training staff and MDPW. It has allowed trainers to combine their training and facilitation expertise with the technical expertise within the organization. Thus training staff and the organization are working cooperatively to help MDPW develop its capabilities and achieve its potential.

IMPLICATIONS

The systems model and operational approach described in this paper helped the Institute for Governmental Services training team provide appropriate training and education programming to MDPW while the organization was undergoing major changes. The models offered frameworks for assessing MDPW and planning how best to serve and work with the organization.

Given the complexity and instability of MDPW's environment, how training staff delivered training became as important as what they delivered. It was critical that staff stop action and reassess not only MDPW but also their own team organization and roles vis-à-vis MDPW. The constant reassessment engaged in by the training staff helped maintain their flexibility and responsiveness to MDPW's needs. To use both Kotter and organization states model terminology, the training team needed to maintain the adaptability of its own elements and to engage in problem-solving processes to continually realign itself with MDPW's changing status. This reassessment and realignment must continue as MDPW emerges from crisis and restabilizes.

As part of their responsibility to MDPW, training staff are attempting to help that organization develop and maintain adaptability and strengthen survival skills. To do this, staff employ a form of action research that involves groups of organization members in all phases of training from needs assessment through program delivery. Using this approach, which stresses problem identification and resolution, staff are helping strengthen the organization's ability to solve problems and take control of its own future. In times of rapid change and organizational transition, this may be the most important survival skill a training unit can develop in an organization.

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Inexpensive Travel Demand Model for Small and Medium-Sized Cities

C. J. KHISTY and ABDULRAHEM AL-ZAHRANI

ABSTRACT

A simplified travel demand model that uses routinely collected traffic ground counts to forecast traffic volumes on a street system is described. It is an internal volume forecasting (IVF) model based on a model first proposed by Low in 1972, and incorporates improvements suggested by Smith and McFarlane in 1978. The model is applied to the city of Spokane, Washington. Results from this application indicate that routinely collected traffic counts in a base year can be used to estimate traffic volumes in a horizon year with reasonable accuracy. By eliminating the need for a home-interview survey, the model provides an inexpensive, quick, and transparent technique for forecasting travel in small and medium-sized cities. The model is also suggested for use in cities of less developed and developing countries because of its simplicity and low cost. The output from this model is essentially trips for all purposes. Home-based, non-home-based, and other trip categories could also be obtained with additional data.

The main objective of transportation planning is to provide the information necessary for making decisions on when and where improvements should be made in the transportation system and for controlling travel and land development patterns that are in keeping with community goals and objectives (1,pp. 8-9). One of the most important pieces of information, which is crucial for such decision making, is horizon-year traffic volumes on the major links of a city's transportation network.

Conventional urban travel demand models, which are currently used to forecast horizon-year traffic volumes, have been the subject of much criticism because of their enormous costs, a significant proportion of which is spent on the collection and analysis of large amounts of data by means of a home-interview survey, for example. These data-hungry models also require extensive computer use for analysis, which further adds to their cost (2-4). Small and medium-sized cities usually lack the financial resources and expertise that are needed to use these models. In 1972 Low proposed an inexpensive travel demand model that used routinely collected traffic counts as a substitute for the conventional home-interview survey (2). Low's model has since been modified, improved, and tested by several researchers (3-6).

An evaluation of the effectiveness of a modified form of Low's model in a medium-sized urban area is presented. Socioeconomic variables needed for the model are derived from census data. A brief discussion of the development of the model, its structure, and its theoretical limitations is presented. The model is then applied to the city of Spokane (1980 population = 171,300) for the base year 1970, and a forecast of the traffic volumes on the street network is obtained for the horizon year 1980. The results are compared with actual ground counts for 1980. Conclusions about the prediction capability of the model and its suitability for general use are presented in the last section of this paper.

