A Simplified Method for Forecasting Urban Traffic

REX H. WIANT, Traffic and Highway Planning Department, Division of Planning, Iowa State Highway Commission, Ames

During the last year, new concepts of origin-and-destination studies and traffic forecasting were applied for the first time in Iowa. In 1959, an 11-member study committee was created by Iowa's 58th General Assembly. The committee was directed to make a fiscal, administrative and engineering survey of Iowa's highways, roads, and streets, and report its findings to the 1961 session of the legislature. Subsequently, two firms were employed, the Automotive Safety Foundation and the Public Administration Services, to supervise and direct the studies.

One phase of the engineering study was to determine what city street improvements would be needed by 1980 to provide a tolerable level of traffic service. The problem was naturally most acute in the larger metropolitan areas where the greatest population gains for the next 20 years are expected. The purpose of this paper is to discuss briefly the techniques employed in forecasting 1980 traffic volumes in Iowa's seven largest urban areas. Some discussion of the application of this data in selecting arterial street systems is also included.

● O-D INTERVIEW methods currently used in collecting Iowa traffic data were discarded because all data for the seven cities had to be collected, processed and analyzed within six months. Concepts of mathematical traffic models and traffic synthesis from land-use data were introduced to overcome the obstacles presented by conventional techniques. Basic population and land-use data were supplied by the local officials of the seven cities, data processing was handled by the Iowa State Highway Commission, and the Automotive Safety Foundation supervised the operation. Within this organizational framework, the processing and evaluation of all seven O-D studies proceeded simultaneously.

In 1957 a complete O-D survey was made of the Cedar Rapids-Marion Urban Area (1). Information from this survey was used to develop trip production, trip attraction and time-distance relationships. Design of the gravity traffic model was similar to the one used in Baltimore, Maryland (2). All auto-driver trips were placed in one of the following trip purpose groups: (a) home to work, (b) other home base, and (c) non-home base. Social and shopping trips are examples of the other home base category where the auto-driver's home was one end of the trip. The non-home base group included all trips not beginning or ending at the driver's residence.

Work trip production was related to the labor force residing in each zone. In calculating the number of auto-driver work trips originating in any zone, adjustments were made for transit riders and auto passengers. Zonal employment data was the basic attraction factor for the work trips. Other home base trip production was directly re-

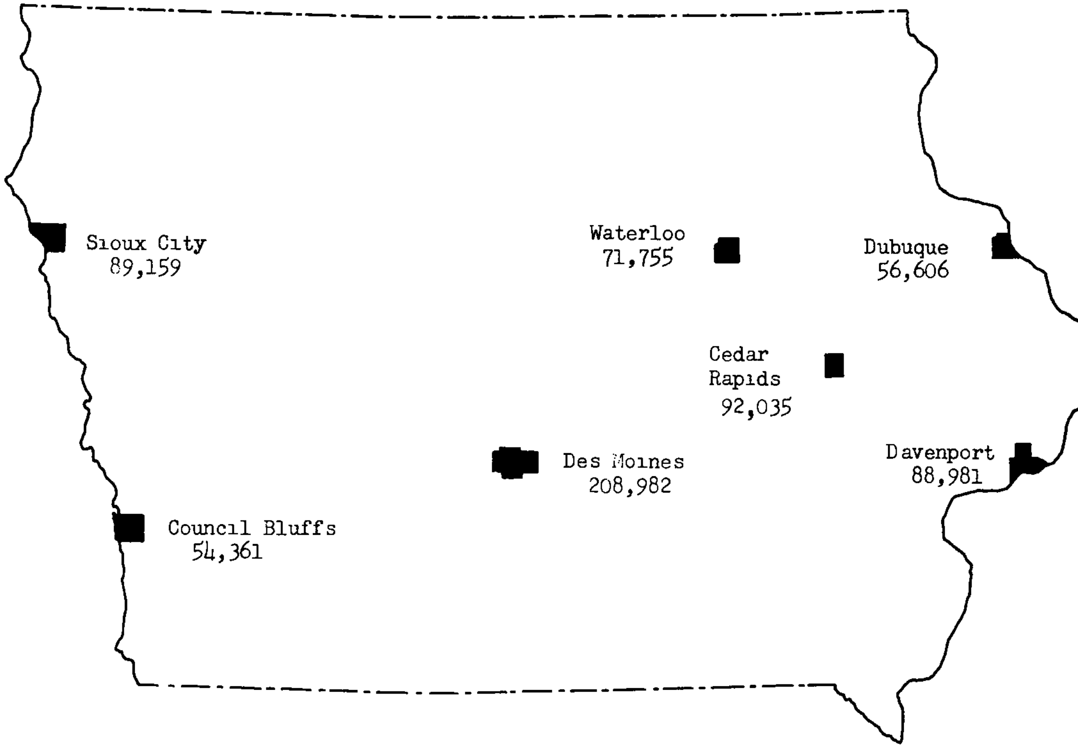

Figure 1. Iowa cities where traffic forecast techniques were applied. Population figures are from 1960 census data.

