Advances in Civil Engineering 2004

6th International Conference

Boğazici University · October 6-8 · Istanbul, TURKEY

III

Editors
Turan Özturan · Cem Yalçın · Yavuz Tokmak · Cenk Güngör

ADVISORY COMMITTEE

Gülay Altay (Bogazici University)
Fuat Erbatur (Middle East Technical University)
Sumru Pala (Istanbul Technical University)
Tuğrul Tankut (TUBİTAK)
Cengiz Toklu (Cyprus International University)

SCIENTIFIC COMMITTEE

Darçın Akın (GYTE)
Atilla Akkoyunlu (BU)
Süheyl Akman (ITU)
Gülay Altay (BU)
Atilla Ansal (BU)
Ali Rana Atılgan (BU)
Cem Avcı (BU)
Nuray Aydınoğlu (BU)
Ayşe Edinçliler Baykal (BU)
Gökhan Baykal (BU)
Mehmet Berilgen (YTU)
Osman Börekçi (BU)
Feyza Çinicioğlu (IU)
Erdal Çokça (METU)
Ayşen Ergin (METU)
Gökmen Ergün (BU)
Emin Güçbilmez (EMU)
Erol Güler (BU)
Faruk Karadoğan (ITU)
Cengiz Karakoç (BU)
Hilmi Luş (BU)
Abdulrezak Mohamed (EMU)
Mehmet Omurtag (ITU)
Emre Otay (BU)
Şevket Özden (KOU)
Turan Özturan (BU)
Mehmet Ali Taşdemir (ITU)
Semih Tezcan (BU)
Cengiz Toklu (CIU)
Mustafa Tokyay (METU)
Mehmet Utku (METU)
Tanvir Wasti (METU)
Cem Yalçın (BU)
Özal Yüzügüllü (BU)

LOCAL ORGANISING COMMITTEE

Turan Özturan (Chair)
Cem Yalçın (Vice Chair)
Gökhan Baykal
Cem Avcı
Cengiz Karakoç
Cenk Güngör
Yavuz Tokmak
Esra Mete Güneyisi

SPONSORS

Congress Official Sponsors:

S.S. İstanbul Anadolu Yakası Kumcular Üretim ve Pazarlama Kooperatifi
Maurer Söhne
Türkiye Hazır Beton Birliği

Main Sponsors:

Arcelor
Sika Yapım Kimyasalları A.Ş.
Tekfen Emlak Geliştirme Grubu
Tekfen İnşaat ve Tesisat A.Ş.- Türkiye Çimento Müstahsilleri Birliği

Other Sponsors:

Alacalı İnşaat Sanayi ve Ticaret A.Ş.
Altınok Müşavir Mühendislik Taahhüt Sanayi ve Tic. Ltd. Şti.
Doğuş Yapı Sanayi A.Ş.
Gerb Vibration Control Systems
Göçay İnşaat Taahhüt ve Tic. A.Ş.
TMMOB İnşaat Mühendisleri Odası İstanbul Şubesi

and

Boğaziçi University

Sixth International Congress on Advances in Civil Engineering, 6-8 October 2004
Boğaziçi University, Istanbul, Turkey

Fuzzy Reconstruction of Traffic Flow Data for Qualified VMS Information

A. Akbaş, V. Topuz, M. Tektaş
University of Marmara, Istanbul,Turkey

M. Ergün
Istanbul Technical University of Istanbul, Istanbul, Turkey

Abstract

Contemporary communication and information technology have led to the use of the new traffic control approaches for the alleviation of traffic congestions on urban freeways. Such an approach being used in freeway traffic control systems is maintained by using variable message signs (VMS). In this approach, traffic information are delivered as text messages, which allow drivers the freedom to decide for themselves on their choice of route, as well as their speed limiting requirements. Because the quality of information content is a decisive factor in driver satisfaction, the content of VMS messages should be determined carefully, so that, it must reflect the real traffic situations with time and space related to traffic flow. This situation has a special importance for the efficiency of the traffic control actions in Istanbul urban freeways connected with the two Bosporus bridge crossings, on which some VMS panels have been installed in recent years. In this study, a fuzzy reconstruction method has been suggested for obtaining the qualified VMS information about the space related real time speed limits. VISSIM simulations have shown that the time saving by this way is satisfied.