BACKGROUND

A travel demand forecasting model, which used routinely collected traffic ground counts, was originally proposed by Low (2) in 1972. Traffic volumes in the base year were used to calibrate the model. The horizon year's socioeconomic variables and the base year-calibrated model were then used to predict the future traffic volume in selected links of the network in the horizon year. Low's model is essentially an internal volume forecasting (IVF) procedure that estimates trips for all purposes.

Low tested the model in a small urban area in West Virginia and compared the results with forecasts obtained from conventional travel demand modeling techniques, and the results obtained were reasonably good--model root-mean-square (rms) was 24 percent.

In 1976 a similar approach was proposed and tested on a hypothetical 22-link network by Hogberg (3). He confirmed the validity of Low's approach in this hypothetical situation. An evaluation of Low's model was conducted by Smith and McFarlane (4) in 1978. Their findings indicated that the model produced reasonable estimates of both base year and future year traffic volumes. The estimation error in corridor volumes ranged between 1 and 7 percent. However, this study called attention to some theoretical limitations of the model that will be discussed later.

In 1981 Willumsen (5) compared Low's model with three similar models and asserted that, by resolving the model's theoretical limitations, it could be recommended for use in small and medium-sized cities because it offers three attractive features: (a) simplicity of use, (b) computational efficiency, and (c) low cost.

LOW'S MODEL

This model was developed on the assumption that the traffic volume on each link in a transportation network is proportional to what Low referred to as "the interzonal trip probability factor." The value of the trip probability factor provides a measure of the number of vehicular trips between the different zones in the urban area. The mathematical form of the interzonal trip probability factor is given by the following expression:

$$f_{ij} = P_i A_j t_{ij}^{-n} \quad (1)$$

where

f_{ij} = interzonal trip probability factor between zones i and j,
P_i = a socioeconomic characteristic of zone i that is related to trip production (Low used population),
A_j = a socioeconomic characteristic of zone j that is related to trip attraction (Low used employment),
t_{ij} = travel time between zones i and j, and
n = some exponent to be determined by calibration (Low assumed n = 2).

The model mechanism is explained as follows:

1. Socioeconomic variables (P_i's and A_j's) for the zones are determined for the base year, and the interzonal trip probability factors (f_{ij}'s) are calculated between all the zones in the study area.
2. Trip probability factors are assigned to the transportation network using one of the traffic assignment techniques. The all-or-nothing assignment, via the shortest routes, is probably the simplest and easiest technique appropriate for this model.
3. The total trip probability factors for selected links on the major streets are obtained by adding the f_{ij}'s assigned to each link.
4. The corresponding traffic volumes (in the base year) on each link are obtained from routinely collected traffic counts, and a linear relationship between the traffic volumes and f_{ij}'s is established using the following linear regression equation:

$$V_{k\ell} = a + bP_{ij}^{k\ell} \sum_{ij}\sum f_{ij} \quad (2)$$

where

$V_{k\ell}$ = traffic volume on the link $k\ell$,
f_{ij} = interzonal trip probability factor between zones i and j, and
a,b = parameters to be determined by calibration.

$P_{ij}^{k\ell}$ is the probability that the trip between zones i and j will use link $k\ell$. The value of $P_{ij}^{k\ell}$, using the all-or-nothing assignment technique, is

$$P_{ij}^{k\ell} = \begin{cases} 0 & \text{if the link } k\ell \text{ is not used by the trip maker between zones i and j} \\ 1 & \text{if the link } k\ell \text{ is used by the trip maker between zones i and j.} \end{cases}$$

5. The least-squares method is used to calibrate the model for the base year for which the two parameters (a and b) can be determined. Finally, to estimate the traffic volume for the horizon year, it is necessary to establish the projected interzonal trip probability factors using the socioeconomic variables of the horizon year.

MODEL DEFICIENCIES AND POTENTIAL IMPROVEMENTS

Smith and McFarlane (4) identified two misspecifications in Low's model: first, in representing trip productions and attractions by production and attraction "characteristics," and second, in the omission of origin-zone accessibility in the denominator of the probability factors.

