# Variable Speed Approach for Congestion Alleviation on Boshporus Bridge Crossing

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**Abstract:** The steadily increasing traffic jam on urban freeways have led to the use of several control mechanisms. Basically, these are formed by using ramp metering and variable speed control actions. In the variable speed control, the control mechanism is maintained by limiting the free flow speed of the vehicles between the specified freeway sections. The first and second Bosphorus Bridge Crossing are playing an important role in the city traffic of Istanbul. The first and second Bosphorus Bridge Crossing are very congested peak hours of day. The traffic jam may be reduced by variable speed control actions. To alleviate the jam due the lane drops in upstream flow on the first Bosphorus Bridge during the evening peak, the simulation based tests are applied. The result of these test shows that the delay per vehicle and the stops per vehicle on the first Bosphorus Bridge are decreased satisfactorily, but there is little bit change in the capacity usage.

**Keywords:** Freeway traffic control; variable speed control.

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## 1 Introduction

The capacity of the main arterial is limited by the minimum value of the flow (volume). Mainly in the two directional arterial, the lane drop is always seen the downstream flow due to the traffic jam or accidents. In this kind of case, if the upstream demand passes the downstream flow, the traffic jam spread out along the downstream. It is always faced with this kind of problems in the road network of Istanbul, as seen frequently on the Bosphorus Crossings.

This situation is shown in Figure1. In this figure, stream 1 represents the downstream flow, stream 2 represents the upstream flow. The lane drop starts at the $x_d$ point and the total lane increase to 4 after this part in the upstream flow, the total line drops to 2 on the downstream flow before this point.

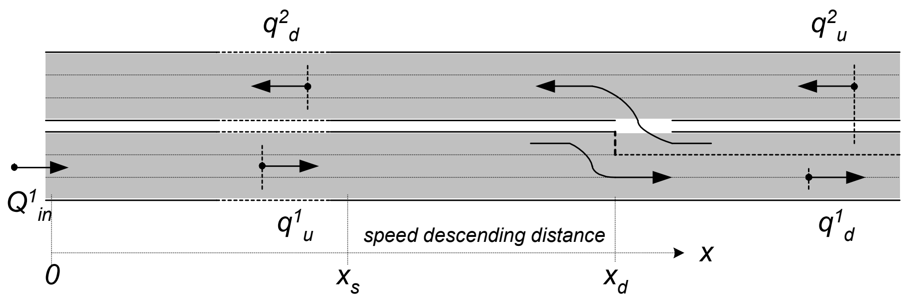


**Figure 1**. The lane drop schematic for freeway traffic system, with its up and downstream notations.

To control process for optimising the traffic volume of the main arterial in urban areas for inspection process, it must be necessary to determine the incident at real-time and to alleviate the traffic jam before spread out along the downstream. If the traffic jam is set up (all vehicles are stopped) the capacity usage of flow will be decreased minimum 5-10% although the traffic jam is totally removed. It is well known that the outflow ($q^1_d$ , $q^2_d$) in case of jam is lower by some 5-10% than the freeway capacity[1,2]. To reach the aim of optimising the traffic volume of the main arterial, it would be used different methods such as the variable speed control and ramp metering. In the variable speed control method, the main principle is to limit the free vehicle speed gradually before the traffic jam section. The speed limits and application distances are determined by different model approaches using basic flow equations.

The new model for using to determine the vehicle speed at variable speed control process via discrete time approaches is proposed in this study. Proposed model is developed to define the relation along the macroscopic flow characteristics *(qp*v),* macroscopic density (p), and average vehicle speed *(v)* at any road section using Greenshield model principles.

The effect of the lane drop on Bosphorus Bridge Crossing which causes the traffic jam in the evening peak is searched by using variable speed control process via simulation study. Before the lane drop (approximately 4,8 km. from the entering point of bridge) the free vehicle speed is limited as proposed in the model. Test results show that there can be clearly seen development in the average delay per vehicle and average number of stops. But there is very small satisfaction in the capacity usage. These result supports our expectation about the real-time variable speed control of traffic jam would be developed the performance of the road.

