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SYNTHESIS OF VEHICLE TRIP PATTERNS IN SMALL URBAN AREAS

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This paper presents the development of a simplified technique for trip generation and distribution for the small urban area of Madisonville, Kentucky. This model, developed on the basis of experience in small urban areas, is an economical alternative to an internal origin and destination study. The input to the study consists of an external origin and destination survey, existing daily traffic volumes on the major street system, and limited socioeconomic data. Internal vehicle trips and corresponding travel time factors were developed based on experience in small urban areas. Internal and external trips were related to population and employment through a multiple linear regression procedure. The conventional gravity model was used to distribute trips. Analytical and statistical tests were used in the calibration of the model. The ultimate test was for the model to reproduce as closely as possible the ground counts on the major street system. The conclusions of the study were that the developed model adequately synthesized internal trip patterns in the Madisonville urban area. The model uses 3 socioeconomic factors that can be easily forecast—population, total employment, and industrial employment. Such a procedure is recommended for use in small urban areas. However, the model needs to be developed and calibrated for each small urban area.

•IN RECENT YEARS, a major emphasis in transportation planning in urban areas has been development of procedures and methodology for solving planning problems in large urban areas. The conventional comprehensive origin and destination surveys with the use of home interviews to collect existing travel data often cannot be economically justified for small urban areas (population less than 50,000). Synthesis of existing travel patterns can provide a feasible alternate to the conventional comprehensive origin and destination surveys. In addition, typical transportation study models require data for many independent variables, yet comprehensive inventories of all of these items often cannot be warranted for studies in small urban areas.

One of the prerequisites for detailed forecasts of travel patterns is a conceptually reasonable, operationally realistic, and financially feasible model for trip generation and trip distribution. This paper presents such a model that was developed for synthesizing trip patterns in the Madisonville, Kentucky, urban area. The synthesis procedures provide a means for determining existing travel patterns and for forecasting future trip patterns. Moreover, the model was 3 socioeconomic factors that can be easily projected—population, total employment, and industrial employment.

The Madisonville urban area is situated in Hopkins County, Kentucky, 110 miles southwest of Louisville and 60 miles northeast of Paducah. In 1968, the study area population was 18,224, and the total employment in the study area was 6,036.

An external origin and destination survey was conducted for the Madisonville study area in 1968. At the same time, surveys of a planning-inventory nature were performed to provide data for use in all phases of the comprehensive plan. The study area was divided into 50 analysis zones. Eight external stations were established. The results

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of these inventory surveys provide the base data regarding characteristics of the area and existing travel patterns within the area on a typical day. These data are needed for model preparation.

METHOD OF APPROACH

The approach used in the Madisonville Urban Area Transportation Study (MUATS) has been to develop an overall traffic model that will adequately predict the existing travel pattern within the study area on a typical weekday. Development of this model is composed of 2 distinct phases—trip generation and trip distribution. These phases incorporate the use of mathematical expressions or equations that are based both on observations of travel within the study area and on various travel-related characteristics of the study area. A general outline of the model development procedures utilized in the Madisonville study is given in Table 1 and is described in the following paragraphs.

In the trip-generation phase of the model development process, generation is defined as the sum of trips beginning and ending in an area. In the development of trip attractions and trip productions, the traditional trip-purpose concept of home-based trips and non-home-based trips is followed. For home-based trips, a trip production is defined as the home end of the trip, which can be either a trip origin or a trip destination. A trip attraction is defined as the nonhome end of the home-based trip, and it also can be either a trip origin or a trip destination. In the non-home-based category of trips, the origin is always the production end, and the destination is always the attraction end.

Because an internal origin and destination survey was not available for the Madisonville study area, the internal trip-attraction and trip-production equations were developed by using the results of comprehensive origin and destination studies in other small urban areas. In the development of the mathematical model for internal and external trips, the data from the external origin and destination survey conducted for the Madisonville urban area were summarized for each traffic zone. These observations were then mathematically related to a number of known conditions within each zone, such as population, dwelling units, and employment. From the series of mathematical expressions analyzed, the best estimating equation was chosen for use in calculating both the existing and the future internal and external trip attractions. The selection of the appropriate internal and external trip-attraction equation was based on a consideration of the possibility that travel characteristics different from those existing at the time of the external origin and destination survey might occur.

The trip-distribution analysis involves a determination of the number of trips that will be produced in 1 zone and attracted to another zone. The conventional gravity model was used for the distribution of trips among zones. This trip-distribution process requires trip-production and trip-attraction data for each zone in the study area and a measure of the spatial separation between each pair of zones in the study area. Thus, the need for compatibility between the trip-generation analysis and the trip-distribution analysis becomes apparent.

The following objectives are important in the development of a mathematical traffic model:

1. Establishment of associations between model elements (trip generation and trip distribution) and the physical development of the study area;
2. Maintenance of control of the distribution rates for trips with different trip lengths;
3. Development of traffic-model procedures compatible with a total model concept (direct progression from an updated planning data file to estimated traffic on the streets); and
4. Maximization of the adaptability of the results to continuing planning activities.