To eliminate these two errors, Smith and McFarlane recommended "replacement of the zonal production and attraction characteristics by direct estimates of trip productions and attractions, and inclusion of origin-zone accessibility in the denominator of the probability factor" (4,p.39). This improvement resulted in a formulation that is identical to a simplified gravity model.

When Low applied his model, P_i was assumed to be the population of zone i, A_j was assumed to be employment in zone j, and the travel time exponent (n) was assumed to be two. The suggested production and attraction variables, as well as the friction factors that are used in the present study, are as follows:

1. Because work trips are the least flexible of all trips, the production zone variable (P_i) that is used here is the number of employees who reside in zone i (ER_i).
2. Similarly, the attraction zone variable (A_j) is the number of employees who work in zone j (EW_j).
3. Because the trip interchange index is of the gravity model type, it is appropriate to calculate the friction factor [$F(C_{ij})$] values in a manner similar to that used in trip distribution models. $F(C_{ij})$ is an indirect indicator of the cost of travel between zones. Based on the work of Zaryouni and Kannel (7), the friction factor is

$$F(C_{ij}) = \exp(-0.10t_{ij}) \qquad (3)$$

The second theoretical limitation can be avoided simply by dividing the attraction term (EW_j) at the destination by the total attractions ($\sum_j EW_j$) of the study area. Also, the term interzonal trip probability factor can be replaced by another term that could be called the interzonal trip interchange index (I_{ij}). This simple modification does not compromise the simplicity and the computational efficiency of the model (5). Therefore, Equation 1 can be rewritten as

$$I_{ij} = (ER)_i[(EW)_j/_j(EW)_j]F(C_{ij}) \qquad (4)$$

and the link traffic volume can be calculated as

$$V_k = a + bP_{ij}^{k\ell}\sum_i\sum_j f_{ij} \qquad (5)$$

MODEL APPLICATION

The modified model was applied to the city of Spokane as a case study area. The sequential steps of the model application are shown in Figure 1. The

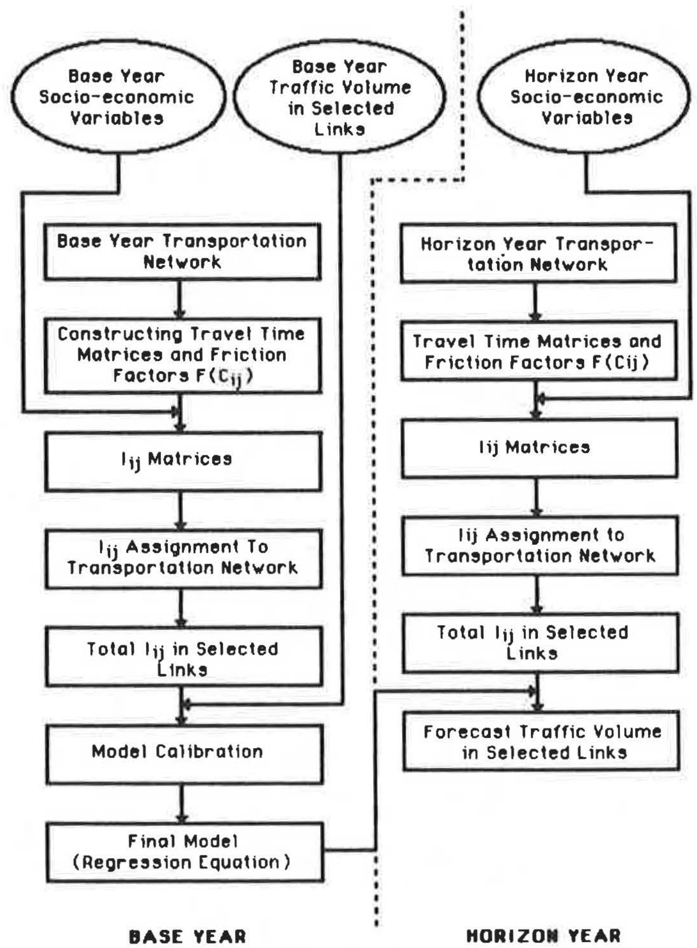

FIGURE 1 Sequence of model application.

city of Spokane was divided into 26 planning areas for the purposes of this model.