In the following sections; the basic considerations on freeway traffic flows have been studied first. Then, the proposed variable speed control model, and the simulation based test studies which are realised in VISSIM simulation environment have been introduced. Finally, effectiveness of the variable speed control have been evaluated, and it has been discussed how it can be increased.

## 2 Basic Considerations on Freeway Traffic Flows

Traffic flow process on a freeway is characterised by three basic macroscopic parameters: flow (volume), $q$; density, $\rho$; and velocity, $v$. Flow is defined as the number of vehicles passing a specific point in a lane basis and in an hourly rate (veh/h/lane). Density is defined as the number of vehicles occupying per km. of the way in a lane basis (veh/km/lane). Speed is defined as the average rate of motion. It is expressed in km. per hour (km/h). All of these macroscopic flow parameters are the function of the time and the space, $q(x,t)$, $\rho(x,t)$, $v(x,t)$), as shown in Figure 2.

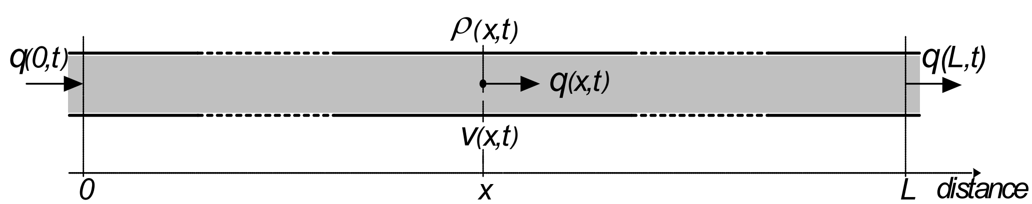


**Figure 2.** The freeway traffic system with its parameters.

According to these definitions, the basic flow model is expressed as following [3]:

$$q(x,t) = \rho(x,t) * v(x,t) \qquad (1)$$

There are various static models which have been used to represent the relationship between the velocity and density parameters. The most simple one of these proposes a linear relationship between these two parameters [4]:

$$v = v_f \left(1 - \rho / \rho_{jam}\right) \qquad (2)$$

where $v_f$ is the free flow speed, $\rho_{jam}$ is the jam density. By substituting (2) to (1), we can easily show that relations $q=f(\rho)$ has the parabolic characteristic.

$$q = v_f \left(\rho - \rho^2 / \rho_{jam}\right) \qquad (3)$$

So, the static relationship between the macroscopic flow and the macroscopic density, $q=f(\rho)$, can be shown as in Figure-3. In this figure $q^{max}{}_u$ and $q^{max}{}_d$ represent the lane based flow capacity of the upstream and the downstream, respectively. Here;

$$q_u^{\max} = Q_u^{\max} / \tag{4}$$

$$q_d^{\max} = Q_d^{\max} / \tag{5}$$

where $Q^{max}{}_u$ and $Q^{max}{}_d$ are the flow capacity of the upstream and the downstream, respectively; $\Delta_u$ and $\Delta_d$ are the number of lanes of the upstream and the downstream, respectively.