A number of validity checks (statistical and analytical) are made to ensure acceptability of a traffic model. The basic philosophy involves an acceptance of the model if it reproduces the ground counts to an adequate degree. In general, the primary purpose of the validity checks is to ensure the best possible match between the total traffic volume on each segment of the major street system as derived from the models and as measured in the field. Discrepancies between these 2 values are resolved until the

TABLE 1

OUTLINE OF SIMULATION PROCEDURE (MUATS)

I. Trip generation
  - A. Internal trips
    1. Determine internal vehicle trip rate per capita based on experience in urban areas of less than 50,000 population.
    2. Determine percentage distribution among trip purposes (home-based work, home-based nonwork, and non-home-based) based on experience in relatively small urban areas.
    3. Select pertinent trip generation equations by reviewing mathematical models for small urban areas.
    4. Determine existing internal zonal productions and attractions by purpose by using selected trip-generation equations cross-checked with reasonable trip rate per capita and reasonable percentage distribution among trip purposes.
    5. Balance attractions to productions for each trip purpose. Adjust if necessary.
  - B. Internal and external trips
    1. Develop multiple linear regression model based on trip data from external origin and destination survey.
    2. Use population, total employment, dwelling units, commercial employment, industrial employment, and public employment as the only independent variables.

II. Existing major street network
  - A. Prepare existing major street network according to new Federal Highway Administration procedures.
  - B. Assign speeds to the various facilities based on functional class and location within the urban area.

III. Trip distribution
  - A. Internal trips
    1. Determine travel time factors for each trip purpose based on experience in relatively small urban areas.
    2. Distribute productions and attractions from step 1 by using selected travel time factors and the existing major street network in accordance with gravity model procedures.
       - a. Use 1-min terminal time in residential zones, 2 min in industrial areas, and 2 to 3 min in commercial areas (3 min in the CBD).
       - b. Check resulting trip length frequencies for reasonableness.
  - B. Internal and external—Develop the internal and external travel time factors from the existing trip patterns as obtained from the external origin and destination survey, in accordance with standard gravity model procedures.

IV. Traffic assignment
  - A. Assign the internal and external trips, memory J, to the existing major street network on an all-or-nothing basis.
  - B. Assign the total trips, memory J, (internal and external trips, through, and distributed internal trips) to the existing major street network on all-or-nothing basis.
  - C. Plot assigned volumes and ground counts on a major street network map.

V. Validity checks
  - A. Compare total assigned volumes with most recent ground counts for the major streets.
  - B. Compare total vehicle-miles by street class for the synthetic data and the ground counts.
  - C. Screenline comparisons
    1. Establish north-south and east-west (general orientation) screenlines.
    2. Establish loop screenlines around the CBD and surrounding area.
    3. Compare total volumes at each screenline segment for the synthetic data and ground counts.
  - D. Trip comparisons and link volumes—Analyze frequency distribution of differences between ground counts and assigned volumes. For each volume group, determine the root mean square error. Apply this test to the final calibration of the models only.

VI. Model adjustments
  - A. Adjust the models according to results of comparisons (step V) between synthetic data and ground counts.
  - B. Adjust travel time factors if total vehicle-miles agree reasonably but the distribution by location is off.
  - C. Adjust the zonal productions and attractions up or down if total number of trips is not being simulated.
  - D. Adjust both travel time factors and the productions and attractions if both the total vehicle-miles and the distribution by location are off.
  - E. Adjust speeds so that model is brought as much as possible to link-by-link agreement with ground counts.

TABLE 3

INTERNAL VEHICLE TRIPS BY PURPOSE

Study Area	Home-Based Work (percent)	Home-Based Nonwork (percent)	Non-Home-Based[a] (percent)
Murray, Kentucky	14.9	48.1	37.0
Pine Bluff, Arkansas	13.5	48.6	37.9
Fort Smith, Arkansas	22.5	38.7	38.8
Kingsport, Tennessee	20.4	42.9	36.7
Greenville, South Carolina	16.9	39.6	43.5
Memphis, Tennessee	21.2	41.5	37.3
Pulaski, Arkansas	21.8	47.3	30.9
Avg	18.8	43.8	37.4

[a] Includes truck and taxi trips.

The trip-generation equations from the 3 urban areas of Pine Bluff, Fort Smith, and Kingsport were combined with the selected trip-generation rate based on data given in Table 1 to develop the initial trip-generation equations to be used in the MUATS travel synthesis. The trip-generation equations resulting from this analysis are as follows.

Production Equations

1. Home-based work = 0.42 (population)
2. Home-based nonwork = 1.02 (population)
3. Non-home-based = 0.34 (population) + 1.57 (employment)

Attraction Equations

1. Home-based work = 1.268 (employment)
2. Home-based nonwork = 0.40 (population) + 2.22 (total employment - industrial employment)
3. Non-home-based = 0.34 (population) + 1.57 (employment)

The following total trips by trip purpose result from application of these equations and check closely with the initial trip-purpose distribution and per capita trip rate:

Trip Purpose	Internal Trips Number	Internal Trips Percent	Vehicle Trips Per Person
Home-based work	7,653	18.2	0.42
Home-based nonwork	18,589	44.4	1.02
Non-home-based	15,675	37.4	0.86
Total	41,917	100.0	2.30

As given in Table 2, there are ranges of reasonable internal trip-generation rates for use in this study. The selected trip rate of 2.30 internal vehicle trips per capita was considered reasonable for the initial trial synthesis of the internal vehicle trips. It was anticipated that this initial trip rate and, consequently, the trip-generation equations would require modification to achieve adequate balance between data and actual vehicular travel information. The section of this paper dealing with validity checks discusses the adjustments made in the trip rate during overall model calibration and presents the final trip rate and corresponding trip-generation equations.

