RESEARCH NOTE

THE INFLUENCE OF URBAN NETWORK FEATURES ON THE QUALITY OF TRAFFIC SERVICE

J. Shahi and B. Amini

Department of Civil Engineering
University of Science & Technology
Tehran, Iran

Abstract The work reported here presents a methodology based on a two-fluid model to assess the degree of influence of various geometric and control features of an urban network on the quality of traffic service. The two-fluid model gives a curvilinear relation between the trip time and stop time per unit distance and its parameters characterize the quality of traffic service in urban networks. Any change in geometric and control features of a network would alter these parameters and the relationships permit the engineer to predict and evaluate traffic impacts of a given modification in advance.

Key Words Urban Network, Two-Fluid Model, Traffic Service, Auto-Restricted Zone

چکیده در این مقاله روشی برای ارزیابی میزان تاثیر جنبه های مختلف هندسی و کنترلی شبکه راههای شهری در کیفیت جریان ترافیک براساس مدل دو سیال ارائه می شود. مدل دو سیال یک رابطه خط - منحنی میان زمان سفر و زمان توقف در واحد مسافت برقرار می کند و پارامترهای آن مشخصه کیفیت جریان ترافیک در شبکه راههای شهری هستند. هرگونه تغییر در خصوصیات هندسی و کنترلی شبکه منجر به تغییر این پارامتراها خواهد شد و مهندس ترافیک می تواند براساس روابط آنها اثرات ترافیکی یک تغییر مفروض را از قبل پیش بینی نماید.

INTRODUCTION

When an urban street network undergoes modifications in its geometric or control features, it is necessary to obtain some quantitative measures to assess the resulting impacts. Similarly, when the need arises to improve the quality of traffic service in a street network, it is desirable to predict the level of improvements to be attained as a result of any specific modifications. This would allow engineers to identify strategies which yield the greatest improvement per unit cost. The comparison of various traffic alternatives also requires to introduce common criteria of evaluation.

An extensive macroscopic traffic study has been performed in a 23 square-kilometer urban street network in the Central Business District (CBD) of Tehran. The objective of this study was to assess the influence of the study network features on the quality of traffic service based on the two-fluid model.

The two-fluid model correlates the average travel time per unit distance to the stopped delay per unit distance in a network and its parameters are characterizers of traffic conditions in urban networks [1]. This model has been used to quantify the quality of traffic service in many cities around the world [2].

APPROACH

The methodology presented to assess the degree of influence of various geometric and control features on the quality of traffic service is based on the development of relations between network features and two-fluid parameters. There are many factors affecting the quality of traffic service in an urban network but in this study only four key accessible features have been considered as follows:

- Average intersection distance
- Average number of lanes per street
- Signalized intersection density
- Unsignalized intersection density

Data on each of the above features were collected for eight networks in and out of the Auto-Restricted Zone of Tehran (Figure 1). The quality of traffic