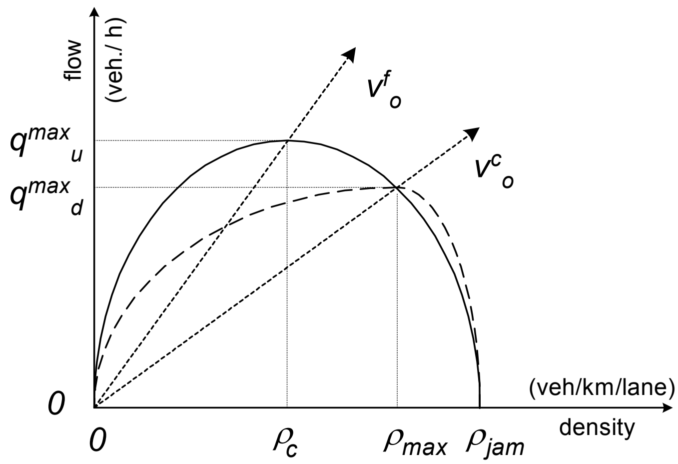


**Figure 3.** The static relationship between the macroscopic flow parameters, $q=f(\rho)$.

From these relationship it can be clearly stated that, each freeway flow has its optimum average speed, $v_o$ , which corresponds a critical value of its density, $\rho_c$, at any time and any position of the way. The flow which corresponds to these speed and density has its maximum value, $q^{max}$, which is equal to the flow capacity, $q^{cap}=q^{max}$. When the density of the traffic flow exceeds the critical density, the volume and average speed of the flow begin to decrease, so that, at the jam density, $\rho=\rho_{jam}$, both flow and average speed become zero. So, the flow-density relationship, $q=f(\rho)$, is referred to as the fundamental diagram of traffic flow, for designing a control process [5,6].

If the density of the traffic flow is greater or smaller than this critical value; the flow can not achieve the maximum value, so, the capacity usage and the transportation performance of the freeway become worst. However, the importance of performance decreasing are occurred when density exceeds the critical density, $\rho>\rho_c$. Because of that, control action must be taken in consideration for these conditions. Due to this, the control aim is to ensure that:

$$\begin{aligned} &\rho(x,t) < \rho_{\max} \\ &\rho_c \le \rho_{\max} < \rho_{jam} \ , \forall\ x \in L\ \ t \in \ ^{+} \end{aligned} \tag{6}$$

where $\rho_{max}$ is a maximum density between the $\rho_c$ and $\rho_{jam}$. So, the control aim can be achieved by having a critical density value close to the maximum flow density as the target density of the controller.

## 3 Variable Speed Control Model

In this section, variable speed control supports this aim by limiting the free flow speed of the vehicles between the specified freeway sections, so that:

$$q^{cap} = q^{max} = v_o^{'} \cdot \rho_{max} = v_f^{'} \left(\rho_{max} - \rho_{max}^2 / \rho_{jam}\right) \qquad (7)$$

where $v'_f$ is the necessary vehicle speed for variable speed control; $\rho_{max}$ is a maximum density at $v'_f$ as found in equation (6); $v^f_o$ is optimal flow speed extracted from equation (2) without any constrains; $v^c_o$ is optimal flow speed extracted from equation (2) with constrains.

The free vehicle speed limitation $v'_f$, the maximum flow density could be found using $q^{max}{}_d$ at the lane dropped situation and $\rho_{max}$ related with equation 6 as shown in equation 8.

$$v_f^{'} = q_d^{max} / \left(\rho_{max} - \rho_{max}^2 / \rho_{jam}\right) \qquad (8)$$

where maximum density $\rho_{max}$ is found out from practical measurements; the stopping density $\rho_{jam}$ is determined from vehicle composition and road physical condition.

The downstream capacity $q^{max}{}_d$ is calculated from above equation using the normal road conditions:

$$q_d^{max} = q_u^{max} \cdot \quad / \qquad (9)$$

In addition to this, the free vehicle speed is calculated from equation 8, the upstream flow density pass over the $\rho_{max}$ depending on the demand. The upstream flow density must be measured in real-time condition to get development in the performance n this situation and the speed limit must be changed using equation 8. In this study, all simulation based test are principally real-time control process. The application of this process shows that the significant developments gained from the traffic performance point of view.

## 4 Simulation based Test Studies

Simulation based test studies have been realised in VISSIM simulation environment to compare the effectiveness of the variable speed control, with respect to the uncontrolled conditions. Here, the simulation package VISSIM consist of two different programs: traffic simulator and signal state generator. The traffic simulator is a microscopic traffic simulation program based on Weidmann statistical model including the car following and lane change logic. The result of the simulation on-line is the animation of traffic operations and off-line the generation of output files gathering statistical data such as travel time and delay [7].