Internal and External Attractions

Because an external origin and destination survey had been conducted for the Madisonville urban area, standard regression techniques were used in developing the internal and external trip-generation equation. The particular analysis procedure used in this study is referred to as a stepwise regression procedure. In this procedure, a sequence of multiple linear regression equations are computed in a stepwise manner in which 1 variable is added to the regression equation at each step. The variable added is the one that will show the greatest increase in the predictive accuracy of the equation. The IBM 1130 statistical package—stepwise multiple linear regression program—was used in performing this analysis.

The multiple linear regression procedure is very well documented in statistics textbooks, and no attempt will be made here to explain the procedure used and the various analytical and statistical tests conducted. The procedures used were in line with those recommended by the Bureau of Public Roads (10). Table 4 gives the series of equations developed, the selected equation, and related evaluation statistics.

TRIP-DISTRIBUTION MODEL

The trip-distribution model technique used in the Madisonville Urban Area Transportation Study was the gravity model. Because the basic approach is well known and accepted, a detailed discussion of all underlying principles and techniques is not repeated in this report (see 9, 10, 11, and 12 for specific details). However, pertinent examples are given in the ensuing discussions to illustrate the results obtained in the Madisonville study.

The basic gravity model expression relates trip interchanges between 2 zones in terms of the total trips produced in the zone of production, the total trips destined to the zone of attraction, and measures of the spatial separation of the 2 zones. Spatial separation relates primarily to travel time information and involves the development of relative tri-distribution rates for stipulated increments of time between zones. The gravity model expression is stated normally in the following general form:

$$T_{i-j} = \frac{P_i A_j F_{i-j}}{\sum_{x=1}^{n} A_x F_{i-x}}$$

where

T_{i-j} = trips produced in zone i and attracted to zone j;
F_{i-j} = relative trip-distribution rate reflecting the spatial separation between zones i and j;
P_i = total trips produced in zone i;
A_j = total trips attracted to zone j;
n = total number of zones;
F_{i-x} = relative rate for distributing trips between zones i and x, where x varies from 1 to n; and
A_x = total trips attracted to zone x, where x varies from 1 to n.

Internal Trips

Application of the gravity model for distributing the internal trips requires that the zonal productions and attractions and the relative trip-distribution rates, F, be known. The synthesis of the internal vehicle trip productions and attractions by purpose was presented earlier in the section on trip generation analysis.

In preparation for the distribution of internal trips and for the calibration of the internal and external model, the existing major street and highway networks was prepared. The street and highway network was prepared in accordance with the specifications outlined by the Bureau of Public Roads in 1964 (12). Speeds on each facility contained in the existing network were estimated on the basis of functional classification and relative location within the urban area. Intrazonal driving times were calculated by applying an estimated speed for the local street system to average distances

TABLE 4

INTERNAL AND EXTERNAL TRIP ATTRACTIONS

Generation Equation	Cases[a]	Multiple Correlation Coefficient R	Mean	Standard Error of Estimate	Coefficient of Variation[b]	Student t-Test				Intercept as Percentage of Mean[c]
						1st Variation	2nd Variation	3rd Variation	4th Variation	
1. INT-EXT ATT = 77.6381 + 2.6163 (employment)	50	0.95	393	206	52	21	—	—	—	20
2. [d]INT-EXT ATT = 44.7115 + 0.3434 (population) + 2.5928 (employment)	50	0.97	393	172	44	5	25	—	—	11
3. INT-EXT ATT = -27.1529 + 0.3154 (population) + 2.3491 (employment) + 0.9009 (public employment)	50	0.97	393	153	39	5	21	4	—	7
4. INT-EXT ATT = -3.9865 + 0.2859 (population) + 1.1695 (employment) + 1.2963 (commercial employment) + 2.0530 (public employment)	50	0.98	393	139	35	5	3	3	5	1

[a] The number of zones used as observations in developing the equation.

[b] The standard error of estimate divided by the mean and expressed as a percentage.

[c] The constant term in the equation.

[d] Selected equation for forecasting purposes.

measured from the centroid of each zone to its extremities. These intrazonal times averaged 1 min in the Madisonville area. Terminal times were estimated based on consideration of the time spent walking to and from a parking place and the time spent looking for a parking place. The resulting terminal times for the MUAT study varied from 1 min in residential zones to 3 min in the CBD. Intrazonal travel time was then computed by adding intrazonal driving time to twice the terminal time.

Development of the initial travel time factors to be used in the MUAT study was based on a review of similar information of other small urban areas. These urban areas included Fort Smith, Arkansas; Pine Bluff, Arkansas; Kingsport, Tennessee; Murray, Kentucky; and average data from 7 cities in Iowa. The resulting plots of this information are shown in Figure 1 for each of the 3 trip purposes used in the internal trip-generation analysis previously discussed. In some instances, various curves were shifted so that all curves would pass through a common point. However, the basic shape of the curve and, hence, the relative values represented by the curve were not altered by making the shift. This common point was selected at F = 100 and t = 4 min, inasmuch as travel time factors for the first 3 to 4 min are of doubtful value in a gravity model distribution. Table 5 gives the initial travel times selected for use in the distribution of internal trips for the Madisonville study and based on the values obtained from the analysis of

TABLE 5

INITIAL TRAVEL TIME FACTORS BY TRIP PURPOSE

Travel Time[a] (min)	Work	Nonwork	Non-Home-Based
1	200	360	310
2	156	250	200
3	124	160	135
4	100	100	100
5	85	75	72
6	72	60	53
7	62	45	41
8	54	36	32
9	47	27	25
10	41	19	21
11	36	14	18
12	33	11	16
13	29	9	13
14	26	7	11
15	22	6	10
16	20	5	8
17	16	4	7
18	14	3	6
19	11	2	5
20	9	1	4
21	7	—	3
22	5	—	3
23	3	—	2
24	2	—	1
25	1	—	—

[a] Includes terminal time.