lated to car ownership and the zonal attraction factor used for this trip purpose was population plus 25 times retail employment. The total number of non-home base trips produced was related to total car ownership in the urban area, and the number of trips beginning or ending in a particular zone was associated with that zone's respective percent of the urban area's population plus 25 times retail employment. Factors were also derived from the Cedar Rapids data to describe the relation of travel time and trip frequency.

After preparing a computer program to handle the trip distribution calculations (3), the model design was checked against the interview data by trip length and desire line comparison. Results of the trip length comparison are given in Table 1.

The first desire line comparison revealed that the traffic model estimate of travel between Cedar Rapids and Marion was 50 percent higher than the home-interview observations (Fig. 2). Further research indicated that the relation was constant for all trip purposes. Marion is a satellite community of approximately 10, 000 people and is located just northeast of Cedar Rapids. The differential in calculated and actual trip movements between the two communities was adjusted by "weighting" the trips with an origin or destination in Marion to make them conform to actual observations. In effect, more trips were confined to Marion and Cedar Rapids by the weights with less travel interchange between the two areas.

Travel patterns similar to those between Cedar Rapids and Marion cropped up in other urban areas with a neighboring satellite community. Between Sioux City, Iowa and South Sioux City, Nebraska, Davenport and Bettendorf and Waterloo and Cedar Falls the traffic model overestimated the interchange of trips. The smaller neighbor community was not a matching segment of the larger urban area as far as travel habits were concerned. In some cases, this result was completely contrary to local opinion.

TABLE 1

COMPARISON OF TRIP LENGTH DISTRIBUTION FROM CEDAR RAPIDS TRAFFIC MODEL AND HOME-INTERVIEW DATA

Trip Length (min)	Accumulated Percent of Trips—By Trip Purpose							
	Work		Other		Non-Home Base		All	
	Model	Actual	Model	Actual	Model	Actual	Model	Interview
1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3	90.1	90.1	79.7	80.5	76.5	74.7	82.5	82.7
6	65.8	66.7	55.5	51.6	50.6	44.5	57.9	55.4
9	44.7	43.6	36.0	31.4	32.3	25.9	38.1	34.6
12	28.6	27.2	23.2	21.1	21.1	16.0	24.6	22.2
15	19.1	18.2	16.4	16.6	14.9	10.3	17.0	15.8
18	14.0	13.9	13.2	14.3	11.8	8.3	13.2	12.9
21	10.8	11.7	11.2	13.1	10.4	7.2	10.9	11.4
24	10.0	11.3	10.7	12.9	10.0	7.0	10.3	11.1
27	9.2	10.7	10.0	12.1	9.2	6.4	9.6	10.4
30	7.6	8.7	8.3	9.9	7.3	5.1	7.9	8.5
33	6.4	7.5	6.5	7.7	5.7	4.2	6.3	6.9
36	3.7	4.3	3.4	3.9	3.5	2.4	3.5	3.7
39	2.6	2.9	2.1	2.7	2.0	1.4	2.2	2.5
42	1.4	1.4	1.1	1.8	1.0	0.9	1.2	1.4
45	0.4	0.4	0.2	0.4	0.2	0.3	0.3	0.4
48	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1

Local officials had previously assumed that travel behavior was similar throughout an urbanized area containing a satellite city.

After "weighting" the model to reflect the true interchange of Cedar Rapids-Marion trips, the traffic model desire line volumes were compared to their home-interview counterparts. The Cedar River which cuts diagonally across the city was used as a screenline and this comparison revealed that there were 2.4 percent more model trips across the river than indicated by the home-interview information.

To further assess the accuracy of the model calculations, a comparison was made with the home-interview data using the trip-trace method employed in evaluating sample size in the Phoenix, Arizona survey (4).