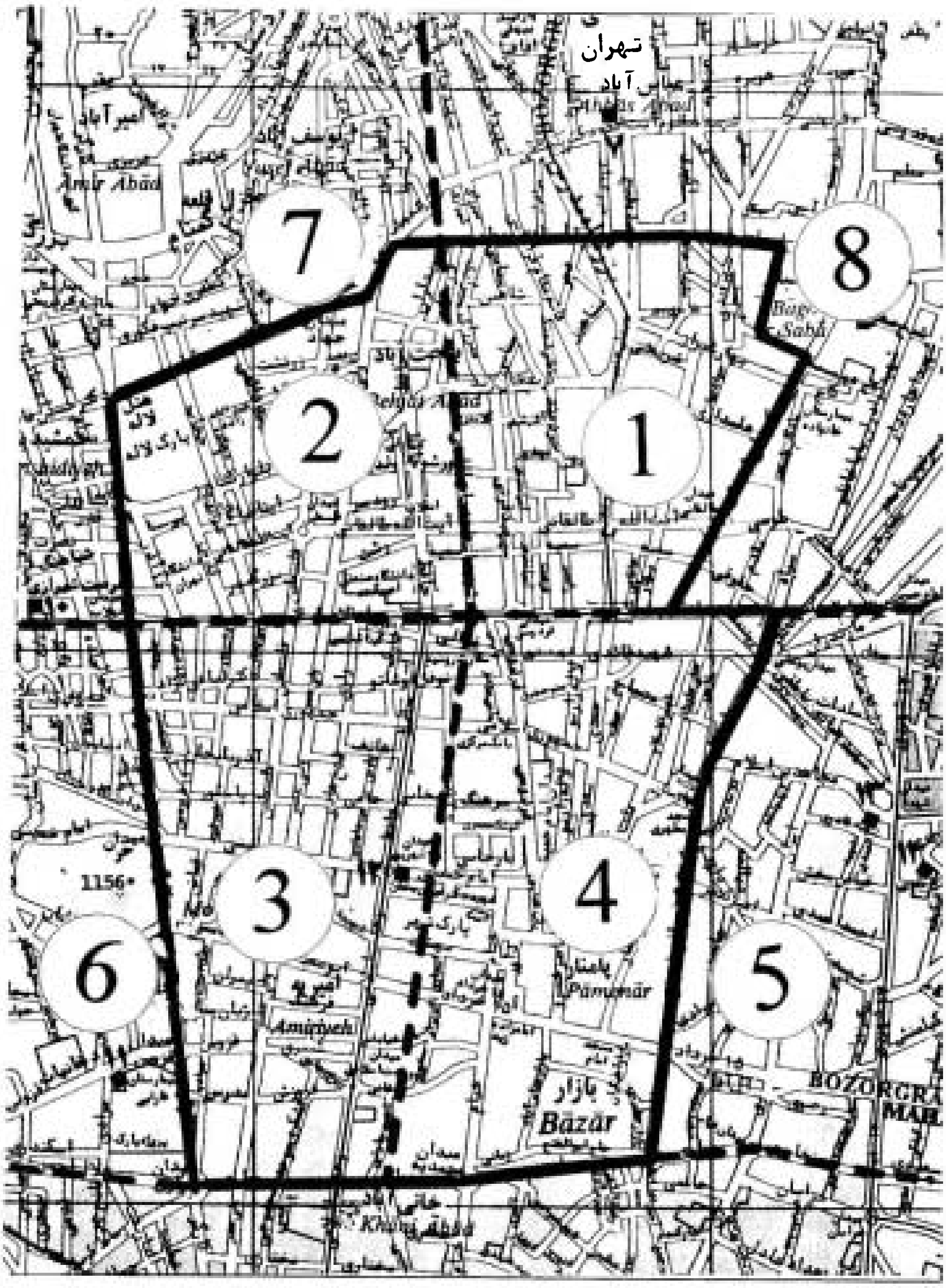

Figure 1. Study area map.

service in these networks was studied based on the two-fluid model. A regression analysis was used to determine the degree of influence of the above variables on the two-fluid parameters.

THE TWO-FLUID MODEL

The concept of two-fluid model appeared in the kinetic theory of multilane highway traffic when transition to the so-called collective flow regime was made at sufficiently high vehicular concentrations. In the case of highway traffic the speed distribution for the cars splits into two parts at collective transition: one part corresponds to the moving vehicles and the other to the vehicles that are stopped as a result of congestion, traffic signals, stop signs and other traffic control devices, as well as obstructions resulting from constructions, accidents, etc., but not parked vehicles. The parked cars are ignored since they are not a component of traffic but rather form a part of the geometric configuration of the street.

In the two-fluid model the ideas in the kinetic theory of traffic are followed by assuming that the average speed of the moving cars, v_r, depends on the fraction of the cars that are moving, f_r, in the following form:

$$v_r = vf_r^{-1} = v_m f_r^n = v_m(1 - f_s)^n \qquad (1)$$

where $\mathbf{f_s}$ is the average fraction of vehicles stopped, v_m is the average maximum running speed in the network system, v is the average speed of the traffic and **n** is a parameter the significance of which will be discussed later. The following identities should also be noted:

$$f_r + f_s = 1 \qquad (2)$$

$$v_m = 1/T_m \qquad (3)$$

$$v_r = 1/T_r \qquad (4)$$

$$v = 1/T \qquad (5)$$

Where $\mathbf{f_s}$ and $\mathbf{f_r}$ are the fraction of the vehicles stopped and moving respectively, $\mathbf{T_m}$ is a parameter representing the average minimum trip time per unit distance, $\mathbf{T_r}$ is the average running time per unit distance and **T** is the trip time per unit distance. If in addition, the stop time per unit distance is denoted by $\mathbf{T_s}$ it follows that:

$$T = T_s + T_r \qquad (6)$$

In the model it is also assumed that the fraction of the time stopped for an individual vehicle circulating in a network, (T_s/T), is equal to the average fraction of vehicles stopped in the system, f_s, over the same time period, namely:

$$f_s = (T_s/T) \qquad (7)$$

The assumptions stated in the Equations 1 and 7 lead to the two-fluid model relation between the trip time per unit distance, T, and running time per unit distance, T_r, namely:

$$T_r = T_m^{1/(n+1)} T^{n/(n+1)} \qquad (8)$$

Or

$$T_s = T - T_m^{1/(n+1)} T^{n/(n+1)} \qquad (9)$$

The parameters **n** and $\mathbf{T_m}$ associated with a traffic network can be obtained from Equation 8 or 9 by collecting trip time versus stop time data for a test vehicle circulating in that traffic network. Parameters $\mathbf{T_m}$ and **n** are meaningful indicators of the quality of traffic service in an urban street network. Smaller values of these parameters offers lower trip time per unit distance and therefore better quality of traffic service in the network.