MODEL CALIBRATION

To calibrate the model for the base year 1970 the following input data were gathered:

1. A base map showing the major transportation network (Figure 2). The network configuration and the link speeds were investigated to set up travel time matrices.

2. Traffic volumes for selected links of the surface network with ground counts throughout the network. These traffic volumes are a combination of internal-internal (V_{II}), internal-external (V_{IE}), external-internal (V_{EI}), and external-external (V_{EE}) trips. V_{IE}, V_{EI}, and V_{EE} trips were subtracted from the total traffic count (V_T). Because cordon counts were not readily available for V_{EE}, V_{EI}, and V_{IE}, an approximate method of obtaining these volumes was used as suggested in NCHRP Report 187 (8). This procedure is necessary because the trip interchange indices are computed between zones within the study area and the traffic volume used must be the internal traffic volume on the link.

3. Socioeconomic characteristics, related to each production and attraction planning area. The production zone characteristics (number of employees residing in zone i) were obtained from 1970 Census data, and the attraction zone characteristics (number of employees working in zone j) were obtained from data provided by the Spokane Regional Conference.

Using the input data in steps 2 and 3, a matrix of the trip interchange indices was calculated for the base year. The resulting matrix of I_{ij}'s was then assigned to the transportation network using the all-or-nothing assignment technique.

The estimate of the two parameters a and b in Equation 5 was performed by selecting 37 links on the city's street network. This selection covered the entire set of links on the major street system (Figure 2). When the traffic volume values for these 37 links were plotted against the corresponding I_{ij}'s (Figure 3) it was observed that it would be appropriate to use two equations: the first for those links with a traffic volume of fewer than 4,500 (Figure 4) and the second for those links with a