Keywords: Freeway traffic control, fuzzy logic, variable message sign, VMS/DMS

Introduction

To determine the traffic jams on main arterials using real time observations and prevent the jams spread out from the starting point to backward is the main aim of the traffic control applications in metropolitan cities. So, it is well known that the outflow in case of congestion is lower by some 5-10% than the freeway capacity (Papageorgiou, 2000). Because of this fact, the steadily increasing traffic congestions on urban freeways have led to the use of several traffic control mechanisms. Basically, these are formed by using ramp metering and variable speed control actions.

In the variable speed control action, the control mechanism is maintained by limiting the free flow speed of the vehicles between specified freeway sections. This method could help to minimise the effect of traffic jam that we face on the first and second Bosporus bridge crossings. Likewise the claim about this method is supported by another study using simulation-based tests. In the study, first of all, the variation of speed along the main arterial are measured with the real time techniques and then, the traffic flow information is changed according to this information. Finally, expectations on the improvement of the traffic flow performances on the main arterial are increased (Akbaş, 2003). But in this study, the fuzzy control system is proposed for the variable speed control on the main arterials of Istanbul's highway network.

Variable message signs (VMS) have been installed along the collector roads of the first and second Bosporus Bridges to warn drivers about any incident or traffic jam since the year of 2000. Today, these signs are displaying limited information such as whether the traffic jam is intensive or not, bridge is open or not, and there is an accident or not. The better utilization of the VMS system would be realised by using variable speed information to control the traffic jam. These signs will support driver's decisions by advising them to change their course and the following signs will be giving information about their speed limit, finally, these will result in the development of the traffic performance of the road section. The proposed system is tested by a simulation model.

To fix the expected speed limit for congestion analysis, the information about the average velocity of traffic flow near the VMS must be collected with real time measurements. With this objective, the microscopic traffic flow information collected from the near side of each VMS panel is evaluated in different time intervals. The velocity information collected from all VMS panels transferred to the main traffic control centre and these raw data will be used as input to fuzzy controller. Fuzzy controller processes data and reconstructs the desired vehicle speed limits as traffic flow data and finally sends the information to the related VMS panels.

The average velocity of traffic flow near the each VMS panels is fixed by the occupancy time and flows collected from the detectors using an algorithm developed in this study. The time interval for the measurement of the microscopic flow parameter is chosen as 10 minutes as generally used.

In the following, first the basic properties of main traffic revised briefly. Then, the information related to raw speed limits which is calculated using the microscopic traffic flow parameters and fuzzy control method is introduced. At the end of the study, the improvements on the main arterial (one-way freeway) segmented into four sections (four VMS panels), provided by proposed fuzzy control method are tested in the VISSIM simulation environment.

Basic Considerations on Freeway Traffic Flows

Traffic flow process on a freeway is characterized by three basic macroscopic parameters: flow (volume), q, density, ρ, 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 kilometre of the way in a lane basis (veh/km/lane). Velocity is defined as the average rate of motion. It is expressed in kilometres per hour (km/h). As shown in Figure 1, all of the flow parameters are the function of time and space, $q(x,t)$, $\rho(x,t)$, $v(x,t)$.

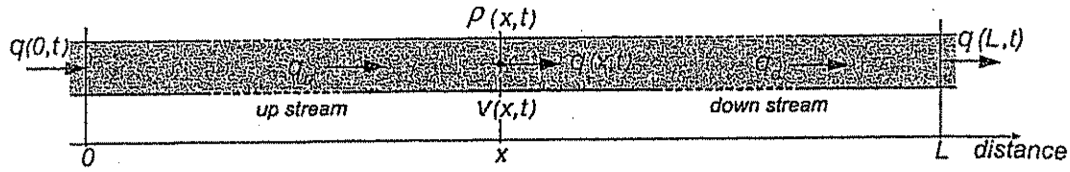

Figure 1. Macroscopic flow parameters of the freeway traffic flow

The basic relation between the macroscopic flow parameters is expressed by the following model (May, 1990):

$$q(x,t) = \rho(x,t) * v(x,t) \tag{1}$$

Besides this basic relation, the static relationship between the velocity and density parameters can be expressed, due to the Greenshield model, as following,

