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# A Mean Speed Prediction Model for Surface Streets

**Siamak A. Ardekani, Hemanth U. Shivagangaiah**
**Department of Civil Engineering**
**The University of Texas at Arlington**
**Box 19308**
**Arlington, TX 76019-0308**

## ABSTRACT

A macroscopic model for estimating the mean speed along urban surface streets is presented. The model captures all geometric, control, and demand conditions identified in the Highway Capacity Manual as being significant factors influencing travel time and levels of service along urban streets. The proposed model is calibrated using a combination of CORSIM, VISSIM, and SYNCHRO simulation models. Regression analyses are performed to determine the speed penalty imposed on the free flow speed resulting from each of the twelve predictor variables representing geometric, control, and demand conditions on urban streets.

**Keywords:** *Mean Speed Estimation, Travel Time Estimation, Surface Streets, Urban Arterials, Corridor Management*

## I. INTRODUCTION

Mean speed or its inverse, travel time, is an important variable for evaluating the operating efficiency of streets, highways and traffic networks. Travel time can be used to assess the performance of traffic management strategies. In addition providing reliable estimates of travel time for an urban arterial road network is essential to the success of strategies such as integrated corridor management strategies and other similar traffic management endeavors. Reliable estimates of travel time are particularly challenging under altered roadway conditions due to events such as construction/maintenance activities, lane closures, and inclement weather conditions.

There are fairly reliable methods, such as those in the Highway Capacity Manual [1], for estimating mean speed and travel time for uninterrupted flows on freeways. However, the interrupted nature of traffic flow on surface streets and numerous other factors that affect surface street speeds make estimation of mean speed on such roads a much more challenging task.

This work presents a macroscopic model for estimating the mean speed along urban surface streets. This model captures all geometric, control, and demand conditions identified in the Highway Capacity Manual as being significant factors on urban streets. It also attempts to include additional influential factors which may constrain lane capacities such as bicycle lanes, driveway density, two-way left-turn lanes, etc. The proposed model is calibrated using a combination of CORSIM, VISSIM, and SYNCHRO simulation models.

## II. BACKGROUND

Chapter 15 of the 2000 Highway Capacity Manual (HCM) [1] provides a piecemeal method of evaluating traffic conditions along urban streets. The average speed along an arterial is estimated on the basis of detailed calculations of average delays experienced by through vehicles at each passed signalized intersections. The delay is calculated by using chapter 16 for signalized intersections. The travel time between the intersections is added to the delays to obtain the total travel times, which are then converted to the travel speeds. Although this approach is acceptable for operational analysis and short-range planning, the methodology does not account for the conditions that can occur between intersections such as (a) presence or lack of on-street parking; (b) driveway density or access control; (c) lane additions and lane drops; (d) other capacity constraints between intersections such as marked mid-block crossings; (e) medians; and (f) two-way left-turn lanes. Because any one of these conditions might have a significant impact on the speed of through traffic, the HCM-based method would be inefficient and may result in inaccurate predictions.

Although several models have been proposed for arterial streets, their use in estimating mean speed is problematic and does not encompass a variety of geometric and modal demand conditions. The Link-Journey-Speed model for arterial traffic as proposed by Zhang [2]-, for example, estimates the speed based on the critical volume to capacity ratio, where loop detectors measure volume and occupancy. This model estimates the speeds based on the detectors placed at the intersection but does not consider the traffic and geometric conditions that may influence the speed between the intersections. The Singapore Centre for Transportation Studies (CTS) model [3] estimates arterial travel time as a function of traffic density and minimum stopped delay per intersection under free-flow conditions. The CTS model does not provide any method for predicting these two quantities, however; and the suggested values are limited in range and cannot be used for a wide range of traffic conditions encountered on urban surface arterials.

A number of other models for travel time on arterial, such as those proposed by Davidson [4] and Akcelik [5] require specifying the degree of saturation as essentially a surrogate for control parameters. The degree of saturation is a function of signal timing, which must be assumed for distance future. In addition, the Akcelik model is derived from the queuing theory for isolated bottlenecks, which means it does not include the effect of signal progression, adaptive signals, and other such control strategies. Another model by Tarko, et. al[6] considers input parameters such as distance between the intersections, travel time between the intersections, cruise speed, number of lanes, and traffic volume. However, this model does not include the impact of variables such as curb parking, transit use, bicycle lanes, pedestrian activity, median type and vehicle mix, which could collectively have a considerable influence on speed of traffic on urban streets.

In order to develop a simple yet accurate model to predict the mean speed on urban streets, it was necessary to consider the entire spectrum of major factors that could affect traffic speed. These factors were selected based on chapters 10, 15, and 16 of The Highway Capacity Manual [1]. In all, twelve control conditions/functions have been identified. They include traffic demand (volume to capacity ratio), number of signals per mile, type of signal (pre-timed, coordinated, adaptive) number of lanes/direction, lane width, number of access points per mile (both unsignalized intersections & driveways), curb parking, median type, transit use, vehicle mix, pedestrian activity, and bicycle use.

A simple model that would capture the net effect of all twelve conditions was developed. The major factors were represented as variables $x_1$, $x_2$, $x_3$………..$x_{12}$ in the model and their corresponding parameters were represented as $f_1$, $f_2$, $f_3$………$f_{12}$. The values of the parameters were estimated using two micro simulation software programs, CORSIM, VISSIM, and SYNCHRO.