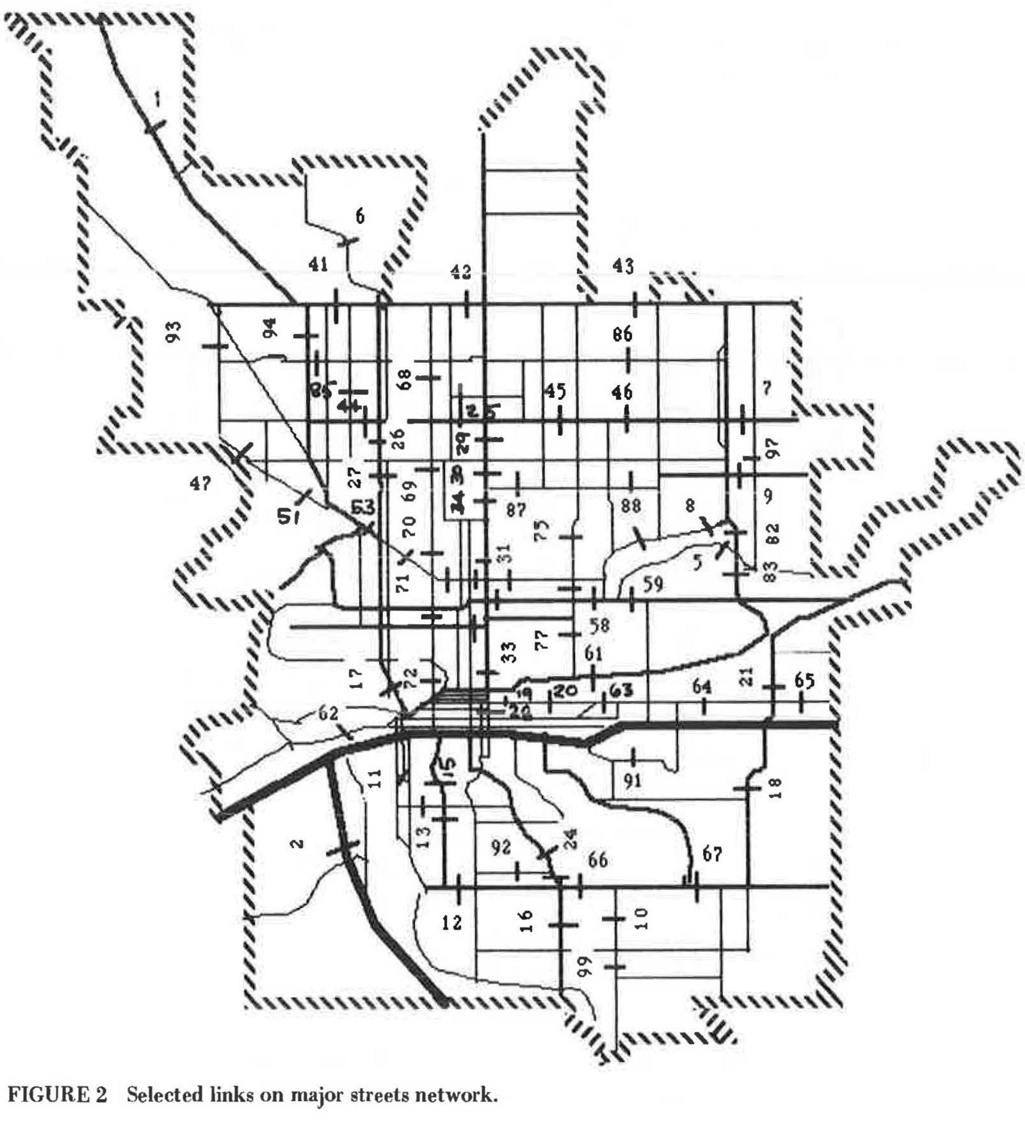

FIGURE 2 Selected links on major streets network.

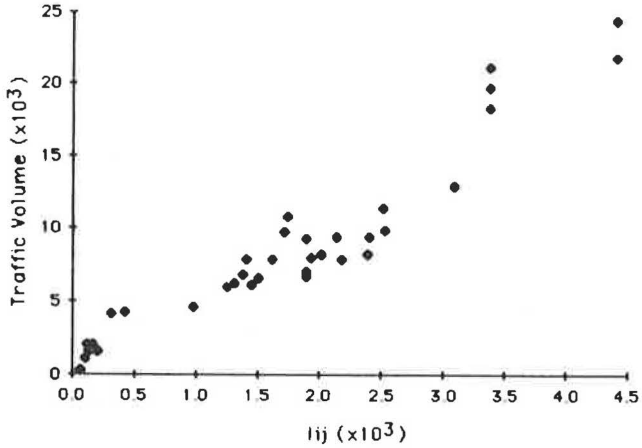

FIGURE 3 Traffic volume versus I_{ij}'s.

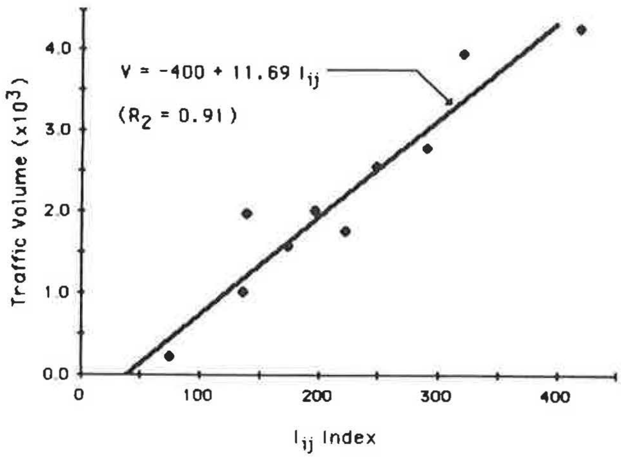

FIGURE 4 Regression line for links with traffic volume less than 4,500.