The first trip-trace comparison was made using the original traffic model data from the Cedar Rapids study. Volume deviations related to both trip production and trip distribution are measured in this analysis. Results of this comparison are included in Table 2.

Root-mean-square error means that two-thirds of the time, this error will be less than indicated. The percent root-mean-square error is found by dividing the RMS error by the interview mean volume for the volume group under consideration.

The traffic model calculations produced about three percent more trips than were included in the home-interview figures. This error is included in the previous comparisons and constitutes part of the deviations measured by the statistical analysis.

A second trip-trace comparison was made using gravity model data with controlled trip production. The actual trip production and attraction values from the home-interview data were substituted for the zone figures calculated and used inthe original model. Identical trip distribution methods were applied to these data and the resulting zonal movements were compared to the home-interview material using the trip-trace program. Deviations measured in this analysis are related only to trip distribution and are summarized in Table 3. These tests would indicate that in dealing with volumes in the 5 to 10 thousand range, that about 40 percent of the errors of the model are related to trip production variation between zones.

TABLE 2

GRAVITY MODEL VERSUS HOME-INTERVIEW TRAFFIC VOLUMES CROSSING TRIP-TRACE SCREENLINES IN CEDAR RAPIDS, IOWA

Volume Group	Number of Sections	Mean Volume		Root-Mean-Square Error	RMS Error (%)
		Interview	Model		
0- 99	66	47	101	87	185.1
100- 249	47	169	233	112	66.3
250- 499	48	358	397	130	36.3
500-1,499	65	884	985	293	33.1
1,500-2,499	66	1,962	2,105	447	22.8
2,500-4,999	54	3,717	3,870	539	14.5
5,000-9,999	38	6,839	7,117	914	13.4
10,000+	10	15,894	17,045	1,984	12.5

TABLE 3

TRAFFIC VOLUME DEVIATIONS ACROSS TRIP-TRACE SCREENLINES RELATED ONLY TO TRAFFIC MODEL DISTRIBUTION ERRORS

Volume Group	Number of Sections	Mean Volume		Root-Mean-Square Error	RMS Error (%)
		Interview	Model		
0- 99	66	47	93	77	163.8
100- 249	47	169	223	94	55.6
250- 499	48	358	385	119	33.2
500-1,499	65	884	940	235	26.6
1,500-2,499	66	1,962	1,661	336	17.1
2,500-4,999	54	3,717	3,667	368	9.9
5,000-9,999	38	6,839	6,933	508	7.4
10,000+	10	15,894	15,138	1,212	7.6

Using the same basic trip production, trip attraction and travel frequency factors derived from the Cedar Rapids-Marion study, 1959 travel patterns were synthesized for the six other urban areas included in the study. Results from these calculations were verified by screenline counts. In the cities that were a segment of a larger metropolitan area (for example, Davenport-Rock Island-Moline and Council Bluffs-Omaha), the screenline counts indicated that trip production levels were lower than the figures derived from the Cedar Rapids research. Previous research has indicated that there are fewer trips per car in larger cities (5).

FORECASTING TECHNIQUES

After formulating the 1959 traffic patterns for the seven cities by use of the gravity model and land-use concepts, the next step was to make an evaluation of what traffic desires would be in 1980. This work was based on the premise that if it is possible to synthesize today's traffic pattern from land use and population data, future traffic desires could be formulated from the prediction of expected land use and population distributions. Estimates of the 1980 population, employment and car ownership expected in each zone of the study areas established the basic framework for the traffic forecasts. By substituting these values for the 1959 data originally used in the traffic model the 1980 O-D pattern was calculated. The accessibility model approach used to forecast future land use was a modification of the concepts presented by research work of Hansen (6).

POPULATION ESTIMATES

Population trends since 1950 in each zone of the urban areas were analyzed and a theoretical growth was computed for each zone. The first step in calculating the theoretical growth quantity was to multiply the additional holding capacity, C, available for new homes in 1950 times the accessibility index, I, of the zone to employment. Holding capacities were in terms of people rather than square feet so as to resolve the differeng residential densities encountered. Accessibility index values for each zone were computed as a part of the gravity traffic model distribution program used in the first phase of the Iowa study. It is a relative measure of the availability of employment to a particular zone. The index for a zone equals the sum of the products of the employment, A, times the travel frequency factor, B, for each of the other zones in the study area. It could be expressed as:

$$\text{Index (I)} = \Sigma AB = A_1B_{1-1} + A_2B_{1-2} \ldots \ldots + A_nB_{1-n}$$