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

Here v_f is the free flow speed, ρ_{jam} is the jam density (Greenshield, 1934). By substituting (2) to (1), it can be easily shown that relations $q=f(\rho)$ is a parabolic function,

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

So, the static relationship between the macroscopic flow and density parameters, $q=f(\rho)$, can be illustrated as in Figure 2. This relationship is referred to as the fundamental diagram of traffic flow, for designing a control process (Zhang, 1996).

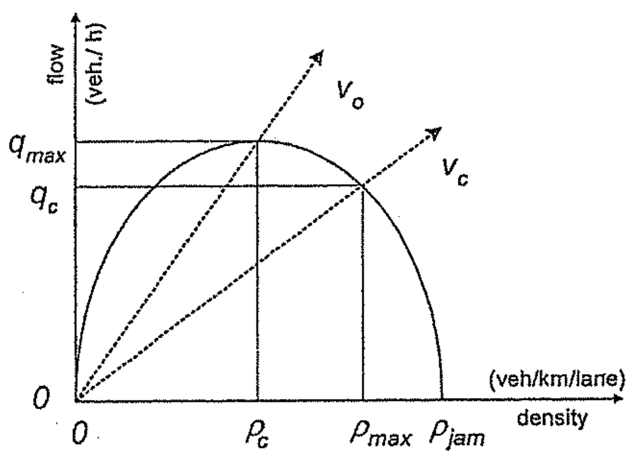

Figure 2. Static relationship between the macroscopic flow parameters, $q=f(\rho)$.

From these relationships it can be clearly stated that, each freeway flow has its optimum average velocity, v_o, which corresponds to a critical value of its density, ρ_c, at any time and position along the way. The flow which corresponds to these velocity and density has its maximum value, q_{max}, which is equal to the flow capacity, $q_{cap}=q_{max}$. Similarly, each freeway flow has its critical average velocity, v_c, which corresponds to the maximum value of its density, ρ_{max}. When density exceeds the critical density, or when the average velocity falls behind the optimum average velocity, flow begin to decrease, so that, at the jam density, $\rho=\rho_{jam}$, both flow and average velocity become zero.

If the average velocity becomes smaller than its critical value, $v<v_c$, then traffic congestion begins to occur. So, the capacity usage and the performance of the freeway become worst. Because of that, a control action must be taken into consideration for these conditions. According to this fact, the control aim is to ensure that:

$$v(x,t) > v_c \qquad , \forall x \in L, t \in R^+ \tag{4}$$

So, the control aim can be achieved by having a critical average velocity value, v_c, below the optimal velocity, v_o , which is close to the maximum flow density, as the target average velocity.

Measuring the Average Velocity of Traffic Flow

Consider a one-way freeway traffic system as shown in Figure 3. Each VMS in the system is denoted by a double-dotted line, VMS_i ($1 \le i \le N$). Let Δ_i denotes the number of lanes, so that, each has its own traffic detector, D_{ij} ($1 \le j \le \Delta_i$), in vicinity of the signal VMS_i. Then, the lane based densities within the time period $[kT, (k+1)T]$ are calculated as follows,

$$\rho_{ij}(k) = \rho_{jam} \frac{1}{T} \int_{t=kT}^{(k+1)T} o_{ij}(t)\, dt \qquad , \qquad 1 \le j \le \Delta_i \tag{5}$$

Where, T is sampling period in terms of seconds, k denotes discrete time index, i denotes the space index corresponding to VMS number, and j is the number of lane, ρ_{ij} represents the lane based density measured at time period $[kT, (k+1)T]$, o_{ij} is the corresponding occupancy parameter that is a measurable logical function of the time, which has a value of 1 or 0 at any time, depending on the occupation of the traffic detector by any vehicle, and ρ_{jam} denotes the jam density, which is constant.