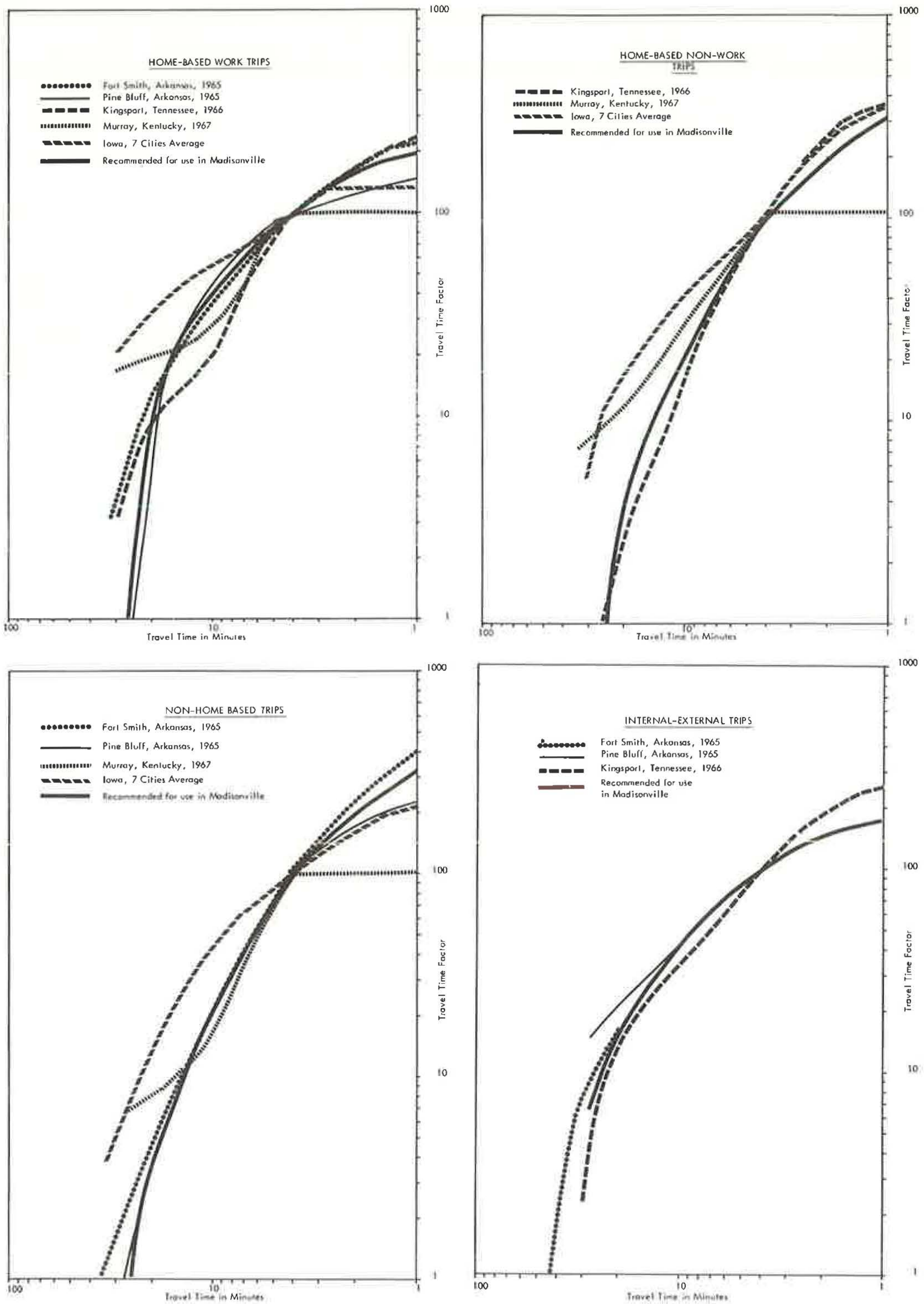

Figure 1. Travel time factor comparisons.

other small urban areas shown in Figure 1. The trip length frequencies shown in Figure 2 are derived from application of the gravity model expression to the zonal productions and attractions for each purpose obtained from the generation analysis.

As shown in Figure 2, the trip-length frequency for each of the 3 trip purposes used in the study was altered between the first and third trial calibrations performed on the models during the process of obtaining an adequate comparison between the model and the actual ground information within the study area. The details of the changes made between each trial calibration are presented in a later section of this report dealing with the validity checks performed on the travel models.