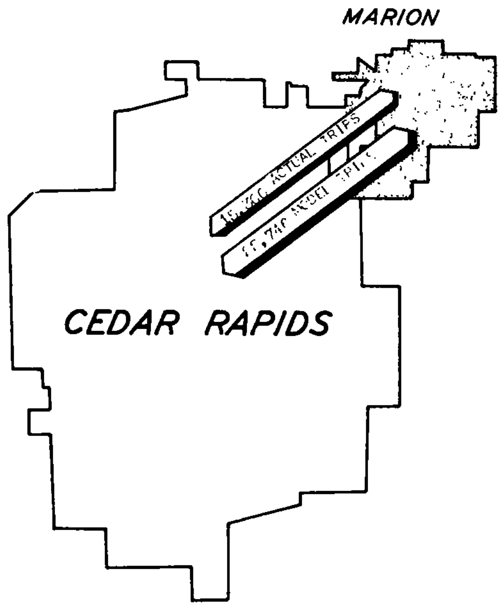

Figure 2. Comparison of travel between Cedar Rapids and Marion as indicated by traffic model calculations and actual interview data. "Weights" were used to adjust this differential.

Actual population growth was plotted over the accessibility-additional holding capacity products, IC, for each zone and an exponent was derived to describe the resultant curve. Thus the term, $(IC)^x$, was a measure of the theoretical growth of a zone relative to the other zones in the study area. Total population growth observed for the area was distributed in accordance to each zone's portion of the sum of the accessibility-additional holding capacity products. For example, zone n's share of population growth would be determined by the ratio of $\frac{(I_nC_n)^x}{\Sigma(IC)^x}$.

This calculated distribution of growth accounts only for the effects of available land and accessibility to work. Other considerations which affect an individual's decision in selecting a residential lot probably include the accessibility to schools, churches and shopping centers. Topographic conditions and the availability of sanitary sewers and other utilities also play a part in the growth of a particular residential zone. To evaluate this multitude of variables, the actual population change for each zone since 1950 was divided by the calculated growth for the same period. This quotient was a measure or "weight" of the influence of factors other than available land and accessibility to employment which prevailed over the zone's rate of residential development during the last ten years.

Results of these calculations for the Cedar Rapids-Marion study are illustrated in Figure 3. This figure shows that zones 5, 6, and 7 grew about twice as fast since 1950 as explained by the factors included in the computations. In reviewing this material with the local officials, these zones were considered the most desirable area in the city for medium-priced housing. Zone 36 grew over three times faster than expected by the calculations and this was due primarily to the outstanding promotion efforts of the builder subdividing the area. On the other hand, there were zones whose growth did not keep pace with the rest of the city; for example, zones 12, 39, 20 and 32. Local planners pointed out that growth was restrained in these areas by the lack of sanitary sewers. Zone 33 has a growth ratio of only 0.1 and this was explained by the fact that most of the area is zoned for industrial purposes, thus reducing its residential desirability.