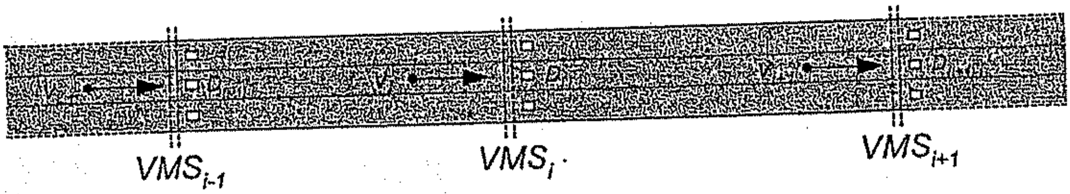

Figure 3. One-way freeway traffic system with VMS panels.

The lane based average macroscopic density of traffic flow near the VMS_i is calculated as follows,

$$\rho_i(k) = \frac{\sum_{j=1}^{\Delta_i} \rho_{ij}(k)}{\Delta_i} \tag{6}$$

Let n_{ij} denotes the number of vehicles passing through the detector D_{ij} within the time period $[kT, (k+1)T]$ in terms of seconds. Then, the lane based macroscopic flow is calculated as follows,

$$q_{ij}(k) = 3600\frac{n_{ij}(k)}{T} \quad , \quad 1 \le j \le \Delta_i \tag{7}$$

The lane based average macroscopic flow near the VMS_i is calculated as following;

$$q_i(k) = \frac{\sum_{j=1}^{\Delta_i} q_{ij}(k)}{\Delta_i} \tag{8}$$

Substituting the equations (6) and (8) to equation (1), the average macroscopic velocity of traffic flow realized within the time period $[kT, (k+1)T]$ is calculated as following,

$$v_i(k) = \frac{q_i(k)}{\rho_i(k)} = \frac{\sum_{j=1}^{\Delta_i} q_{ij}(k)}{\sum_{j=1}^{\Delta_i} \rho_{ij}(k)} \quad , \quad 1 \le j \le \Delta_i \tag{9}$$

Fuzzy Reconstruction of Vehicle Speed Limits

The input data for fuzzy controller is the raw average velocity data gathered from all VMS panels along the road segment at the end of each $[kT, (k+1)T]$ separate time period. Fuzzy controller process and evaluate these data and send the new speed limits to the VMS panels to display at the following time period. The block diagram of the fuzzy controller is shown in Figure 4 for the main arterial road system with limited four VMS panel number.

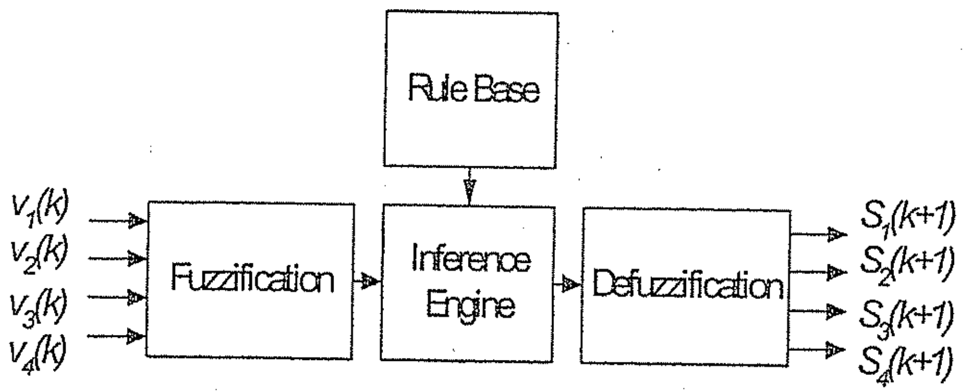

Figure 4. The block diagram of the fuzzy controller.

