effect of both the variable speed limit and ramp metering on motorway traffic flow. It was concluded that the efficiency of traffic flow can be considerably enhanced with the application of VSL control, especially in combination with ramp metering [8]. In general, the speed limits change the shape of the flow-density and speed-flow diagrams when the speed limits are reduced. To evaluate this hypothesis, more than 800 km of motorway in Britain was equipped with variable message signs. Results indicated that curves were used to analyse the impact of speed limits are influenced the flow-occupancy relationships[9]. Speed limits when applied at under critical densities have the effect of decreasing the slope of flow-density diagram. The smaller imposed speed limit leads to larger decrease in the slope of flow – density curve.

The effectiveness of variable speed limit controls on highway work zone operations were studied using two online algorithms[10]. The aim of using the two online algorithms was firstly to reduce the traffic queue preceding the work zone area and secondly to maximize the entire throughput over the total work zone. The study showed that VSLs models can produce a potential increase in both work zone throughput and a reduction in entire vehicle delays[10 & 11].

Van Woensel (2008) indicated that the speed data is not readily available for many urban roads but flow data. This scenario a clear image of the risks associated with ignoring the effect of speed on the traffic conditions in the road network. That’s imply the necessity to investigate the impact of speed related impacts on the traffic behaviours[12]. According to Retting and Cheung (2008) assessed the effect of increasing car speeds on the productivity of trips (the flow multiply the density of the arterial links) on a motorway. Increasing speed leads to increase the number of passenger vehicles towards the destination area, so that this increment of speed creates unbalance condition in the flow rate which makes the inbound traffic volume much higher than the outbound traffic volume. This traffic situation leads to bottleneck condition that drastically decreases the road capacity and creates traffic congestion[13].

As can be seen from above the application of variable speed limits to freeways (expressway or motorways) and work zones can help to improve the traffic flow condition and subsequently reduces the occurrence of traffic congestions. However the application of VSL does not appear to have been used in urban road network to control the traffic congestion. Therefore this study was aimed to examine the possibility of employing variable speed limit (VSL) for upstream traffic during the peak period to improve the traffic performance through signalised intersections and urban arterials.

2. Hypothetical road network model

2.1 Model Calibration

A hypothetical signalised network has been proposed to investigate the VSL application using VISSIM micro software. Figure 1 depicts a simple network scheme of five signalised intersections with minimum right turn movements and minimum signal phases. This network is adopted to simplify understanding of VSL application. The eastbound direction (flow from west to east) comprises one lane and is considered as the major road flow, whereas the northbound direction (flow from south to north) also comprises one directional flows and are considered as the minor roads. The reason for choosing one lane is to avoid the complications arising from vehicle lane change movements. Only through movements on the major and minor roads have been modelled except the movement at the intersections C, D & E where right turn movements has been added to the minor roads. Only passenger cars have been considered for both major and minor roads. All the geometric characteristics are considered to represent an ideal condition. 3-km entry link (XA) and 1-km exit links (EY) are considered in order to accommodate all the simulated vehicles during the simulation period. A segment (link) length of 500 m was constructed between intersections A & B, as well as B & C. Similarly, a segment’s lengths of 250 m were constructed between intersections C & D and D & E.

Figure 1: A typical road network used in a model

The VISSIM model was also calibrated to generate a saturation flow rate equal to 1800 veh/lane/hour. Since the saturation flow value is a consequence of combining parameters relevant to the simulation, the relevant driving behaviour parameters such as average standstill distance (2.0m), and acceptable safety distances (2.8 m to 3.0 m) have changed to gain this specific saturation flow rate. The simulation has been run five times with a posted speed limit of 70 km/h for the entire network. The modelled has been used to simulate the flow for 11400s where the first 600s has been considered as a warm up period to fill the network with vehicles.

2.2 Input traffic parameters and control strategies

Two phase timing has been used to control the traffic flow for the five intersections. The percentage of green/red is equally allocated for intersections A, B, and C with a cycle length 120s including 78s effective green for major
road; 30s effective green for minor road; and 6s for amber plus all red per phase. Similarly for intersections at D and E, the green split of 58s and 50s are set for the major and minor road, respectively. The offsets between the signalized intersections have been set to reflect the signal coordination system for the main traffic stream.

The demand on the main and minor roads has been created to represent the ideal flow condition including a peak demand at 1800s as shown in Figure 2. Additional 10% of main traffic was added at the intersections C, D, & E to represent the right turn movements from the side-streets to the main road.