Internal and External Attractions

Development of the initial travel time factors for the internal and external trips also was based on a review of information from the same urban areas considered for the

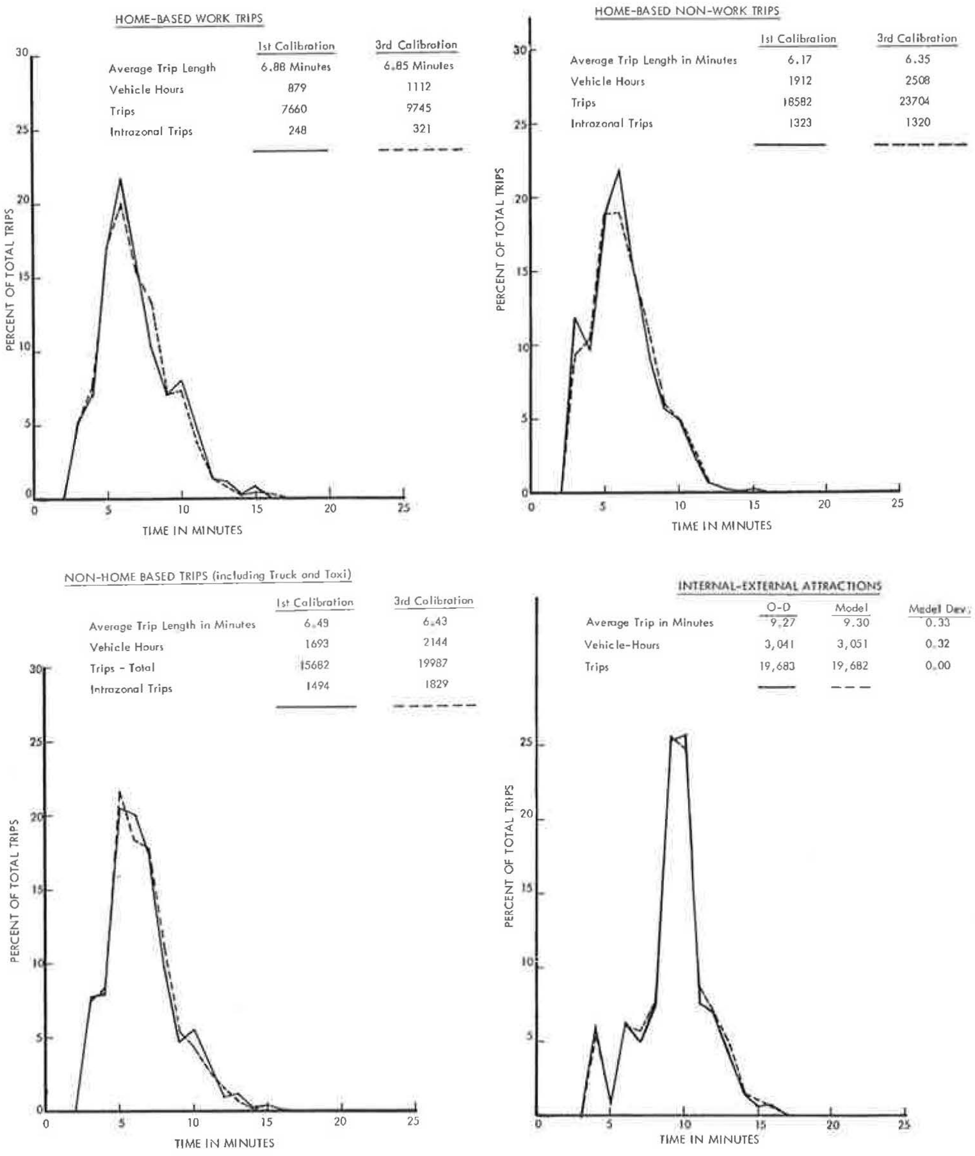

Figure 2. Trip length frequency distributions.

TABLE 6

RECOMMENDED TRAVEL TIME FACTORS BY TRIP PURPOSE

Travel Time[a] (min)	Work	Nonwork	Non-Home-Based	Internal and External
1	200	250	220	170
2	156	170	160	150
3	124	130	125	120
4	100	100	100	100
5	85	75	72	86
6	72	60	53	76
7	62	50	41	64
8	54	41	32	56
9	47	34	25	48
10	41	28	21	42
11	36	24	18	38
12	33	21	16	34
13	29	18	13	31
14	26	16	11	28
15	22	14	10	25
16	20	12	8	23
17	16	11	7	21
18	14	10	6	19
19	11	8	5	17
20	9	6	4	15
21	7	4	3	14
22	5	2	3	12
23	3	1	2	11
24	2	—	1	10
25	1	—	—	9

Note: Includes terminal time.

internal distribution model. The resulting travel time factors for the internal and external trip distribution selected for use in the initial trial calibration of the gravity model are given in Table 6 and are shown in Figure 1.

An initial gravity model calibration was made on the trip data for the Madisonville study to obtain trip-length frequency information for comparison purposes. Figure 2 shows the comparison of the trip-length frequency of the external origin and destination trips and the trip-length frequency obtained from the first trial calibration of the gravity model. Figure 2 also shows comparisons of the origin and destination data and model data for the percentage of deviation in trips, vehicle-hours, and average trip length. The model deviation is well within the 3 percent value generally considered the maximum acceptable percentage of deviation. Thus, the values given in Table 6 were selected as the final travel time factors for internal and external trip distribution.