In this figure, $v_1(k)$, $v_2(k)$, $v_3(k)$ and $v_4(k)$ represent the realized average velocity of traffic flow at time index k, near the corresponding VMS panel, $s_1(k+1)$, $s_2(k+1)$, $s_3(k+1)$ and $s_4(k+1)$, represent the reconstructed speed limits for the next time index.

The inference engine of the fuzzy controller is formed by Mamdani method and for the defuzzification, Centroid method is used. In the fuzzy controller, four input variable

$v_1(k)$, $v_2(k)$, $v_3(k)$, $v_4(k)$ are called as V1, V2, V3, V4 respectively. For the each variable, two fuzzy sets [called as Slow (V1S, V2S, V3S, V4S) and Fast (V1F, V2F, V3F, V4F)] are defined as shown in Figure 5. The speed intervals of the all variables are between 0 and 110 km/h. The input membership function shape is chosen as S shape with the values between 0 and 1.

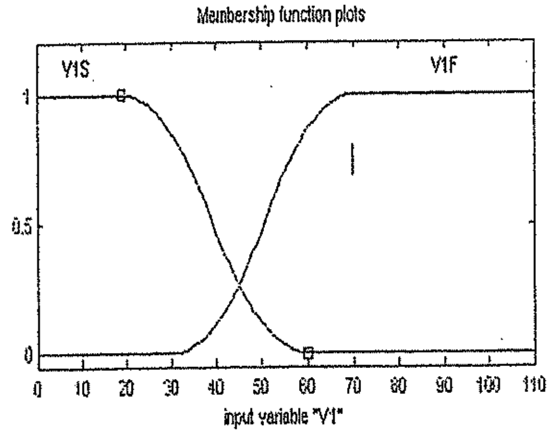

Figure 5. Fuzzy controller input membership functions for V1.

The four output variables, $s_1(k+1)$, $s_2(k+1)$, $s_3(k+1)$ and $s_4(k+1)$, are called S1, S2, S3, S4. For the each variable, two fuzzy sets [called as Low (S1L, S2L, S3L, S4L) and High (S1H, S2H, S3H, S4H)] are defined as shown in Figure 6. The speed intervals of the all variables are between 0 and 90 km/h. The input membership function shape is chosen as S shape with the values between 0 and 1.

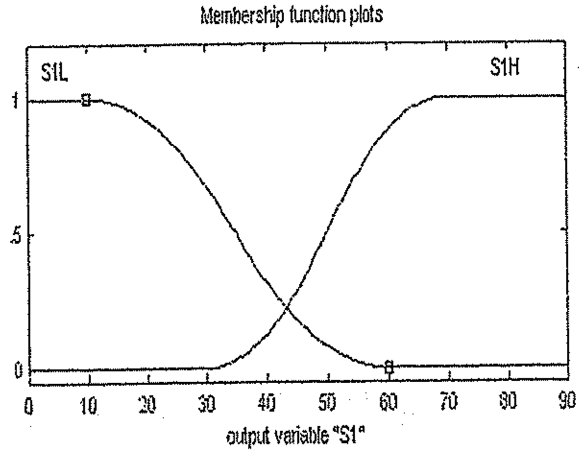

Figure 6. Fuzzy controller output membership functions for S1.

Fuzzy controller rules are created by using Mamdani method and 16 rule bases are shown in Table 1.

Table 1. Fuzzy controller rule base

Rule	input variable				output variable			
	V1	V2	V3	V4	S1	S2	S3	S4
1	V1F	V2F	V3F	V4F	S1H	S2H	S3H	S4H
2	V1F	V2F	V3F	V4S	S1H	S2L	S3L	S4L
3	V1F	V2F	V3S	V4F	S1L	S2L	S3L	S4H
4	V1F	V2F	V3S	V4S	S1L	S2L	S3L	S4L
5	V1F	V2S	V3F	V4F	S1L	S2L	S3H	S4H
6	V1F	V2S	V3F	V4S	S1L	S2L	S3L	S4L
7	V1F	V2S	V3S	V4F	S1L	S2L	S3L	S4H
8	V1F	V2S	V3S	V4S	S1L	S2L	S3L	S4L
9	V1S	V2F	V3F	V4F	S1L	S2H	S3H	S4H
10	V1S	V2F	V3F	V4S	S1L	S2L	S3L	S4L
11	V1S	V2F	V3S	V4F	S1L	S2L	S3L	S4H
12	V1S	V2F	V3S	V4S	S1L	S2L	S3L	S4L
13	V1S	V2S	V3F	V4F	S1L	S2L	S3H	S4H
14	V1S	V2S	V3F	V4S	S1L	S2L	S3L	S4L
15	V1S	V2S	V3S	V4F	S1L	S2L	S3L	S4H
16	V1S	V2S	V3S	V4S	S1L	S2L	S3L	S4L