[Figure 2: Traffic demand used over simulation period]

The philosophy of VSL technique is to delay the traffic flow at upstream towards the congested area so that the queue blockage or spill back at the downstream traffic can be resolved. As explained earlier in the previous section 2.1, the capacity of the intersection D & E is less than the capacity of intersections at A, B & C. Therefore the intersection C could be considered as the most critical intersection. In addition to this traffic expectancy, a control strategy was built to run the model to improve the performance of downstream signalized intersection. The algorithm of an intelligent transport system employed while employing the variable speed limits are given in Figure 3.

During the VSL application speed control at the upstream flow (entry point) was reduced in order to control the traffic flow at the signalized intersections located in downstream flow direction. Speed has been reduced during the peak period 1800s to 4500s for this entry link to range of 35 km/hr. There is a trade-off between the speed limit that should be used and the travel time per vehicle along the network. The balance in choosing a threshold speed value with less travel time is necessary to identify an appropriate value of the speed limit. Analysis has been conducted for each 15 minutes to speed up the calculations and to reduce the arbitrary fluctuations.

3. Parameters used in evaluation

This section attempts to clarify the critical performance indicators that will be employed to determine the potential impact of using a VSL scenario. These parameters could be divided into two sections, signalised intersection indicators and traffic flow indicators on a road segment. The differences of the individual indicators were examined for both non-control and control conditions to evaluate the effectiveness of VSL application.

The general parameters that were used to discern the vitality of an intersection operation are the vehicle queue length, average delay per vehicle and the average number of stops per vehicle. The macroscopic traffic parameters in a network such as average density, average travel speed and the traffic flow rate were used for comparing the effectiveness of VSL applications from the simulated results.

4. Results

4.1 Signalised intersections

It was identified from the previous sections that the intersection C would be the critical one among these five hypostatical intersections in the model. Result from the evaluation of effectiveness on average queue length, delay and the expected stopping in a critical link are given below.

The average queue length in the Eastbound of the intersection C is given in Figure 4. As it can be seen, the queue length has dramatically changed after applying VSL control. Potential queue length reduction has occurred at the beginning of VSL application where the queue length has significantly dropped down from 346m to 111m, where a vehicle length is considered as 8 m with a standstill stopping distance of 2.0m. During the period from 4500s to 8100s the improvements in the queue length becomes very small. Also it was noted that the speed limit at the entry point during this period is not effective because the vehicle’s speed becomes less than the speed threshold. Secondly due to the side street right
turn movements to the main road at intersections C, D and E (adding 10% of main traffic at the intersections during this period) lads to increasing the queue length and ultimately reducing the effectiveness of the control strategy. As consequence, 18% of total queue length has been reduced during the peak hours by using VSL technique.

![Figure 4: Average queue length at EB of intersection C](image)

The results of average vehicle’s delay at eastbound of interstation C under non-control and control scenario is shown in Figure 5. The delay has been computed by summation of the average stopped delay and average delay time per vehicle. The results show considerable delay reduction per vehicle during the employing of VSL scenario at the beginning of VSL application. After some period of time, the differences in delay reduction between the two conditions have decreased. This could be related to the stochastic behaviour of traffic flow where the flow distribution at the start of application was arbitrary distribution and after employing the VSL application make the traffic trend to be more uniform distribution. The comparison between the two traffic conditions has revealed that initially the average delay per vehicle has improved by 16% through employing the VSL technique.

![Figure 5: Vehicle delay at EB of intersection C](image)

Similar to the vehicle delay, the number of stops per vehicles has also reduced at the east bound of the intersection C due to the same reasons as stated above, and the results are shown if Figure 6. Initially, about 16% improvements in reducing the number of stops per vehicle were achieved by utilizing the VSL application. Reducing the number of stops is a good indicator to the traffic flow quality at a signalised intersection that in turn maximises the flow features and enhances the delay time for traverse vehicles.

![Figure 6: Average number of stops per vehicle on EB of intersection C](image)

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The travel time has also been investigated when employing the VSL technique for this hypothetical network. Detectors have placed in the entry point and another at the exit point to calculate the travel time per vehicles with respect to the VSL application. The travel time calculation has achieved minimal improvements of about 6% if compared with other signalised indictors. These minimum improvements could be attributed to a control strategy that imposes reduction in speed of vehicles for a long time at the upstream flow to transfer the advantages of this control to the downstream flow. Therefore the travel time parameter has been minimally affected by using the VSL scenario because the significant improvements that have occurred at the downstream are influenced by the speed limit at the upstream flow. Consequently that tends to slight improvements in the travel time.