2 different tests have been completed under the same traffic conditions: Test1, for uncontrolled case; Test2, for variable speed control case. For this aim, all the hardware elements of the freeway traffic system which represent the first Bosphorus bridge crossing on the direction of Asia to Europe, including 7.53 km length of main-link between the E5 freeway Kozyatağı section and Bosphorus bridge entrance section has been configured in VISSIM simulation environment. Lane drop has been applied at 7.47 km position of the way

which is near the bridge entrance, through the simulations. The lane drop section of the link in VISSIM simulation screen has been shown in Figure 4. The variable speed adaptation point has been chosen at 2.73 km position of the link; thus the speed descending distance has been chosen as 4.8 km between the 7.53 and 2.73 km of the main-link positions, as indicated in Table 1.

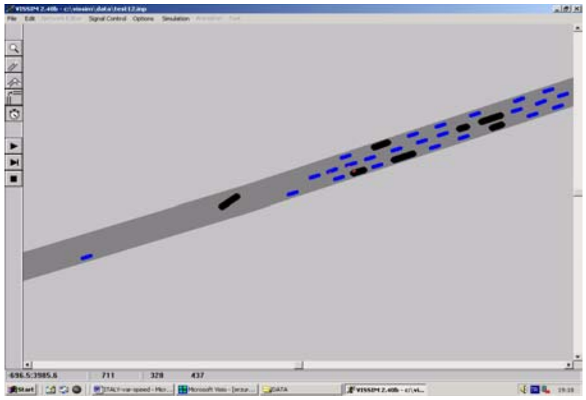

**Figure 4.** The lane drop section of the link in VISSIM simulation screen.

Assignments for the tests as follows: the number of lanes, $\Delta_u$ =3 for upstream side, $\Delta_d$ =2 for downstream side; the free flow speed distribution are 80-100 km/h for cars and heavy good vehicles (HGV), that is $v_f$ = 100 km/h; vehicle length distributions are between -10 m.; HGV ratio is 0.20. Upstream capacity $Q^{max}_u$ = 4200 veh/h., $\rho_c$=60, and $\rho_{jam}$=130 veh/km/lane for all the main-link segments.

The traffic scenario and related control assignments have been chosen as shown in Table 1, for the 7200 sec (2 hours) of simulation based tests.

| simulation time (seconds) | main-link input $Q_{in}$ (veh./h) | free-flow speed $v_f'$ (km/h) | speed desc. dist. $x_d$ - $x_s$ (km) | perf. meas. dist. $x_{m2}$ - $x_{m1}$ (km) |
|---|---|---|---|---|
| 0 - 3600 | 2500 | 100 | no speed desc. | 7.16 - 3.93 = 3.26 |
| 3601 - 7200 | 5000 | 35 | 7.53 - 2.73 = 4.8 | 7.16 - 3.9 = 3.26 |

**Table 1.** The traffic scenario chosen for the tests

It would be no speed limitation for 2 hours test in the Test1. So, the traffic performance data is gathered by the simulation of uncontrolled condition along the 3,6 km. length. There would be speed limitation during first hour simulation at 100 km/h in Test2, but the speed limit is chosen as 35 km/h as explained equation 6 during second hour.

## 5 Results

The performance data have been evaluated as the total delay along the 3.26 km. of main-link segment between the 3.9-7.16 km. positions of the link. In addition to the total delay, the total number of stops and capacity usage of the same main-link segment have also been evaluated by using VISSIM data gathered through the simulations. For this length, the results obtained about the total delay, the number of stops and capacity usage through the 2 hours of simulations have been shown in Figure 5, Figure 6 and Figure 7, respectively.

According to the obtained results, average delays are 524.4, 251.5 sec./veh for Test1 and Test2, respectively. Also, average number of stops are 14.12, 9.57 stops/veh for Test1 and Test2, respectively. Total vehicle numbers passed along the 3.26 km of performance test length of the link are 4137 for Test1 and 4027 for Test2.
Due to these results, the average delay is decreased %52 by the variable speed control, with respect to uncontrolled conditions. The average number of stops is decreased %32.2 by the variable speed control, with respect to uncontrolled conditions. Also, the average capacity usage has decreased %2.66 by the variable speed control, with respect to uncontrolled conditions.