Simulation Based Test Studies

Simulation based test studies have been realized in the VISSIM simulation environment to compare the effectiveness of the fuzzy reconstructed variable speed control process, with respect to the uncontrolled conditions. VISSIM 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 (Vissim, 2000).

Traffic control program can be transferred to the VISSIM test environment by using an additional Vehicle Activated Programme module (VAP). For this aim, the control model is written as a text file by using the functions and commands of VAP. The fuzzy controller has been programmed in this way.

Two different tests have been completed under the same traffic conditions: Test1 for uncontrolled (without any control system) case; Test2 for fuzzy reconstructed variable speed control case. For this aim, all the hardware elements of the freeway traffic system including 5.45 km length of the main-link have been configured in VISSIM. The VMS positions on the main-link have been chosen 0.75 km, 1.95 km, 3.15 km, and 4.35 km respectively. The vehicle speed reduction to 40 km/h has been applied at 4.75 km position of the link, due to time table shown in Table 2. The traffic scenarios and related assignments have also been chosen as shown in this table, through the 7200 seconds (2 hours) of simulations, for both controlled and uncontrolled cases.

Table 2. The traffic scenario and measures chosen for tests

simulation time (seconds)	main-link input q_{in} (veh/h/lane)	free-flow speed v_f (km/h)	speed desc. pos. x_d (km)	perf. meas. dist. $x_{m2} - x_{m1}$ (km)
0 - 3000	1000	110	no speed desc.	5.4 - 0.35 = 5.05
3001 - 3600	1200	110	4.75	5.4 - 0.35 = 5.05
3601 - 5400	1400	110	no speed desc.	5.4 - 0.35 = 5.05
5401 - 7200	1500	110	4.75	5.4 - 0.35 = 5.05

Assignments for the traffic generator and test conditions in the simulator are as follows: the number of lanes along the main-link, Δ_i =3; the free flow speed of the vehicles is v_f = 100 km/h, its distributions are between 80-100 km/h for cars and heavy good vehicles (HGV); vehicle length distributions are between 6-10 meters; HGV ratio is 0.20; Lane based flow capacity q_{max}=1800 veh/h., ρ_c=60, and ρ_{jam}=130 veh/km/lane; v_o=70, and v_c=50 km/h for all the main-link segments.

Through the simulations the average vehicle speeds and average delays have been established from the VISSIM's off-line analysis results in 10 minutes basis and arranged as different graphics to show the performance developments.

Results

The performance data have been evaluated as the average vehicle speeds and the average delay per vehicle along the 5.05 km. section of the main-link between the 0.35-5.4 km positions of the link. These data have been gathered through the VISSIM simulations. For this length, the results obtained about the average vehicle speeds and the average delays per vehicle through the 2 hours of simulations have been shown in Figure 7 and 8, respectively. Total number of vehicles passed through the 5.05 km of main link is acquired from VISSIM data files. They are realized as 6273 for Test1, and 6192 for Test2.