In addition, the two-fluid model postulates a relation between the fraction of the vehicles stopped, f_s, and the average network concentration, **k**, in the form of:

$$f_s = f_{s,\,min} + (1 - f_{s,\,min})\,(k/k_m)^{\pi} \qquad (10)$$

where $\mathbf{k_m}$ is the average maximum concentration at which traffic jams in the system, π is a parameter and $f_{s,\,min}$ is the minimum fraction of stopped vehicles. Parameter π and $\mathbf{k_m}$ are in some sense measures of the quality of the traffic service in the network. Since $\mathbf{k/k_m}<1$, then for a given $\mathbf{k/k_m}$ the higher the π, the smaller the f_s and the better the quality of traffic service. Parameter k_m is an indicator of spatial distribution and travel pattern of vehicles in the network. The higher the k_m, the smaller the f_s and the more uniformity in the vehicles distribution across the network.

DATA COLLECTION

The data collection phase of the study was performed in September 1993. At first, the data needed for calibration of the two-fluid model were gathered. Figure 2 shows the two-fluid trends for the eight study areas. In Table 1 the calibrated parameters **n**, $\mathbf{T_m}$, π, $\mathbf{k_m}$ are presented.

Then the data on each of the following geometric and control features of the study zones were collected based on the appropriate city maps and filed observations:

X_1 = **Average intersection spacing:** calclulated as the average distance of major intersections in meters.

X_2 = **Average number of lanes per street:** calclulated

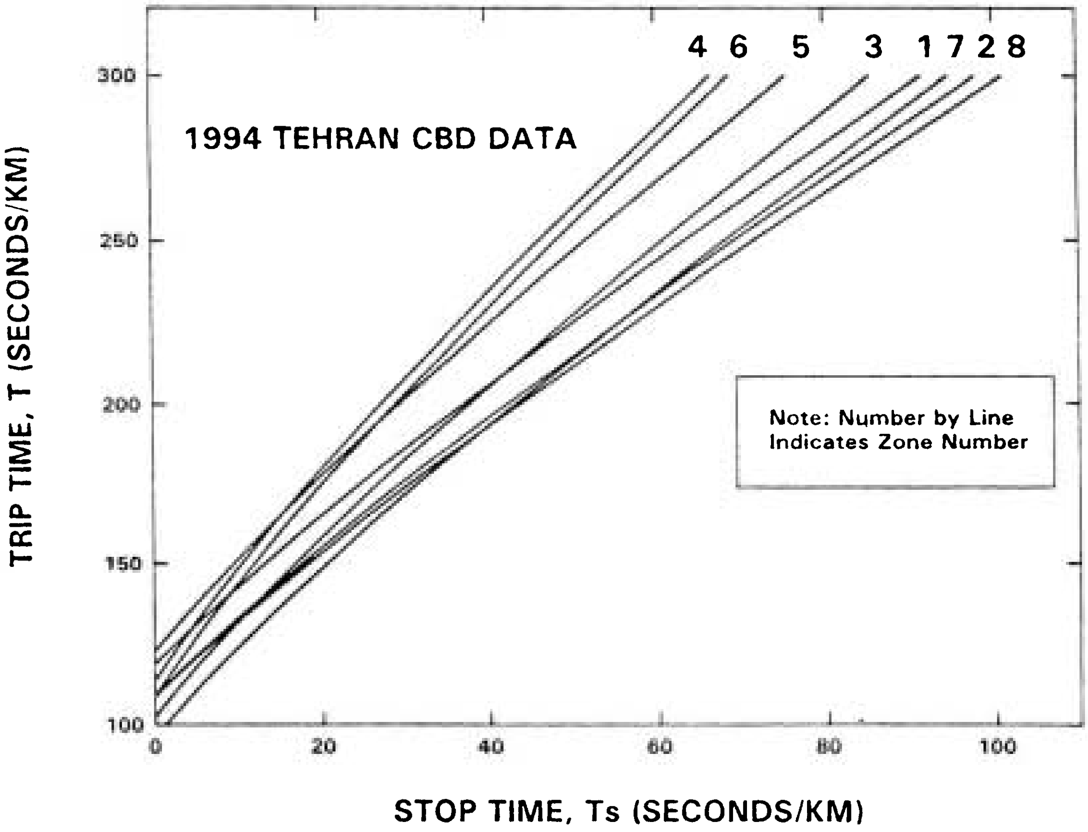

Figure 2. Two-fluid trends of the study zones.