VALIDITY CHECKS PERFORMED ON THE TRAFFIC MODELS

After the internal trips were distributed and the internal and external gravity model was calibrated, various analytical and statistical tests were applied to verify the results of the mathematical models. The basic procedure utilized is given in Table 1 (step V). In brief, the external trip table (internal and external and through trips) and the total trip table (internal, internal and external, and through trips) were assigned separately to the existing major street and highway networks. Vehicle-mile checks and screenline comparisons between the model-assignment values and the ground counts served as the major overall validity checks on model adequacy. The standard "all-or-nothing" assignment procedure and the package of programs developed for the IBM 1130 computer were used. The results of these assignments were compared to the ground counts on key links throughout the network.

To obtain the vehicle-mile validity check mentioned previously required ground-count information for all links in the existing major street and highway network. Inasmuch as blanket coverage of ground-count information was not available, volumes on various links throughout the existing network were estimated. This estimation was based on expansion of historical count information, expansion of peak-hour turning volume counts at the signalized intersections, and current count information for street segments having characteristics and use similar to those of the segments being estimated.

Because the ground count volume on a substantial number of links within the network was estimated, a check was performed to determine the overall adequacy of using these estimated volumes. This check consisted of a vehicle-mile comparison of the assignment volumes and the ground count volumes for all links and for selected links within the network (links where actual ground-count information was available were termed "selected links"). The results of this comparison are shown in the following:

Links	Vehicle-Miles		Percent Deviation
	Ground Counts	Assignment (third calibration)	
Selected	137,600	131,700	4.3
All	213,800	204,700	4.2

It was concluded that the estimated ground counts were reasonable on an overall basis.

Based on the preceding method of comparing the model assignment volumes to the ground count volumes on those links crossing each of the selected screenlines and of comparing the total model assignment vehicle-miles to the ground count vehicle-miles, the initial assignment to the network indicated that the mathematical models were underpredicting travel within the study area. The results of this comparison for the first calibration are given in Table 7.

The internal and external trips and the through trips contained in the model assignment values given in Table 7 were obtained from actual roadside interviews in the external origin and destination survey conducted for the study area. Thus, for the model development it was accepted that these trips reproduce the corresponding ground counts to the required degree of accuracy and, therefore, require no adjustment. Consequently, to obtain a closer check between the model assignment and the ground count values required that the internal trip rate be increased by about 28 percent prior to reassignment of the total trip matrix.

In addition to increasing the internal trip-generation rate from the initial value of 2.30 trips per capita to a new value of 2.93 trips per capita, the second calibration of the model also incorporated speed adjustments on selected links within the network, particularly in and around the CBD so that a closer comparison could be obtained between the model assignment and the ground counts. After these adjustments were made, the internal trips were redistributed by using the initial travel time factors given in Table 5; and the resulting total trip matrix (internal, internal and external, and through trips) were reassigned on an all-or-nothing basis to the revised network.

The screenline and vehicle-mile comparisons mentioned previously were made on the results of the second calibration traffic assignment. The results of these comparisons are also given in Table 7. Overall, the model vehicle-miles were about 8 percent less than the corresponding vehicle-miles computed from the ground counts. The screenline analysis also indicated that the models were still underestimating trips by about 8 percent. However, the results of the screenline analysis for the second calibration traffic assignment showed that the volumes crossing a number of screenline segments were being over-predicted by the model whereas other segments were being

TABLE 7

LOADED NETWORK SCREENLINE COMPARISONS

Screenline	Section	Ground Count	Model	
			Calibration 1	Calibration 2
2	Cordon-B	7,000	6,545	7,356
	B-C	32,939	19,813	24,987
	C-D	4,304	5,364	5,869
	Total	44,243	31,722	38,212
B	Cordon-2	12,000	9,804	11,298
	2-cordon	7,220	8,017	8,262
	Total	19,220	17,821	19,560
C	Cordon-2	5,837	4,931	5,066
	2-cordon	33,066	27,795	30,753
	Total	38,903	32,726	35,819
D	Cordon-2	1,610	1,666	1,694
	2-cordon	24,357	20,447	22,090
	Total	25,967	22,113	23,784
Total		128,333	104,382	117,375
Total vehicle-miles		213,769	189,906	202,860

Note: See Figure 3 for screenline locations.

underpredicted. Thus, it was concluded that adjustment of the initial friction factors used in distributing the internal trips was probably required to obtain a more even distribution.

Several other factors also pointed to the adjustment of the travel time factors as being the most desirable adjustment prior to the third calibration. These factors consisted of the magnitude of the internal trip-generation rate and the problem of possible double crossings of the screenline segment traversing the central area. Because the internal trip rate of 2.93 vehicle trips per capita resulting from the second calibration was approaching an upper limit for urban areas of relatively small size, further adjustment of this internal trip rate was considered undesirable until such time as the distribution of trips was deemed accurate.

Moreover, the largest single difference between the ground-count volume and the model-assignment volume crossing a given screenline segment occurred on screenline 2 from section B to C (i.e., the portion of screenline 2 traversing the CBD). Figure 3 shows the screenline locations. Because of the location of this screenline segment and the high peak-hour parking occupancies noted for on-street parking facilities within the CBD, the possibility existed that the ground counts in this area reflected a considerable number of double crossings resulting from circulating traffic. Consequently, adjustment of the internal trip distribution was considered more appropriate for the third calibration than an additional adjustment in the internal trip-generation rate.

Because the major discrepancies between the ground-count volumes and the model-assignment volumes on a link-by-link basis occurred in and around the central area, the travel time factors for the medium-length trips were selected for adjustment. This adjustment was further limited primarily to the nonwork trips because of the heavy commercial orientation of the central area. The travel time factors resulting from this revision are given in Table 6. These revised travel time factors were used to redistribute and reassign the trip productions and attractions on an all-or-nothing basis.