## III. THE MODEL STRUCTURE

An analytical model for predicting the speed was formulated based on the factors derived from the HCM. As in the HCM procedure for basic freeway segments, estimation of mean speed for an existing or future surface street is accomplished by adjusting a base free-flow speed or posted speed downward to reflect the influence of the predictor variables. The twelve variables selected for the proposed model are shown in Figure 1. The corresponding prediction model is as follows:

$$\text{Speed}= S_0 - f_1/[1+e^{-a(x_1-b)}] - f_2x_2 - f_3 x_3 - f_4 x_4^c - f_5 (12- x_5) - f_6x_6 - f_7x_7 - f_8x_8 - f_9x_9 - f_{10}x_{10} - f_{11}x_{11}- f_{12}x_{12} \quad (1)$$

where,

$S_0$= free flow speed (mph)

$x_1$= traffic demand (v/c)

$x_2$= number of signals /mile

$x_3$= type of signal

$x_3$= {0, 1, 2}

0= actuated coordinated

1= actuated/adaptive

2= pre-timed

$x_4$= number of lanes/direction

$x_5$= lane width (ft)

$x_6$= number of access points/mile (both unsignalized intersections & driveways)

$x_7$= curb parking

$x_7$= {0, 1}

0= not allowed

1= allowed

$x_8$= median type

$x_8$= {0, 1, 2}

0= divided

1= two-way turn lanes

2= undivided

$x_9$= transit use

$x_9$= {0, 1, 2}

0= not a transit route

1= transit route

2= exclusive transit lane

$x_{10}$= vehicle mix (% of trucks)

$x_{11}$= pedestrian activity

$x_{11}$= {0, 1, 2}

0= light (<100 pph)

1= moderate (100-250 pph)

2= heavy (>250 pph)

(here, pph stands for pedestrians per hour)

$x_{12}$= bicycle use

$x_{12}$= {0, 1, 2}

0= no special accommodations for cyclists

1= exclusive bike lane

2= bike route but no exclusive bike lane

In Eq. 1, $S_0$ represents the free-flow speed for the street section under analysis. The analyst is required to select an appropriate $S_0$ as a starting point. In this study, the posted speed limit was used as a surrogate for the free-flow speed. This is because previous studies involving travel time measurements in urban networks (e.g. Herman[7,8]) have shown that even during extreme off-peak conditions, the best a driver on a given surface street can expect to achieve for average maximum speed (average minimum travel time per unit distance) is the posted speed limit for that street.

The variables $x_1$, $x_2$, $x_3$, $x_4$, $x_5$, $x_6$, $x_7$, $x_8$, $x_9$, $x_{10}$, $x_{11}$, and $x_{12}$ in the above proposed model are self-explanatory. However, some factors take on dummy variables depending on whether or not they are present in the network. For example, one such variable is curb parking, $x_7$ whose value is 1 or 0 depending on whether it is allowed or not, respectively. The terms $f_1$ to $f_{12}$, a, b, and c are all model parameters.