TABLE 1. Two-Fluid Parameters in Various Study Zones.

Zone No.	n	T_m (min/km)	π	k_m (veh/km/lane)
1	1.55	2.18	3.20	60
2	1.54	1.93	3.27	52
3	2.20	1.94	3.85	50
4	2.88	2.22	2.66	67
5	2.08	2.28	3.24	65
6	2.90	2.03	3.08	58
7	2.00	1.84	4.13	50
8	1.47	2.00	3.2	62

by dividing the total lane-kilometer by the total route-kilometer in the network.

X_3 = Signalized intersection density: calculated as the total number of signalized intersections in the network divided by the total network area in square kilometers.

X_4 = Unsignalized intersection density: calculated as the total number of unsignalized intersections in the network divided by the total network area in square kilometers.

The values of X_1-X_4 are determined for the network under study and are presented in Table 2.

DATA ANALYSIS

The first step in data analysis was the study of the correlations among the variables. In Table 3, the correlation matrix is presented. Then stepwise regression analyses were performed to identify the influence of the above network geometric and control variables on the two-fluid parameters. Stepwise regression is a procedure to select among a number of potential variables, those that are best for inclusion in the regression model. Stepwise examines all candidate

TABLE 2. Geometric and Control Characteristics of the Study Zones.

Zone No.	average intersection spacing (m)	average No. of lanes per street	signalized intersection density (per sq. km)	unsignalized intersection density (per sq. km)
1	420	2.4	3.2	5.7
2	374	2.3	4.4	3.6
3	503	2.4	2.8	3.3
4	404	2.6	2.3	6.0
5	420	2.4	2.0	2.4
6	466	2.8	3.2	3.3
7	456	2.3	4.1	2.3
8	447	3.4	3.3	6.0

TABLE 3. Correlation Matrix of Variables.

Two-fluid variable	average intersection spacing X_1	average No of lanes per street X_2	signalized intersection density X_3	unsignalized intersection density X_4
n	0.25	- 0.04	- 0.48	- 0.13
T_m	- 0.37	0.01	- 0.81	0.34
π	0.56	- 0.30	0.44	- 0.60
k_m	- 0.38	0.41	- 0.71	0.54

variables for the one which best explains the variations in the dependent variable. This variable enters the model. The significance of each variable entering the model is assessed by the **F** statistic at a level of significance specified by the modeler. The process is repeated to find the next most suitable variable to be included in the model. At each step, however, the correlation between pairs of independent variables already in the model are examined. In case of strong correlations between independent variables, the least significant of those variables is excluded from the model.

Four stepwise regression analyses were conducted, with **n**, $\mathbf{T_m}$, π and $\mathbf{k_m}$ as dependent variables. In each case, independent variables X_1 through X_4 (Table 2) were considered to be included in the model. A level of significance of %25 was used for including or removing variables from the model. The resulting models are as follows:

$$n = 3.130 - 0.333X_3 \qquad (R^2 = 0.23) \qquad (11)$$

$$T_m = 3.378 - 0.002X_1 - 0.021X_2 - 0.166X_3 + 0.011X_4 \qquad (R^2 = 0.91) \qquad (12)$$

$$\pi = 0.514 + 0.007X_1 + 0.304X_2 + 0.263X_3 - 0.066X_4 \qquad (R^2 = 0.76) \qquad (13)$$

$$k_m = 97.77 - 0.092X_1 + 7.329X_2 - 6.094X_3 + 0.222X_4 \qquad (R^2 = 0.72) \qquad (14)$$

All the parameters except **n** are well described by the features. The lower $\mathbf{R^2}$ of **n** indicates that it probably correlates with some variables other than the considered one.

The magnitude and direction of influence of the variables on the parameters are determined by the corresponding coefficients which are partially differentials of the parameter with respect to the given variable. For example in Equation 12:

$$\Delta T_m/\Delta X_1 = -0.002$$

Using relationships as mentioned above and analyzing thier coorelations coefficients may yield some important inferences about the general influence of geometric and control features of urban network on the quality of traffic service as follows:

Average Interrsection Spacing

Average intersection spacing has positive correlation with **n** and π and negative correlation with $\mathbf{T_m}$ and $\mathbf{k_m}$. The longer the block length, the higher the **n** and π values and the lower the quality of service. On the other hand, increasing intersection spacing would decrease $\mathbf{T_m}$ and $\mathbf{k_m}$ values as in Equations 12 and 14, resulting in better traffic service because $\mathbf{T_m}$ is a measure of free-flow speed and $\mathbf{k_m}$ is a measure of containment capacity of the network.