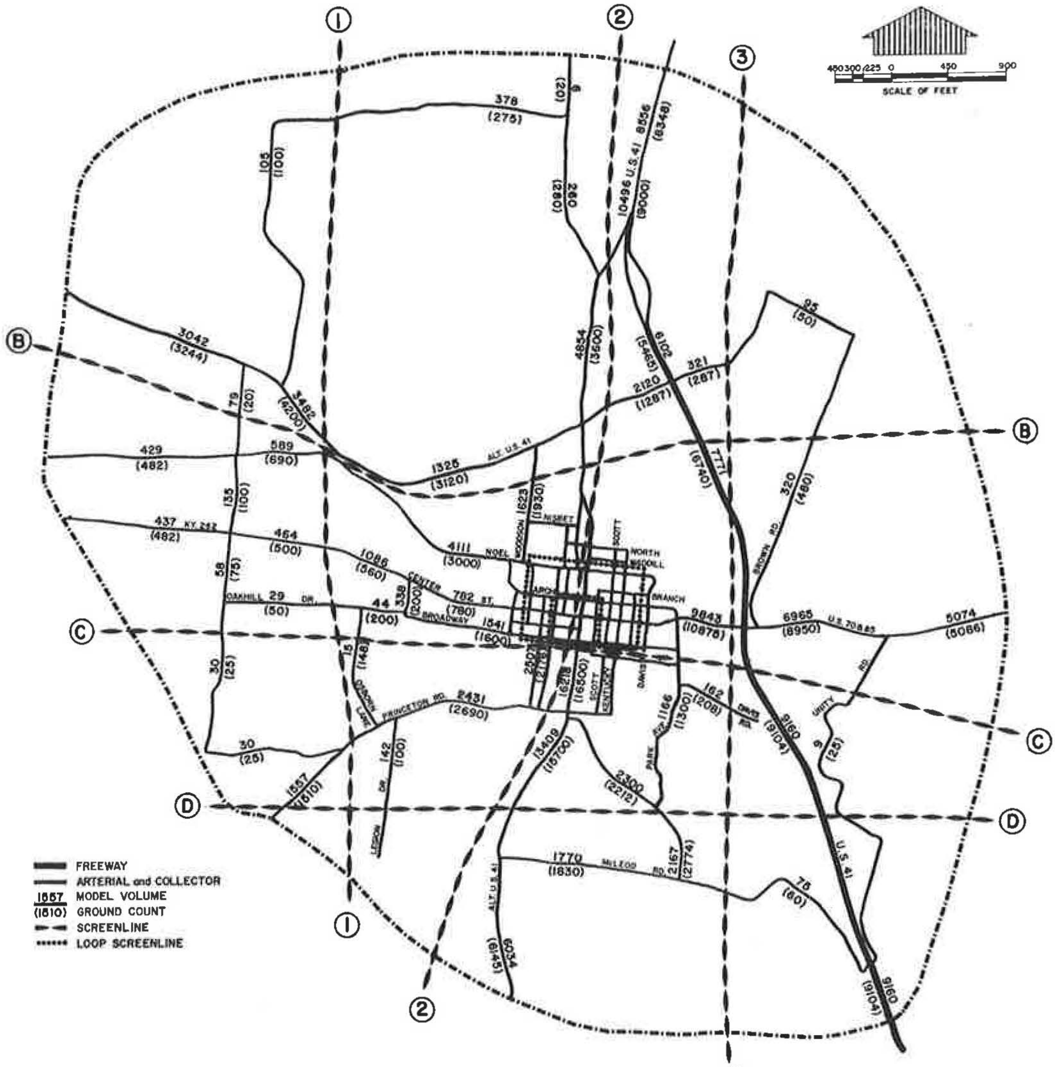

Figure 3. Screenline comparisons of model-assigned trips versus ground counts.

The results of the third calibration traffic assignment are given in Table 8. Analysis of Table 9 reveals that the models reproduced the ground counts within about 5 percent accuracy on an area-wide basis for both the screenline and the vehicle-mile comparison. Figure 3 shows the locations of the screenlines as well as the assigned volumes and the ground counts on selected links throughout the system. Thus, these results indicate that the third calibration of the mathematical model reproduced the existing travel pattern with acceptable accuracy.

This conclusion was verified by selecting a number of additional screenlines. The location of these screenlines is shown in Figure 3. These additional screenlines consisted of 2 north-south and 2 loop screenlines. The location of the north-south screenlines (i.e., screenlines 1 and 3) was selected to bracket the well-developed portion of the existing urban area. The location of the 2 loop screenlines was selected to evaluate the portion of the internal trips traveling to and from the CBD and to minimize the

TABLE 8

LOADED NETWORK SCREENLINE COMPARISON—CALIBRATION 3

Screenline	Section	Ground Count	Assigned Volume
1	Cordon-B	4,300	3,587
	B-C	1,240	1,082
	C-D	2,250	2,312
	Total	7,790	6,981
2	Cordon-B	7,000	7,436
	B-C	32,939	29,748
	C-D	4,304	2,300
	Total	44,243	39,484
3	Cordon-B	287	321
	B-C	17,030	17,609
	C-D	208	162
	D-cordon	980	2,317
	Total	18,505	20,409
B	Cordon-1	20	79
	1-2	11,980	11,582
	2-3	6,740	7,771
	3-cordon	480	320
	Total	19,220	19,752
C	Cordon-1	25	30
	1-2	5,812	4,698
	2-3	23,586	21,396
	3-cordon	9,480	9,169
	Total	38,903	35,293
D	Cordon-1	1,510	1,557
	1-2	100	142
	2-3	15,228	13,428
	3-cordon	9,129	9,169
	Total	25,967	24,296
Total		154,628	146,215
Inner loop		71,323	63,894
Outer loop		67,394	70,941
Total vehicle-miles		213,769	204,687

Note: See Figure 3 for screenline locations.

potential problem of double screenline crossings previously discussed. The results of these screenline comparisons for the third calibration are also given in Table 8.