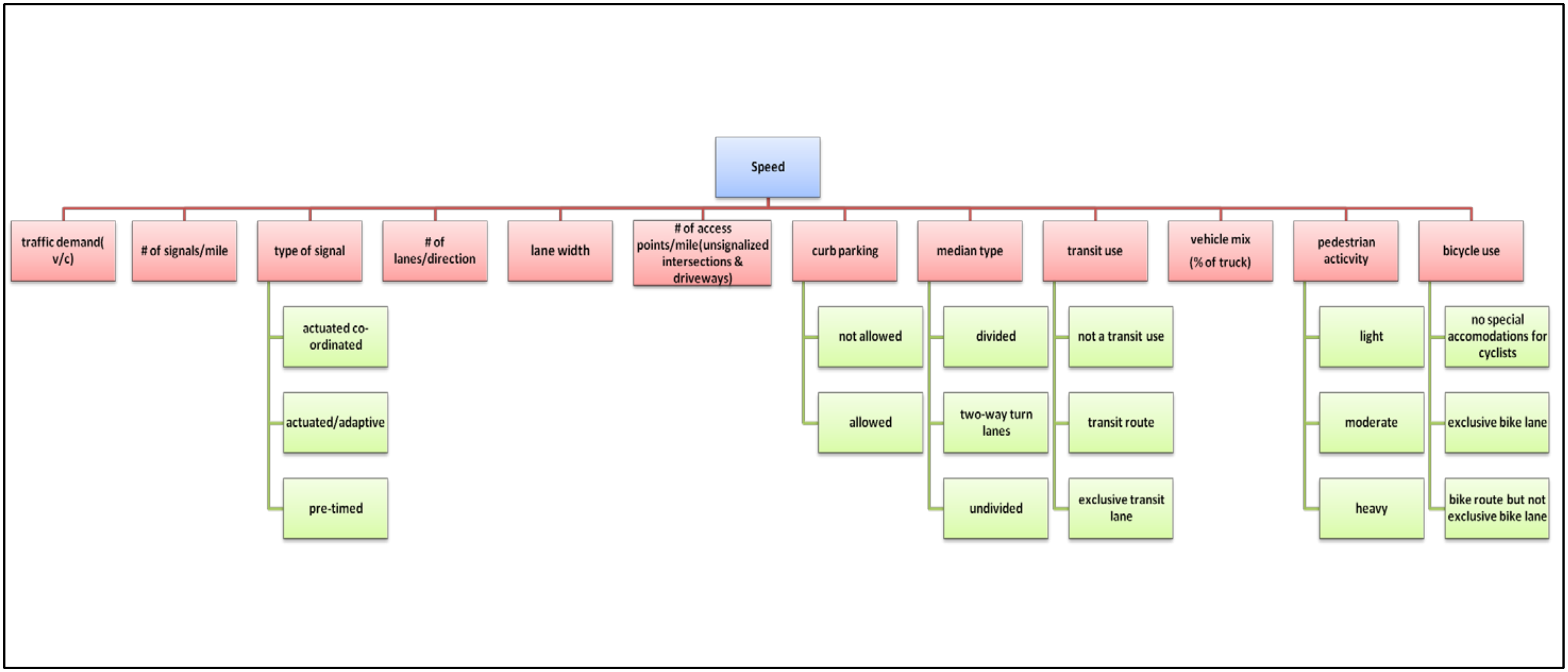

**Figure 1: A flow chart representation of speed control factors selected from the HCM.**

## IV. MODEL CALIBRATION

Computer simulation was used to measure the impact of the twelve predictor variables on the speed and to calibrate the model accordingly. Each variable along with other functional characteristics of an urban street were simulated independently for required input scenarios and the corresponding average speeds were recorded.

The estimation of speed begins with the development of the network in the simulation environment. Once the network is coded, the computer model simulates traffic operations throughout the network under given traffic conditions. For this purpose CORSIM, VISSIM, and SYNCHRO were used to code and simulate the network. For all the variables ($x_1$ to $x_{11}$), except bicycle use ($x_{12}$), simulations were carried out in CORSIM; the bicycle use simulation was done using VISSIM as no such provision existed within CORSIM. The actuated/adaptive and actuated/coordinated signal networks were coded in SYNCHRO, due to the relative ease of coding compared to the other two simulation programs. The input files from both VISSIM and SYNCHRO were later imported into CORSIM to carry out the network simulation.

Various data are required to code the network in CORSIM and VISSIM. Maze and Kamyab [9] classify the required input data into three categories: supply, demand, and control. Supply data include geometric and traffic characteristics of the network such as the number of lanes, lengths of turn bays of approaches to signalized intersections and distances between intersections. Demand data primarily include traffic counts at local streets and major arterials and turning movement counts at major intersections throughout the network within the study zone. The control data include signal types (pre-timed, semi-actuated, and fully-actuated), phase plans, detector types and locations, and other applicable information. The details of the input data to code the network are summarized in Table 1.

A total of twelve networks were coded and changes were made to the input data set according to the impact of specific variables being analyzed. A typical four-lane urban arterial street, with left-turn bays at signalized intersections and four-lane side streets, was assumed as the base condition for all scenarios. The study considered the traffic moving along the northbound direction as the arterial's forward moving direction, and the speeds recorded in that direction were used for model calibration. The eastbound and westbound directions represented the side street conditions. Intersections were signal controlled, and all driveways were controlled by two-way stop signs facing the driveways. A graphical view of the entire network and a segmental animation view are shown in Figures 2 and 3, respectively.