traffic volume equal to or more than 4,500 (Figure 5). Accordingly, two linear regression equations were obtained by means of the least-squares method:

$$V^{70}_{k\ell} = -400 + 11.69 P^{k\ell}_{ij} \sum_{ij}\sum I_{ij}$$

$R^2 = 0.91$ $t_0 = 9.142 > t_{.005} = 3.355$
for traffic volume < 4,500 (6)

$$V^{70}_{k\ell} = -1,650 + 5.40 P^{k\ell}_{ij} \sum_{ij}\sum I_{ij}$$

$R^2 = 0.89$ $t_0 = 14.49 > t_{.005} = 2.779$
for traffic volume $\geq$ 4,500 (7)

MODEL FORECASTING

The calibrated model for the base year 1970 was used to forecast the traffic volume on the same links of the major street system for the horizon year 1980. It was assumed that the major street network would not change significantly between the base year and the horizon year. The only information that was necessary for the application of the modified model was the two variables (ER_i and EW_j for 1980) that were obtained exogenously. These values as well as the friction factor matrix were used to obtain the horizon year trip interchange indices (I_{ij}'s) ma-

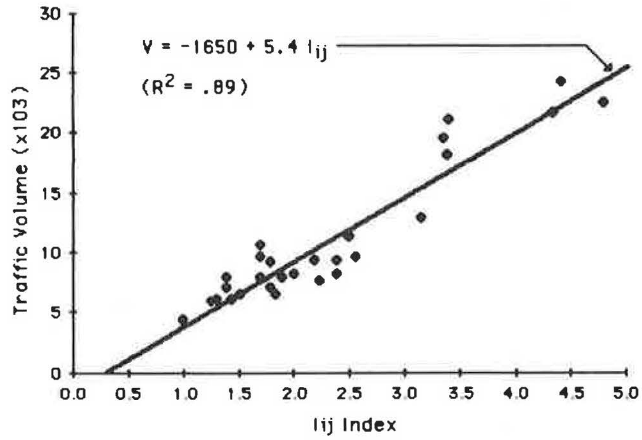

FIGURE 5 Regression line for links with traffic volume greater than 4,500.

trix. The next step was to assign the I_{ij}'s to the transportation network. The total I_{ij}'s in each link were added, and then the internal-internal traffic volume (V_{II}) in the links was obtained from Equations 6 and 7. The external trips ($V_{EE} + V_{EI} + V_{IE}$) were added to the V_{II} trips to obtain the total link volumes (V_T) in 1980. These external trips were forecast from base year data.

PREDICTING TRAFFIC VOLUME ON OTHER LINKS FOR THE HORIZON YEAR

It is evident from the model structure that the traffic volume on those links that lie on the minimum-path route are obtained by applying Equations 6 and 7. The following procedure was used for those links on the major street network that did not lie on the minimum-path route: The predicted traffic volume (obtained from the model) and the base year traffic volume on these links were used to construct a simple regression line. The predicted traffic volume was taken as the dependent variable ($V^{80}_{k\ell}$), the actual base year traffic volume was taken as the independent variable ($V^{70}_{k\ell}$), and the following equations were obtained:

$$V^{80}_{k\ell} = 600 + 1.58 V^{70}_{k\ell}$$

$R^2 = 0.84$; $t_0 = 3.654 > t_{.005} = 3.499$
for links with traffic volumes < 4,500 in the base year (8)

$$V^{80}_{k\ell} = -1,100 + 1.38 V^{70}_{k\ell}$$

$R^2 = 0.89$; $t_0 = 14.837 > t_{.005} = 2.779$
for links with traffic volumes $\geq$ 4,500 in the base year (9)

where

V^{80}_k = estimated traffic volume on link k in the horizon year and
V^{70}_k = actual traffic volume on link k in the base year.