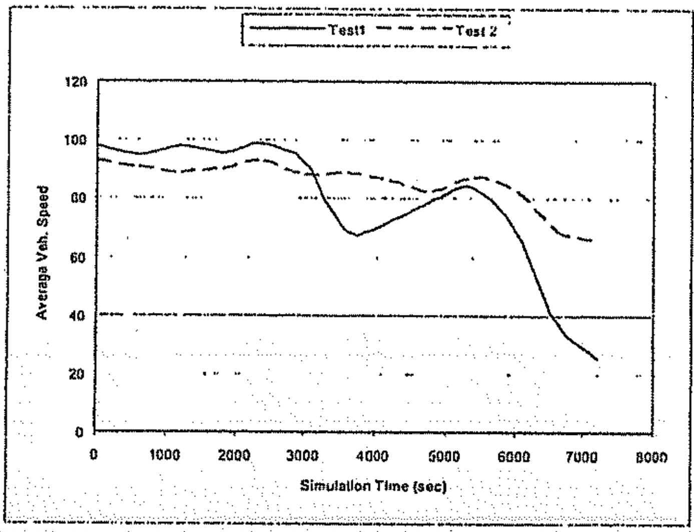

Figure 7. Test results on the average vehicle speeds, along the 5.05 km of link length

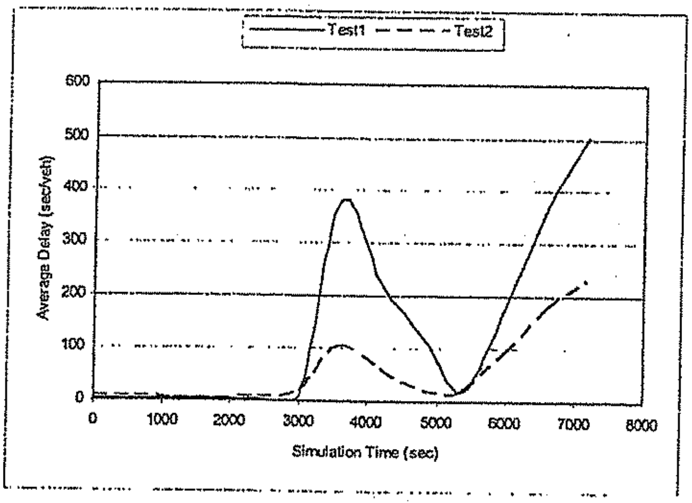

Figure 8. Test results on the average delay per vehicle, along the 5.05 km section.

Due to these results, the average delay is decreased 77% by the fuzzy reconstructed speed control, with respect to uncontrolled conditions. The average vehicle speed is increased 23% by the fuzzy reconstructed variable speed control, with respect to uncontrolled conditions. Average capacity usage has decreased 1.3% by the fuzzy reconstructed variable speed control, with respect to uncontrolled conditions. The test result shows that even there is a small decrease in the capacity usage, the average speed of the vehicle are increased satisfactorily and the average delay per vehicle decreased satisfactorily. Consequently, the projection of the decreasing of the delays from the traffic jams by using this proposed fuzzy reconstructed variable speed control method is fulfilled.

Conclusions

Test results show that the fuzzy reconstructed speed control is decreased the average delay satisfactorily. Thus, average speed is increased approximately 25%. However, there is a small decrease in the average capacity usage.

In the variable speed control method, the fuzzy reconstruction approach is the suitable choice for the traffic control fact as shown in tests. This control method can help to solve the traffic problems of the cities.

References

Akbas, A. (2003). Variable Speed Approach for Congestion Alleviation on Bosporus Bridge Crossing, 19.Dresden Conf. of Traffic and Trans. Sciences, Sept. 22-23 Dresden.

Greenshields, B.D. (1934). A Study of Traffic Capacity. Proc.US HRB., Vol 14.

May, A. D. (1990). Traffic Flow Fundamentals, Prentice-Hall Publication, New Jersey.

Papageorgiou, M. (2000). Freeway Ramp Metering: An Overview, 2000 IEEE ITS Conference Proceedings, pp.228-239, Deaborn (MI), USA.

VISSIM User Manual. (2000). PTV system Software and Consulting GmbH, Stumpfstraße 1 D-76131 Karlsruhe, Germany.

Zhang, H. (1996). Some General Results in the Optimal Ramp Control Problem, Trans.Res. C. Vol. 4, No. 2, pp 51-69.