As an additional test on the adequacy of the calibrated model, the assigned volumes and the ground counts were compared by using a standard Bureau of Public Roads program (modified for use on the IBM 1130 computer) that subdivides the individual links into groups based on the ground-count traffic volume. For each volume group, the computer program tabulates the number of links in the volume group, the average volume for each group, the average difference between the ground counts and the model volumes, and the root mean square error of the differences between the ground counts and the model trips. These statistics for each volume group are given in Table 9.

TABLE 9

LOADED NETWORK COMPARISON BY LINK ONE-WAY VOLUMES

Volume Group	Number of Links	Percentage of Total Links	Average Ground Count	Average Difference	Root Mean Square Error	Percentage of RMSE
Less than 1,999	359	72.3	714	-64	570	80
2,000-3,999	78	16.0	2,790	+291	1,071	38
4,000-5,999	42	8.4	4,910	+690	1,079	22
6,000-7,999	10	2.1	7,050	+914	1,051	15
Over 8,000	6	1.2	8,520	+555	870	10
Total	495	100.0	1,620	+83	750	46

Calculation of the percentage of root mean square error does not provide an absolute check on the adequacy of the calibrated model because of the lack, for the Madisonville study, of an internal origin and destination sampling rate. However, this calculation can provide an indication of whether the calibrated movel is generally adequate or generally inadequate. As given in Table 9 the root mean square error (percentage of RMSE) is reasonable for volume groups of more than 2,000 vehicles per day. The relatively large percentage of root mean square error for those links having an average daily traffic volume of less than 2,000 vehicles per day is relatively insignificant when related to the service volume of a 2-lane highway. That is, from a planning point of view, the errors indicated by this large root mean square error do not change the lane requirements on a specific facility carrying 2,000 vehicles per day or less.

Moreover, this relatively large discrepancy is attributable to the problems inherent in the basic traffic assignment procedure as well as the accuracy of the ground counts used for comparison purposes in this calculation. Because of the small size of the urban area, travel paths differing by fractions of a minute or a second may result and the rounding by the computer may be biased. Because the entire existing major street and highway network was used in the model calibration, the likelihood of large discrepancies between the ground-count volume and the assignment volume is relatively high in those instances of paralleling facilities and of network links located adjacent to zone centroid connectors. In addition, many of the ground-count volumes on these low-volume links were estimated for the purposes of comparison and, therefore, may contain considerable error when analyzed on an individual link basis. However, as indicated by the values given in Table 9, the majority of the volume groups have a generally acceptable root mean square error.

Based on the preceding analyses, the trip-generation and trip-distribution models resulting from the third calibration traffic assignment are recommended for the distribution of future trips. The following are the recommended trip-generation equations:

Production Equations

1. Home-based work = 0.5355 (population)
2. Home-based nonwork = 1.3005 (population)
3. Non-home-based = 0.4265 (population) + 2.0018 (employment)

Attraction Equations

1. Home-based work = 1.6167 (employment)
2. Home-based nonwork = 0.5100 (population) + 2.8305 (total employment - industrial employment)
3. Non-home-based = 0.4265 (population) + 2.0018 (employment)
4. Internal-external = -44.7115 + 0.3434 (population) + 2.5928 (employment)

Table 6 gives the recommended travel time factors by trip purpose resulting from the final calibration of the gravity model. The recommended trip-length frequency distributions for internal trips and internal and external trips are shown in Figure 2 (calibration 3).

CONCLUSIONS

1. The developed model gave good results and is recommended for forecasting future trips. Forecasts based on the trip-generation equation will probably be on the low side. The trip-generation equations have population and employment as the independent variables. Population and employment have been growing and are expected to continue growing at a slower rate than vehicle registration and at an even slower rate than vehicular trips. Control totals for each trip purpose should be established independently of the trip-generation equations.
2. The overall cost of this phase of the Madisonville study is about $6,000. This paper demonstrates that internal trip patterns can be economically synthesized in small urban areas. However, more research is needed to determine the trip-length frequency distribution, factors affecting them, and influence of movement of a big employer into or out of the area or from 1 side of the area to the other.
3. More research is needed to determine the magnitude of intraurban area vehicle trips made by out-of-area residents. In small urban areas, the central city is the focal point of surrounding rural areas. These intraurban area trips, commonly referred to as nonreported trips, could be collected at a low additional cost by including extra questions to this effect on the external cordon survey interview form.
4. The model has the advantages of being simple and economically feasible. It uses 3 socioeconomic factors that can be easily forecasted—population, total employment, and industrial employment. The general procedure is applicable to any small urban area. However, the exact model needs to be developed and calibrated for each small urban area separately.

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