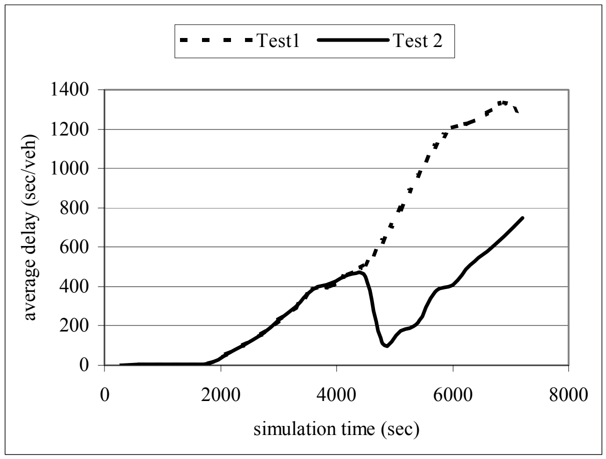


**Figure 5.** Test results for the average delay of 3.26 km of main-link performance test length.

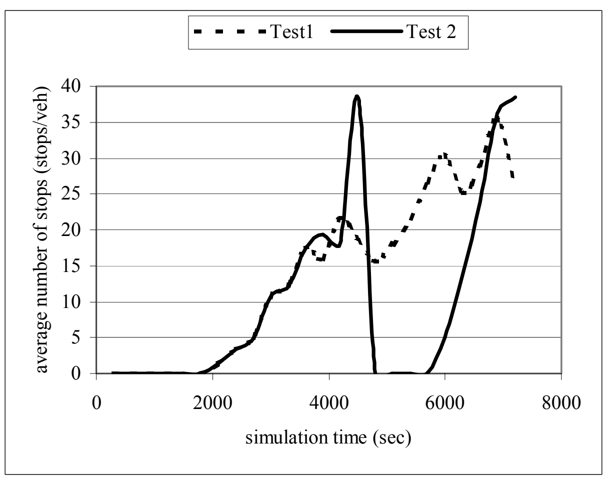


**Figure 6.** Test results for the number of stops of 3.26 km of main-link performance test length.

Test results shows that the average delay per vehicle and average number of stops decreased by satisfied manner even if the capacity usage is decreased very small. Consequently, the traffic jam due to the lane drop at the evening peak on the downstream to prevent the increasing demand on the upstream flow may be alleviated by variable speed control method using simulation based tests.

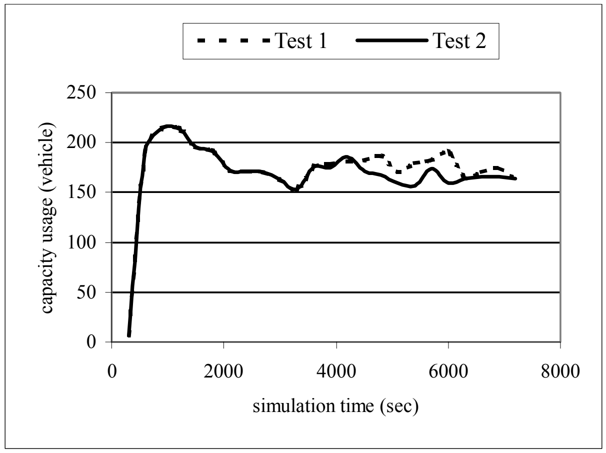


**Figure 7.** Test results for the capacity usage of 3.26 km of main-link length.

## 6 Conclusion

Test results reflects non real-time test and real-time test with speed limitation for 2 hours test condition after the test process for controlling of the main arterial by the variable speed method. When it is looked the main aim of this study it is easy to say that the result is hopeful from the traffic performance point of view under these test condition. If the flow density ($\rho_{max}$) is defined from the real condition of the main arterial and the speed limit can be changed often due to the traffic jam condition, it is clear that it would be reached better performance. Finally, when the proposed method is applied with real-time traffic flow density measurements, the traffic performance result will be developed as expected.

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