**Figure 2: A graphical view of the simulated network in CORSIM**

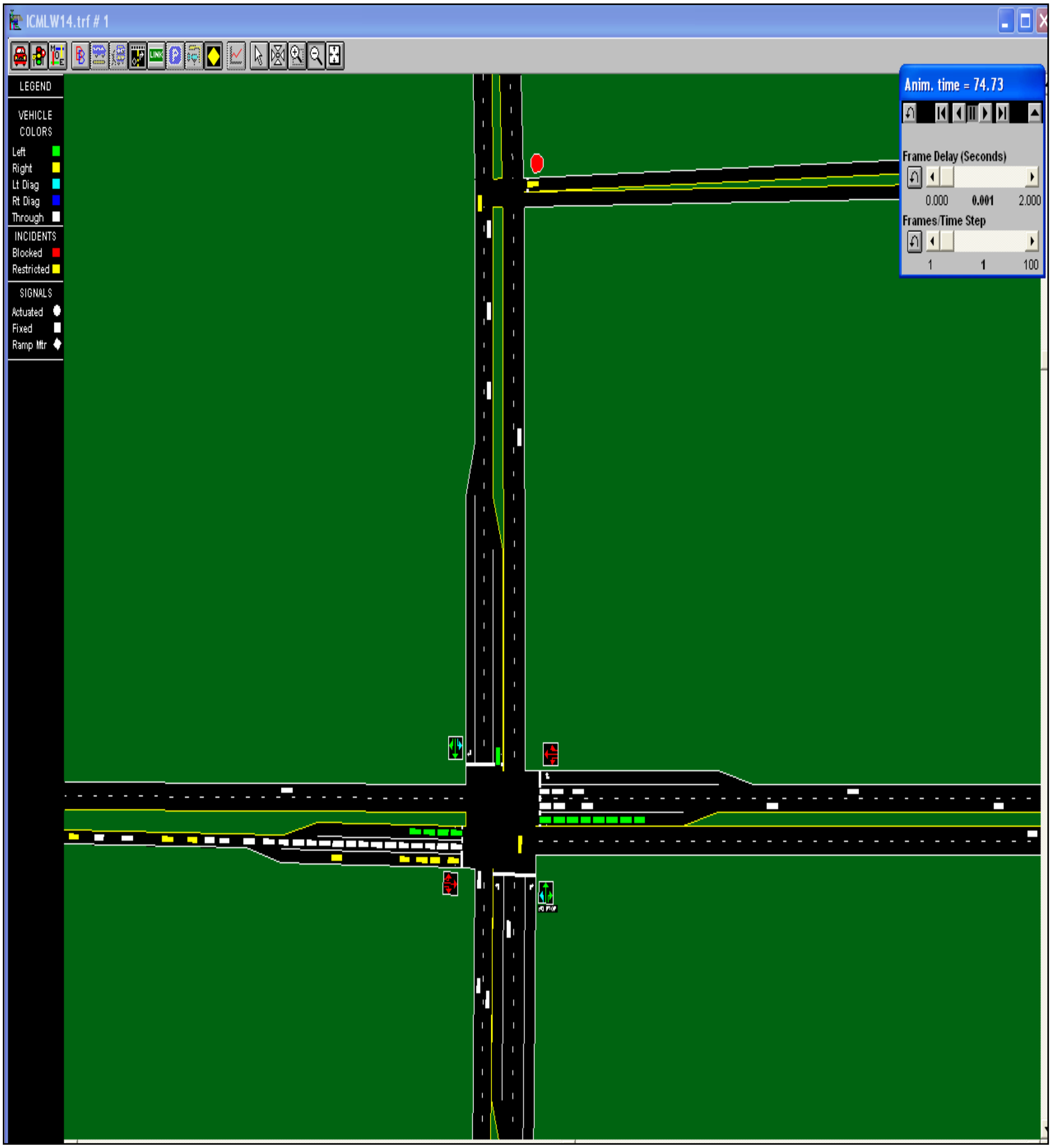

**Figure 3: Animation of a network segment in CORSIM.**

**Table 1: Summary of Data Used to Code the Network**

| | | | Posted Speed(mph) | Distance (mile) | # of lanes/ direction | Lane Width(ft) | Volume (vph) | Access Points | | Signal Cycle length(sec) | Other Conditions | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Signals | Driveways | | | |
| $x_1$ | traffic demand | | 45 | 2.5 | 2 | 12 | 4-3740 | 5 | 8 | 100 | v/c ratio were calculated according to available green time for each turning movemets in the intersections using synchro | traffic volumes were changed as per v/c ratio |
| $x_2$ | # of signals | | | | 2 | 12 | 1200 | 1-7 | 8 | | | # of signals were varied from 1-7 |
| $x_3$ | type of signals | actuated cordinated | | | 2 | 12 | 1200 | 5 | 8 | | detector length=50ft | signal timings and offest were set in Synchro and transferred to Corsim |
| | | actuated /adaptive | | | | | | | | | | |
| | | pre timed | | | | | | | | | | |
| $x_4$ | # of lanes/direction | | | | 2 | 12 | 1200 | 5 | 8 | | | speed recorded by changing the # of lanes |
| $x_5$ | lane width | | | | 2 | 12 | 1200 | 5 | 8 | | | speed recorded by changing the width of the lane |
| $x_6$ | # of access points/mile | | | | 2 | 12 | 1200 | 5 | 1-21 | | | speed recorded by changing the access points |
| $x_7$ | curb parking | not allowed | | | 2 | 12 | 1200 | 5 | 8 | | | right side curb parking |
| | | allowed | | | | | | | | | mean duration =18 sec and parking manuver =180 vph | |
| $x_8$ | median type | divided | | | 2 | 12 | 1200 | 5 | 8 | | | |
| | | two way left turn lanes | | | | | | | | | | |
| | | undivided | | | | | | | | | | |
| $x_9$ | transit use | not a transit route | | | 2 | 12 | 1200 | 5 | 8 | | mean head way=180 sec , mean dwell time=15 sec,distace b/w stops =800ft | right lane used exclusively for transit |
| | | transit route | | | 2 | | | | | | | |
| | | exclusive transit lane | | | 3 | | | | | | | |
| $x_{10}$ | vehicle mix | | | | 2 | 12 | 1200 | 5 | 8 | | | perecnt of trucks were varied in vehicle types entering the network |
| $x_{11}$ | pedestrian activity | light | | | 2 | 12 | 1200 | 5 | 8 | | <100pph | pedestrian cross the intersection parallel to the traffic flow |
| | | moderate | | | | | | | | | 100-250pph | |
| | | heavy | | | | | | | | | <250pph | |
| $x_{12}$ | bicycle use | no special commodations for cyclists | | 0.61 | 2 | 12 | 1200 | 3 | 0 | | bicycle lane width =5ft, bicycle composition =1% of total volume | right lane used exclusively for bicycle |
| | | exclusive bike lane | | | 3 | | | | | | | |
| | | bike route but no exclusive bike lane | | | 2 | | | | | | | |

## CALIBRATION RESULTS

As discussed in the previous section, simulations were carried out based on the data summarized in Table 1 to analyze the relative impact of each variable on travel speeds. Multiple runs were made for each variable and corresponding speeds were recorded. Table 2 shows the calculation of average speed from individual runs. Table 3 shows the values of the parameters obtained by regression analysis carried out on each independent variable (X) and the corresponding speed value (Y).

Table 3 also shows the functional form of the speed versus independent variables. Linear models were shown to be suitable between speed and all but two of the X variables. The two variables which required non-linear modeling were traffic demand ($x_1$) and number of lanes ($x_4$). The general shape of the plot of speed versus demand (v/c), shown in Figure 4, indicated that an exponential fit may be more suitable in this case. An exponential relation was consequently formulated by regressing the speed reduction (reduction in speed compared to speed at v/c=0) as the dependent variable (Y) versus the traffic demand (v/c) as the independent variable ($X_1$).

Likewise, the general shape of the plot of speed versus number of lanes ($X_4$), as shown in Figure 5, indicated that a power function may be suitable in this case. A nonlinear relation was consequently formulated by regressing speed penalty (reduction relative to the speed for five lanes) as the dependent variable (Y) and the number of lanes as the independent variable ($X_4$).