This is a straightforward procedure, whereby base year volumes on non-minimum-path routes are used to obtain an estimate of design year volume.

RESULTS AND MODEL ACCURACY

The output of the modified model in terms of link volumes on the major street network is given in Tables 1 and 2. For low-volume links, the ratio of actual-to-estimated traffic volumes for the horizon year ranged from 0.63 to 1.40, and the rms error was 32. For the high-volume links the corresponding range was from 0.70 to 1.52, and the rms error was 18. However, most link volume estimates were within 15 percent of the actual volumes.

A comparison of the modified model with Low's original model indicates that the modified model output gives somewhat better results. This comparison is given in Table 3. Also, a comparison of observed and estimated horizon year link volumes by volume range is given in Table 4. Although the actual-to-estimated volumes for the horizon year ranged from 0.93 to 1.27, most volume groups were within 10 percent of the actual volumes.

CONCLUSIONS

The primary objective of applying a modified form of Low's model to the city of Spokane was to evaluate its utility in estimating street link volumes in the horizon year using routinely collected traffic counts. The model produces reasonably reliable results. Because network configuration and census data are generally available, the effort required to work the model for a small or medium-sized city might involve 10-15 man-days. This effort represents a small fraction of the time and the money that are needed to run the conventional models. The model combines several conventional submodels into one process and

TABLE 1 Comparison of Actual and Estimated Traffic Volume (< 4,500)

	Base Year 1970			Horizon Year 1980		
Link No.	Actual Traffic Volume (V_o)	Estimated Traffic Volume (V_e)	V_o/V_e	Actual Traffic Volume V_o	Estimated Traffic Volume V_e	V_o/V_e
1	600	800	0.75	2,200	3,500	0.63
2	4,750	4,000	1.19	9,400	7,000	1.34
3	5,000	4,900	1.02	8,700	8,000	1.09
4	1,550	1,600	0.97	1,750	2,200	0.80
5	1,750	2,200	0.80	3,600	4,000	0.90
6	1,750	1,950	0.90	2,200	3,050	0.72
7	2,950	3,200	0.92	4,900	6,850	0.72
8	4,000	3,400	1.18	6,000	4,300	1.40
9	4,300	4,500	0.96	7,300	5,700	1.28
Total	26,650			46,050		

Note: For base year, $V_{\bar{o}}$ = 2961; $(V_o - V_e)^2$ = 1,320,000; RMS error = 434.32; and % rms error = 14.66 ≈ 15.

TABLE 2 Comparison of Actual and Estimated Traffic Volume (> 4,500)

	Base Year 1970			Horizon Year 1980		
Link No.	Actual Traffic Volume (V_o)	Estimated Traffic Volume (V_e)	V_o/V_e	Actual Traffic Volume V_o	Estimated Traffic Volume V_e	V_o/V_e
10	4,500	3,700	1.22	5,050	4,700	1.07
11	6,000	5,200	1.15	8,500	5,850	1.45
12	6,200	5,600	1.11	6,650	5,400	1.23
13	6,200	6,300	0.98	7,150	6,450	1.11
14	6,600	8,600	0.77	9,050	7,500	1.21
15	7,750	6,100	1.27	8,200	5,400	1.52
16	8,150	8,300	0.98	9,000	12,650	0.71
17	9,000	10,200	0.88	17,600	14,400	1.22
18	9,250	12,100	0.76	14,900	17,300	0.86
19	9,500	9,100	1.04	9,500	9,350	1.02
20	9,700	10,600	0.92	11,500	12,200	0.94
21	10,350	11,000	0.94	20,850	13,600	1.61
22	11,350	9,400	1.21	11,650	13,200	0.88
23	11,500	13,800	0.83	14,700	17,800	0.83
24	12,350	9,500	1.30	12,400	13,200	0.94
25	12,600	13,200	0.95	14,250	14,800	0.96
26	13,250	16,400	0.81	16,400	23,400	0.70
27	14,450	16,400	0.88	18,250	23,400	0.78
28	17,600	19,700	0.89	21,500	26,350	0.82
29	23,750	22,200	1.07	28,500	26,700	1.07
30	25,100	22,000	1.13	31,000	26,700	1.16
31	26,600	22,000	1.20	30,400	26,700	1.14
32	27,300	27,700	0.99	28,700	34,100	0.84
33	28,200	30,100	0.94	30,800	36,100	0.85
34	29,800	27,700	1.08	32,500	34,100	0.95
100	27,800	26,800	1.04	37,900	38,400	0.95
101	34,100	33,300	1.02	50,400	53,300	0.95
102	31,700	33,300	0.95	48,300	53,300	0.91