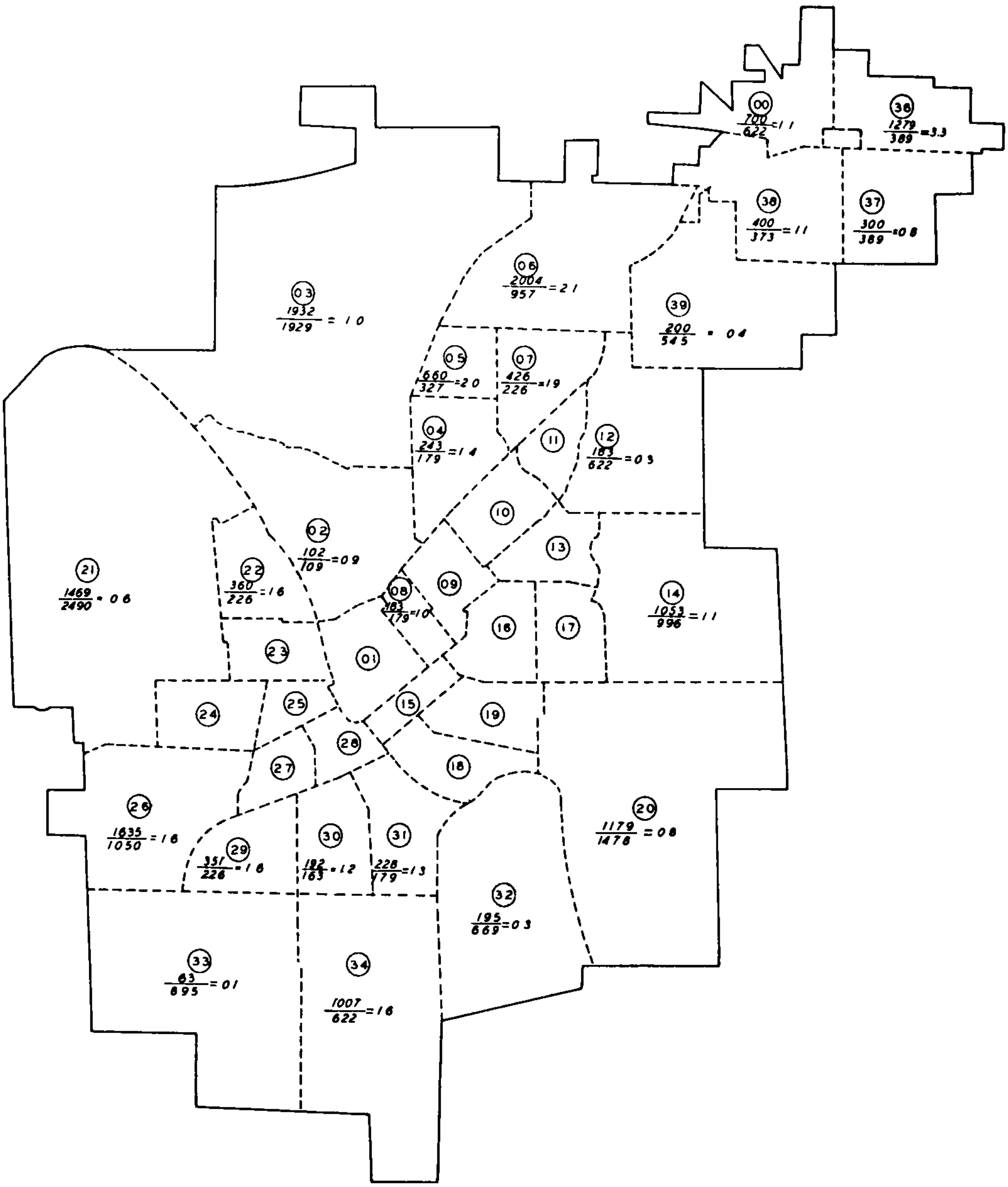

Figure 3. Transportation zones of Cedar Rapids—Marion urban area with zone ratios of actual/calculated population growth.

In reviewing the results of this technique with the local planners and engineers of the six cities where this method of residential growth analysis was applied, they could easily rationalize the deviations in the growth ratios. What was even more significant was that the six groups came up with the same reasons in explanation of the divergent ratios. They were in agreement that zones with ratios of from 2.0 to 3.0 were considered the most desirable areas in their city and that when the ratio approached 4.0 there was some unusual promotional activity in the background. Also in zones with low ratios from 0.1 to 0.8, generally growth was restricted by lack of public utilities or the areas were dominated by racial groups. Some zones had topographic features which would require higher development expenditures and the extra expenses involved in improving these areas had been a deterrent. However, these zones may become more important in the future as other available land supplies are exhausted.

After reviewing the growth ratios with the local officials, discussion turned to the future. What weights would in their judgment be applicable for the next 20 years? Would zones continue to grow at the present rates? Were sewer expansion programs planned or underway? Were urban renewal programs going to alter the present residential areas? These were a few of the considerations that would influence the future growth patterns. In some cases sewer projects had just been completed in zones that had experienced slow growth rates over the last decade. In others, the projects were in the planning and early construction stages. After reviewing the calculated growth ratios and the characteristics of the zones involved, local planners modified the growth ratios to reflect future conditions.

In applying the future growth weights, obviously the available land in some zones would be exhausted long before 1980. The accessibility model permitted growth to continue in these zones until the saturation point was reached and then growth was shifted to zones that still had holding capacity at this point.

In addition to making appraisals of the future zonal growth weights, local officials provided data on the estimated 1980 population of their areas. Changes in travel time between zones and in the distribution of employment opportunities were also considered before proceeding with the zonal population distributions. Techniques used in estimating and distributing future employment is covered in another section of this paper. Anticipated changes in travel times by 1980 were based on the judgment of the local engineers after reviewing the probable changes in their street systems over the next 20 years. With the exception of freeway construction, the local jurisdictions felt that future widening and paving programs would not do much more than maintain the present level of traffic service, and auto travel times would not change appreciably.