By substituting the parameters of the respective variables into Eq. 1, one can calibrate the model, as shown in Eq. 2 below:

$$\mathbf{Speed = S_0 - 24.5/[1 + e^{-6.9(x_1-0.89)}] - 4.02x_2 - 1.05x_3 - 10.8x_4^{-3.34} - 0.04\,(12-x_5) - 0.08x_6 - 5.55x_7 - 0.65x_8 - 0.9x_9 - 0.0067x_{10} - 0.25x_{11} - 1.2x_{12}} \quad (2)$$

The above model can be used to predict the average speed on surface streets under a variety of geometric, control, and demand conditions. This model is based on the speed control factors (variables) selected from the HCM 2000 and calibrated using the micro simulation software, CORSIM, VISSIM, and SYNCHRO.

**Table 2: Calculation of Average Speed from CORSIM Output**

| Link | Link | Veh miles | Veh Trip | Move Time | Delay Time | Total Time | Move Total | Total Time | Delay Time | Total Time | Delay Time | Control Delay | Queue Delay | Stop Time | Stops (%) | Vol (vph) | Speed (mph) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 457.22 | 1649 | 609.6 | 357.7 | 967.3 | 0.63 | 2.12 | 0.78 | 35.1 | 13 | 11.2 | 9.1 | 8.7 | 48 | 1099 | 28.4 |
| 2 | 1 | 253.55 | 921 | 338.1 | 66.1 | 404.1 | 0.84 | 1.59 | 0.26 | 26.3 | 4.3 | 0.3 | 0.1 | 0.1 | 0 | 614 | 37.6 |
| 8001 | 1 |  | 1649 |  |  |  |  |  |  |  |  |  |  |  |  | 1099 |  |
| 2 | 3 | 158.43 | 1361 | 211.2 | 59.5 | 270.7 | 0.78 | 1.71 | 0.38 | 11.9 | 2.6 | 0 | 0.1 | 0 | 0 | 907 | 35.1 |
| 3 | 2 | 116.56 | 991 | 155.4 | 203.8 | 359.2 | 0.43 | 3.08 | 1.75 | 21.6 | 12.3 | 10.2 | 8.3 | 7.9 | 47 | 660 | 19.5 |
| 3 | 4 | 139.4 | 1358 | 185.9 | 458.3 | 644.2 | 0.29 | 4.62 | 3.29 | 28.4 | 20.2 | 18 | 14.9 | 14.2 | 66 | 905 | 13 |
| 4 | 3 | 96.62 | 962 | 128.8 | 49.2 | 178 | 0.72 | 1.84 | 0.51 | 11.1 | 3.1 | 0.2 | 0.2 | 0.1 | 0 | 641 | 32.6 |
| 4 | 5 | 192.72 | 1223 | 257 | 68.1 | 325 | 0.79 | 1.69 | 0.35 | 15.9 | 3.3 | 0 | 0.1 | 0 | 0 | 815 | 35.6 |
| 5 | 4 | 141.26 | 889 | 188.4 | 296.6 | 484.9 | 0.39 | 3.43 | 2.1 | 32.7 | 20 | 17.7 | 16.1 | 15.7 | 49 | 592 | 17.5 |
| 5 | 6 | 141.64 | 1222 | 188.9 | 147.6 | 336.4 | 0.56 | 2.38 | 1.04 | 16.5 | 7.2 | 5.6 | 4.5 | 4.4 | 23 | 814 | 25.3 |
| 6 | 5 | 95.07 | 822 | 126.8 | 27.8 | 154.5 | 0.82 | 1.63 | 0.29 | 11.3 | 2 | 0.3 | 0.1 | 0 | 0 | 548 | 36.9 |
| 6 | 7 | 139.67 | 890 | 186.2 | 194.4 | 380.6 | 0.49 | 2.73 | 1.39 | 25.6 | 13.1 | 10.6 | 9.5 | 9.3 | 34 | 593 | 22 |
| 7 | 6 | 177.63 | 1145 | 236.8 | 172.2 | 409.1 | 0.58 | 2.3 | 0.97 | 21.4 | 9 | 5.9 | 5 | 4.8 | 25 | 763 | 26.1 |
| 7 | 8 | 120.18 | 1031 | 160.2 | 40.2 | 200.5 | 0.8 | 1.67 | 0.33 | 11.6 | 2.4 | 0 | 0.1 | 0.1 | 0 | 687 | 36 |
| 8 | 7 | 144.63 | 1216 | 192.8 | 170.1 | 362.9 | 0.53 | 2.51 | 1.18 | 17.8 | 8.4 | 6.6 | 5.6 | 5.5 | 26 | 810 | 23.9 |
| 8 | 9 | 101.34 | 1031 | 135.1 | 230.8 | 365.9 | 0.37 | 3.61 | 2.28 | 21.2 | 13.4 | 12.2 | 10.7 | 10.4 | 38 | 687 | 16.6 |
| 9 | 8 | 114.47 | 1189 | 152.6 | 57.4 | 210 | 0.73 | 1.83 | 0.5 | 10.6 | 2.9 | 0.3 | 0.2 | 0.1 | 0 | 792 | 32.7 |
| 9 | 10 | 78.53 | 1047 | 104.7 | 40.7 | 145.4 | 0.72 | 1.85 | 0.52 | 8.3 | 2.3 | 0 | 0.1 | 0.1 | 0 | 698 | 32.4 |