4.2 Traffic flow in segments

The previous section has identified the intersection C as critical one, therefore this section consider the segment B-C as critical link in this model. The traffic characteristics such as average density, average speed and the traffic flow for the congested link BC were compared in this section for both with and without control strategy.
(a) Changes in average density

The change in density along the link BC that joined to the most critical signalised intersection C under both traffic conditions (with/without control) is shown in Figure 7. As can be seen from this figure the new traffic control has reduced and modified the road density for this link from 1800s to 4500s. This means the impact of the VSL scenario, which is reasonably effective at the start of the application, eventually effectiveness would disappear. The reason is the threshold speed limit has held the traffic for a specific period of time but not for all the control period. Even though the control is only partially effective, the link density has improved by 13% and thereby traffic flow through similar links can be enhanced.

![Figure 7: Average density on link BC](image)

(b) Changes in average speed

The differences in average space mean speed along the link BC under the base traffic condition (no control) and VSL application (control) are given in Figure 8. About 10% of the speed on the downstream links has increased when the VSL application was employed at the upstream traffic flow. As can be seen from the figure the enhancement in traffic speed was intercept during the period 1800s to 4500s. The result could be attributed to the same reason was mentioned previously.

![Figure 8: average space mean speed along link BC](image)

(c) Changes in traffic flow in a link

After the application of VSL, the effectiveness of traffic flow through the critical link BC is shown in Figure 9. It can be noticed from the figure that the flow isn’t significantly affected by the control scenario. A slight increase of 2% has been achieved in the traffic flow for this. This result shows that the speed control contributes to organising the traffic flow distribution by making it more uniform rather than having a random flow rate. This in turn could enhance the signalised intersection operation rather than the operation of the arterial link.

![Figure 9: Traffic flow through link BC before and after VSL application](image)

5. Conclusion

This paper starts with the question of whether a VSL application of upstream traffic flows is able to control the interrupted traffic at downstream. The VISSIM software has been use to build an appropriate simulation model to examined the influences from VSL applications. This model used a simplified hypothetical network to represent the interrupted traffic flow through five intersections. Over a three hour simulation period was used to establish the real traffic flow conditions for each simulation, and results from the period between 1,800 seconds and 8100 second were taken for subsequent analyses. During the simulation the turning movements through three intersections were allowed, and a pre-timed signal control strategies were used with appropriate offsets to allow continues traffic flow from traffic coordination.

All simulations used dynamic speed control strategies over the peak period for the upstream link to achieve the research objectives. The analysis of effectiveness was carried out for a limit period (1800s–4500s) instead of being for the whole period.

The effectiveness of the variable speed limit applications were examined using various traffic parameters at the signalised intersection as well as along the road segment. The parameters such as average queue length, total delay per vehicle, and number of stops per vehicle were used as performance indicators at
intersections while the parameters such as traffic density, average traffic speed, total traffic flow were considered along the road segments.

Performance indicators used at the signalised intersections indicated improvements for shorter period of time from the change of speed limit sign. The improvements in average queue length (18% reduction), total delay per vehicle (16% reduction) and number of stops per vehicle (16% reduction) were notable at the intersections located closer to the VSL sign.

The main task of VSL is to achieve equity in traffic density and to distribute the traffic flow evenly over the road network. Significant improvements have been achieved in traffic network and arterial roads in terms of density and speed where about 13% reduction in traffic density and 10% escalating of average speed have been obtained. Trip journey has also been modified due to the enhancement which has occurred in the signalised characteristics. Traffic flow through the links has no or little effect, and account about 2%. This may be contributed due to the discharge limitations associated with the signalised intersections.

Results show that the application of VSL control would appear to only have potential for use during the peak period; otherwise adverse traffic performance may result. In addition, the trade-off between the duration of control speed limit, signalised characteristics and travel time needs to be taken into account. Increasing the duration of speed limit could lead to significant modification in downstream signalised performance but presents negative implications for the travel time. In order to improve the throughput of the signalised intersection, cycle length for the downstream intersections should also be increased concurrently with VSL application. Thus, this study should be considered as very early stage to investigate the VSL to an interrupted traffic flow condition and further investigations are recommended.

References