Basically, intersection spacing is not a variable under the control of traffic engineer to be used as a geometric tool. However, it is possible to change this variable indirectly by means of some control and geometric measures likewise, closing minor intersections or grade separation of major intersections. Thus, the relations indicate that increasing spacing would not necessarily improve the quality of traffic service in the network.

Average Number of Lanes

According to the correlation matrix (Table 3), the average number of lanes has a positive influence on all the two-fluid parameters. In addition, the Equations 12 and 14 indicate that the measures like prohibition of on-street parking, widening of streets etc. which increase the average number of lanes would be effective in improving traffic service. Decreasing $\mathbf{T_m}$ results in increasing travel speed and higher k_m is due to more uniformity of vehicles distribution in the urban network.

Signalized Intersection Density

In this study, signalized intersections only include the signals with specific signal timing and phasing programs but not flashing signals. According to the Equations 11 and 12 increasing signal density would raise average travel speed and quality of traffic service. At first glance, this may be counter-intuitive in that the signals are often known as increasing stopped delay. It must, however, be noted that in an urban street network, signals have an important role in regulating traffic which in turn may lead to a better quality of service in the network.

On the other hand, increasing signal density would raise parameter π and k_m, resulting in lower traffic service quality. This could be a result of the platooning effect of signals on traffic flow.

Unsignalized Intersection Density

The general influence of this variable on the quality of traffic service is contrary to the signalized intersections. Increasing unsignalized density would raise both T_m and k_m and decrease π. This is a complex effect and the direction of the result is not clear at all. It depends mainly on the local situation. Thus, any traffic improvement of unsignalized intersections through installation of signals should be made according to these considerations.

CONCLUSIONS

The methodology presented in this article provides an analytical tool for quantifying the impact of geometric and control features on the quality of traffic service in an urban street network. Without resorting to the time-consuming and expensive models, traffic engineers can utilize this macroscopic tool to examine the consequences of various policy decisions such as establishing one-way street systems, prohibiting on-street parking, adding or removing signals, etc.

ACKNOWLEDGMENTS

The authors wish to thank the Research Division of Iran University of Science & Technology for permission to publish the paper. They also thank Tehran Traffic and Transportation Organization for its support in collecting the data used in this study.

NOMENCLATURE

f_r	Fraction of vehicles running
f_s	Fraction of vehicles stopped
$f_{s,\min}$	Minimum fraction of vehicles stopped
k_m	Maximum average concentration (veh/km/lane)
k	Average concentration (veh/km/lane)
n	A two-fluid parameter
π	A two-fluid parameter
T_m	Average minimum trip time (min/km)
T_r	Average running time (min/km)
T_s	Average stopped time (min/km)
T	Average trip time (min/km)
v_m	Average maximum running speed (km/hr)
v_r	Average running speed (km/hr)
v	Average speed (km/hr)
X_1	Average intersection spacing (in meters)
X_2	Averge number of lanes per street
X_3	Signalized intersection density (per square kilometers)
X_4	Unsignalized intersection density (per square kilometers)

REFERENCES

1. R. Herman and S. Ardekani, "Characterizing Traffic Conditions in Urban Areas", *Transportation Science*, Vol. 18, No. 2, (1984).

2. S. Ardekani and R. Herman, "A Comparison of the Quality of Service in Downtown Networks of Various Cities Around the World", *Traffic Engineering & Control*, Vol. 26, No. 2, (1985).
3. R. Herman and I. Prigogine, "A Two-fluid Approach to Town Traffic", *Science*, Vol. 204, (1979).
4. S. Ardekani and R. Herman, "Urban Network-Wide Variables and Their Relations", *Transportation Science*, Vol. 21, No. 1, (1987).
5. J. C. Williams, H. S. Mahmassani and R. Herman, "Urban Traffic Network Flow Models", *Transportation Research* Record 1112, (1987).
6. J. C. Williams, H. S. Mahmassani and R. Herman, "Analysis of Traffic Network Relations and Two-Fluid Model Parameter Sensitivity", *Transportation Reserach Record* 1005, (1985).
7. H. S. Mahmassani, J. C. Williams and R. Herman, "Investigation of Network-Level Traffic Flow Relationships", *Transporation Reserach Record* 971, (1984).