| 10 | 9 | 101.63 | 1312 | 135.5 | 221.2 | 356.7 | 0.38 | 3.51 | 2.18 | 16.3 | 10.1 | 8.4 | 6.8 | 6.4 | 37 | 874 | 17.1 |
| 10 | 11 | 149.69 | 1051 | 199.6 | 13.5 | 213.1 | 0.94 | 1.42 | 0.09 | 12.1 | 0.8 | 0 | 0 | 0 | 0 | 700 | 42.1 |
| 11 | 10 | 184.72 | 1297 | 246.3 | 30.1 | 276.4 | 0.89 | 1.5 | 0.16 | 12.8 | 1.4 | 0.1 | 0 | 0 | 0 | 864 | 40.1 |
| 11 | 12 | 170.75 | 1052 | 227.7 | 12.8 | 240.5 | 0.95 | 1.41 | 0.08 | 13.7 | 0.7 | 0 | 0 | 0 | 0 | 701 | 42.6 |
| 12 | 11 | 208.41 | 1284 | 277.9 | 35.2 | 313.1 | 0.89 | 1.5 | 0.17 | 14.6 | 1.6 | 0.2 | 0 | 0 | 0 | 856 | 39.9 |
| 12 | 13 | 191.87 | 1052 | 255.8 | 177.6 | 433.4 | 0.59 | 2.26 | 0.93 | 24.7 | 10.1 | 8.3 | 6.9 | 6.7 | 34 | 701 | 26.6 |
| 13 | 12 | 230.45 | 1266 | 307.3 | 57.2 | 364.5 | 0.84 | 1.58 | 0.25 | 17.3 | 2.7 | 0.1 | 0 | 0 | 0 | 844 | 37.9 |
| 13 | 14 | 141.48 | 864 | 188.6 | 32.9 | 221.5 | 0.85 | 1.57 | 0.23 | 15.4 | 2.3 | 0 | 0 | 0 | 0 | 576 | 38.3 |
| 14 | 13 | 268.47 | 1635 | 358 | 276.8 | 634.8 | 0.56 | 2.36 | 1.03 | 23.3 | 10.1 | 8 | 6.5 | 6.2 | 34 | 1090 | 25.4 |
| 14 | 15 | 193.79 | 862 | 258.4 | 19 | 277.4 | 0.93 | 1.43 | 0.1 | 19.3 | 1.3 | 0 | 0 | 0 | 0 | 574 | 41.9 |
| 15 | 14 | 364.19 | 1620 | 485.6 | 66 | 551.6 | 0.88 | 1.51 | 0.18 | 20.4 | 2.4 | 0.1 | 0.1 | 0.1 | 0 | 1080 | 39.6 |
| 15 | 16 | 173.23 | 858 | 231 | 167.1 | 398.1 | 0.58 | 2.3 | 0.96 | 27.7 | 11.6 | 9.4 | 7.8 | 7.5 | 42 | 572 | 26.1 |
| 16 | 15 | 296.4 | 1478 | 395.2 | 90.9 | 486 | 0.81 | 1.64 | 0.31 | 19.7 | 3.7 | 0.3 | 0.1 | 0.1 | 0 | 985 | 36.6 |
| 16 | 17 | 182.95 | 936 | 243.9 | 46.9 | 290.8 | 0.84 | 1.59 | 0.26 | 18.5 | 3 | 0 | 0.1 | 0.1 | 0 | 624 | 37.7 |
| 17 | 16 | 334.36 | 1691 | 445.8 | 381 | 826.8 | 0.54 | 2.47 | 1.14 | 29.3 | 13.5 | 11.7 | 9.7 | 9.2 | 48 | 1127 | 24.3 |
| 8002 | 17 |  | 1648 |  |  |  |  |  |  |  |  |  |  |  |  | 1098 |  |
| 2 | 18 | 149.06 | 853 | 298.1 | 43.5 | 341.6 | 0.87 | 2.29 | 0.29 | 24 | 3.1 | 0 | 0.1 | 0 | 0 | 568 | 26.2 |
| 18 | 2 | 125.55 | 709 | 251.1 | 335.6 | 586.7 | 0.43 | 4.67 | 2.67 | 49.7 | 28.4 | 26.9 | 25.4 | 24.9 | 78 | 472 | 12.8 |
| 2 | 19 | 201.17 | 940 | 402.3 | 45.8 | 448.1 | 0.9 | 2.23 | 0.23 | 28.6 | 2.9 | 0 | 0.1 | 0.1 | 0 | 626 | 26.9 |
| 19 | 2 | 155.13 | 711 | 310.3 | 349.9 | 660.2 | 0.47 | 4.26 | 2.26 | 55.6 | 29.4 | 27.7 | 26.1 | 25.5 | 77 | 474 | 14.1 |
| 8003 | 18 |  | 712 |  |  |  |  |  |  |  |  |  |  |  |  | 474 |  |
| 8004 | 19 |  | 712 |  |  |  |  |  |  |  |  |  |  |  |  | 474 |  |
| 4 | 20 | 175.9 | 1024 | 351.8 | 34.1 | 385.9 | 0.91 | 2.19 | 0.19 | 22.5 | 2 | 0 | 0 | 0 | 0 | 682 | 27.3 |
| 20 | 4 | 198.34 | 1142 | 396.7 | 772.4 | 1169 | 0.34 | 5.89 | 3.89 | 61.6 | 40.8 | 39.2 | 37.1 | 36.2 | 78 | 761 | 10.2 |
| 21 | 4 | 176.12 | 1001 | 352.2 | 3305 | 3657.3 | 0.1 | 20.77 | 18.77 | 214.9 | 194.2 | 175.8 | 164 | 152.5 | 100 | 667 | 2.9 |
| 4 | 21 | 201.85 | 1165 | 403.7 | 64.1 | 467.8 | 0.86 | 2.32 | 0.32 | 24 | 3.3 | 0 | 0.1 | 0.1 | 0 | 776 | 25.9 |
| 8005 | 20 |  | 1145 |  |  |  |  |  |  |  |  |  |  |  |  | 763 |  |
| 8006 | 21 |  | 1032 |  |  |  |  |  |  |  |  |  |  |  |  | 688 |  |