Note: For base year, $V_{\bar{o}}$ = 15,737; $(V_o - V_e)^2$ = 97,612,500; rms error = 1,937.60; and % rms error = 12.31. For horizon year, $V_{\bar{o}}$ = 19,880; $(V_o - V_e)^2$ = 359,055,000; rms error = 3,580; and % rms error = 18.01.

TABLE 3 Summary of Results

		Traffic Volume <4,500		Traffic Volume ≥4,500	
Year	Model	RMS Error	% RMS Error	RMS Error	% RMS Error
1970	Low	710	24	2,302	17
	Modified	434	15	1,938	12
1980	Low	2,234	44	3,310	19
	Modified	1,616	32	3,716	18

TABLE 4 Comparison of Actual and Estimated Traffic Volume for All Link Groups (modified model)

Group	Volume Range	Estimated Avg. Volume (E)	Actual Avg. Volume (A)	A/E	Error %
1	1,500-3,000	2,600	2,050	1.27	+26.8
2	3,001-5,000	4,100	4,250	0.96	-3.5
3	5,001-7,000	6,100	5,900	1.03	+3.4
4	7,001-10,000	8,300	8,500	0.98	-2.4
5	10,001-15,000	13,400	13,200	1.02	+1.5
6	15,001-20,000	17,550	17,400	1.01	+0.9
7	20,001-25,000	23,400	21,700	1.08	+7.8
8	25,001-30,000	26,600	28,600	0.93	-7.0
9	30,001-35,000	34,100	31,200	1.09	+9.3
10	>35,000	45,300	45,500	1.00	-0.4

the output in terms of traffic volumes can be statistically described and tested. In summary, the model is quick, reliable, and transparent for forecasting travel in small and medium-sized cities. Caution, however, needs to be exercised regarding

1. The choice of socioeconomic variables--more experience needs to be gained from further applications in cities of varying sizes;
2. The application of this model to cities having a comparatively high percentage of mass-transit patronage;
3. The fact that the output from the model is in terms of trips for all purposes; home-based, nonhome based, and other trip categories could possibly be worked out with additional data;
4. External-external, external-internal, and internal-external trips--Count stations located on the cordon line would be most helpful in dealing with the forecast of such trips;
5. Using this type of model for crucial policy options--The model is sensitive only to network changes; and
6. The high potential for correlation between adjacent links on the network in the regression analysis--This problem could possibly be alleviated or at least reduced by randomly selecting links on the network rather than using two adjacent links. In a large network it may be necessary to use a Monte Carlo technique for the selection of links.

The model appears to be of particular use in the following cases:

1. Modeling small and medium-sized cities, especially freestanding cities in rural regions and extensions of metropolitan areas;
2. Modeling cities in less developed and developing countries where urbanization is taking place at a fast rate, where qualified transport planners are not available, in situations in which a country budget does not allow conventional transport models to be used, and in situations in which long-range planning has little meaning in view of the uncertain changes in urbanization; and
3. Analysis connected with the transportation system management element.

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