| Link | Length(ft) | Speed(mph) | Trave Time(sec) |
|---|---|---|---|
| 2-1 | 1464 | 37.6 | 26.55 |
| 3-2 | 621 | 19.5 | 21.71 |
| 4-3 | 542 | 32.6 | 11.34 |
| 5-4 | 839 | 17.5 | 32.69 |
| 6-5 | 612 | 36.9 | 11.31 |
| 7-6 | 735 | 26.1 | 19.20 |
| 8-7 | 795 | 23.9 | 22.68 |
| 9-8 | 447 | 32.7 | 9.32 |
| 10-9 | 340 | 17.1 | 13.56 |
| 11-10 | 821 | 40.1 | 13.96 |
| 12-11 | 857 | 39.9 | 14.64 |
| 13-12 | 963 | 37.9 | 17.32 |
| 14-13 | 867 | 25.4 | 23.27 |
| 15-14 | 1187 | 39.6 | 20.44 |
| 16-15 | 1066 | 36.6 | 19.86 |
| 17-16 | 1044 | 24.3 | 29.29 |
| Total | **13200** |  | **307.14** |

| | |
|---|---|
| **Speed(mph)** | **29.3** |

**Table 3: Parameters and Functional Form of Speed Factors**

| Variable | Parameter | Value | Functional Form |
|---|---|---|---|
| $X_1$ | $f_1$ | 24.5 | Exponential |
| | a | 6.9 | |
| | b | 0.89 | |
| $X_2$ | $f_2$ | 4.02 | Linear |
| $X_3$ | $f_3$ | 1.05 | Linear |
| $X_4$ | $f_4$ | 10.8 | Power |
| | c | -3.34 | |
| $X_5$ | $f_5$ | 0.04 | Linear |
| $X_6$ | $f_6$ | 0.08 | Linear |
| $X_7$ | $f_7$ | 5.55 | Linear |
| $X_8$ | $f_8$ | 0.65 | Linear |
| $X_9$ | $f_9$ | 0.9 | Linear |
| $X_{10}$ | $f_{10}$ | 0.0067 | Linear |
| $X_{11}$ | $f_{11}$ | 0.25 | Linear |
| $X_{12}$ | $f_{12}$ | 1.2 | Linear |

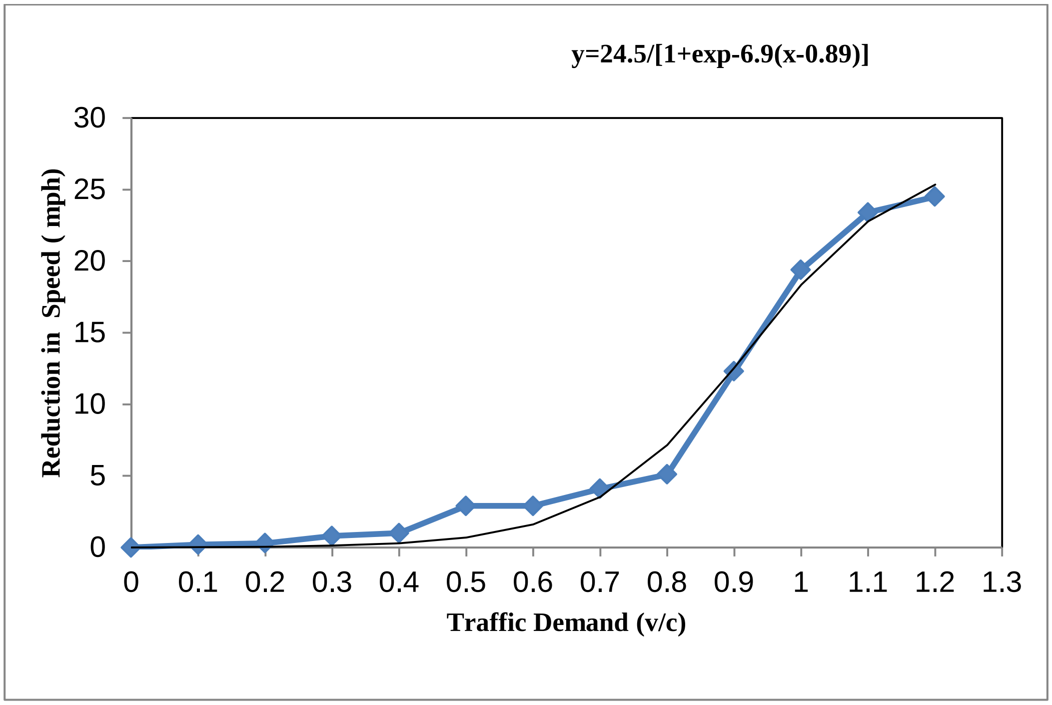

**Figure 4: The Relation Between the Reduction in Speed Versus the Level of Traffic Demand**

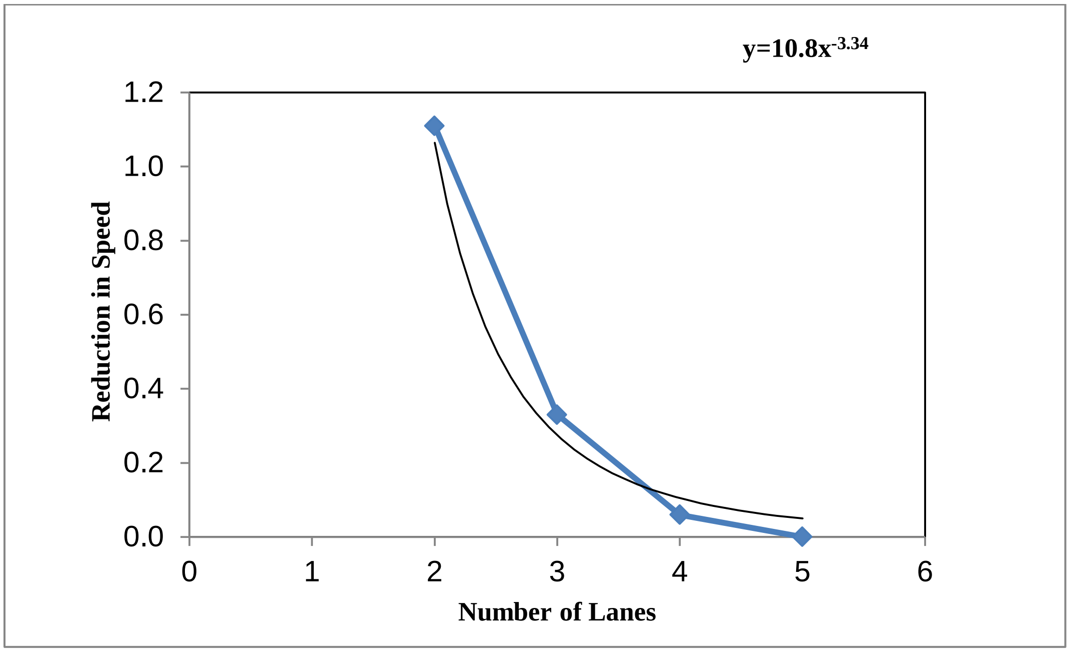

**Figure 5: The relation between the reduction in speed versus number of street lanes.**

## CASE SCENARIOS

The above model (Eq. 2) is applied to several case scenarios in order to illustrate how such a macroscopic model may be used as an analysis tool. Consider a base case divided arterial serving a transit route with a posted speed of 40 mph, with 4 signals per mile, with signals being actuated and coordinated, three 12' lanes per direction, with 8 access points (unsignalized intersections and driveways) per mile, no curb parking, 2 percent trucks in the mix, with moderate pedestrian activities (100-250 peds/hour) and no special accommodations for cyclists. Considering a V/C value of 0.5 as the base-case demand, the above described arterial is predicted to have a mean overall speed of 20.3 mph. If the level of demand increases to V/C=0.8, the mean speed is predicted to drop to 13.3 mph. As demand further increases to a saturated condition (V/C=1), the model in Eq. 2 predicts a mean overall speed of 5.2 mph.

Considering again the base case with the V/C=0.5, if the number of lanes is dropped by one lane (from 3 lanes to 2) due to an incident, for example, the mean speed is predicted to be 19.5 mph compared to 20.3 mph for the base case. Under another scenario, if the number of driveway openings is increased by 4 per mile, the base-case speed is predicted to drop to 20.0 mph. Finally, if the three 12' lanes are re-striped to be 10' wide so that a 6' bike lane could be added, a reduction of about 1.3 mph in the mean overall speed will be expected. The above case scenarios, as summarized in Table 4, are examples of the type of quick analysis which could be conducted using such macroscopic speed prediction models.

## SUMMARY AND CONCLUSIONS

The suggested model incorporates the contribution of various network and operational characteristics to estimate the average overall speed on urban streets. The proposed macroscopic model is based on variables recommended by the HCM, including traffic demand (volume to capacity ratio), number of signals per mile, type of signal, number of lanes/direction, lane width, number of access points per mile (intersection & driveways), curb parking, median type, transit use, vehicle mix(% of trucks), pedestrian activity, and bicycle use. The resulting model has a simple structure and limited input requirements. The input data are easy to collect and can be used in the model to predict the average speed on urban street segments.

The developed model attempts to incorporate all major factors which may influence the mean speed on urban streets. Several directions for future research may be pursued. First, an investigation of any other key variables that might have been overlooked but can significantly influence speed conditions could be undertaken. These could include factors such as pedestrian and bicycle volumes, availability of sidewalks, frequency of crosswalks, etc. Second, instead of using three different simulation models, a single suitable simulation model could be identified and used for simulation-based calibrations. These may include mesoscopic models such as DYNASMART-P [10] or TRANSMODELER [11], as possible models. Finally, the model would need to eventually be calibrated based on field data. For this purpose, an observational study involving travel time runs along various arterials and the corresponding demand conditions would need to be designed and conducted.

**Table 4: Application of the Prediction Model to Case Scenarios**

| Scenario | Demand Condition (V/C) | Mean Overall Speed (mph) |
|---|---|---|
| Base case | 0.5 | 20.3 |
| Base case with increased demand | 0.8 | 13.3 |
| Base case with saturated demand | 1.0 | 5.2 |
| Base case with a blocked lane | 0.5 | 19.5 |
| Base case with 4 additional driveways | 0.5 | 20.0 |
| Base case with an added bike lane and narrower (10’) traffic lanes | 0.5 | 19.0 |

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