After obtaining new estimates of employment distribution and travel times, employment accessibility indexes for 1980 were calculated in the same fashion as those for 1959. Using the 1980 index, I, and the holding capacity, C, available now for development, new values of $(IC)^x$ were calculated. These values times the future growth weights estimated by the local planners were used to distribute the total anticipated population growth of the urban area to the zones.

EMPLOYMENT ESTIMATES

In making estimates of future employment, the available jobs must obviously be in balance with the anticipated population growth. Knowing that about 40 percent of the population composes the employed labor force, the future employment requirements to support the added population can be estimated. The percent of present employment in retailing, services and manufacturing was used as a basis for distributing the future jobs to these general groups. These relationships for six Iowa cities are given in Table 4.

Inasmuch as manufacturing and other industries which need relatively large quantities of land for their operations are generally restricted to industrial sites, future employment is limited to a few zones. The distribution of this portion of future added employment was handled by the local planners who were familiar with their local industrial areas. When there was some indecision about the apportionment, the additional holding capacity of a zone for manufacturing employment and the accessibility of this zone to people and retailing activity were used as factors to distribute the total quantity. The product of these two figures for a particular zone divided by the sum of the accessibility-capacity products for the urban area was used to determine that zone's share of manufacturing employment.

The next step was to distribute the added employment in the service category. Location of these jobs is related to the accessibility to the people which they serve and also to the existing retail areas. On this premise, the service employees added by 1980 were distributed to the zones by using the product of the accessibility index (to people) times the present retail employment as an index. Thus a zone would receive a percentage of the total added service jobs equal to the percent of its accessibility index-retail employment product related to the sum of the zonal index products for the city.

Present employment plus the estimates for manufacturing and service employment for each zone gave an approximation of 1980 employment which was sufficient for computing the 1980 employment accessibility indexes. These were discussed previously in regard to the distribution of added population.

Distribution of the additional future employment involved in retailing were undertaken after the 1980 population calculations were completed. The local planners were consulted for their knowledge of any special retail activity such as new shopping centers under construction or in the planning stage. After allocating retail employment for these centers, the remaining jobs were distributed in accordance with the ratio of population growth for a particular zone to the total population growth of the zones involved. By adding the future retail, service and manufacturing employment figures to the present total employment for each zone, the 1980 distributions were completed.

CAR OWNERSHIP ESTIMATES

Research by the Bureau of Public Roads has indicated that the type of residential area and family income were directly related to car ownership per family. The number of cars per family rises with income levels and when annual income reaches $8,000-$10,000 in a given type of residential area, car ownership does not change appreciably. Figure 4 illustrates this relationship. Thus in outlying zones where residential lots are generally the largest, the car ownership ceiling would be about one car for every two persons. In densely populated zones, car ownership would be only about two-thirds of that figure.

A study in Hartford, Connecticut revealed that car ownership rises toward the ceiling level in direct proportion to the rise in real income. During the last 10 years,

TABLE 4

POPULATION CHARACTERISTICS OF SIX IOWA CITIES

Urban Place	1950 Population	Employed (%)	Employment Class (%) Retail	Services	Mfg. & Other
Cedar Rapids	72,296	44.6	26.6	19.5	53.9
Council Bluffs	45,429	39.3	29.2	18.0	52.8
Davenport	74,549	41.5	28.3	20.5	51.2
Dubuque	49,671	41.2	26.3	19.0	54.7
Sioux City	83,991	42.0	28.2	22.2	49.6
Waterloo-Cedar Falls	79,532	43.1	23.3	17.5	59.2

real income has been increasing nationally about two percent per year. Car ownership would be expected to have increased 20 percent in the last decade in areas where income trends were similar to the national average. This increase would be expected without any population change. The car ownership pattern of families moving into new homes was found to follow the ceiling value of the particular zone involved in the Hartford study.

In view of these relationships and of Iowa car ownership trends, the number of cars in each zone was expanded by a factor of 1.5 for the 1959-1980 period. This expansion was restrained by the ceiling level applicable to the zone involved. Cars for the people moving into new homes during the 1959-1980 period were added to the expanded residual ownership figures to complete the 1980 car ownership estimates.

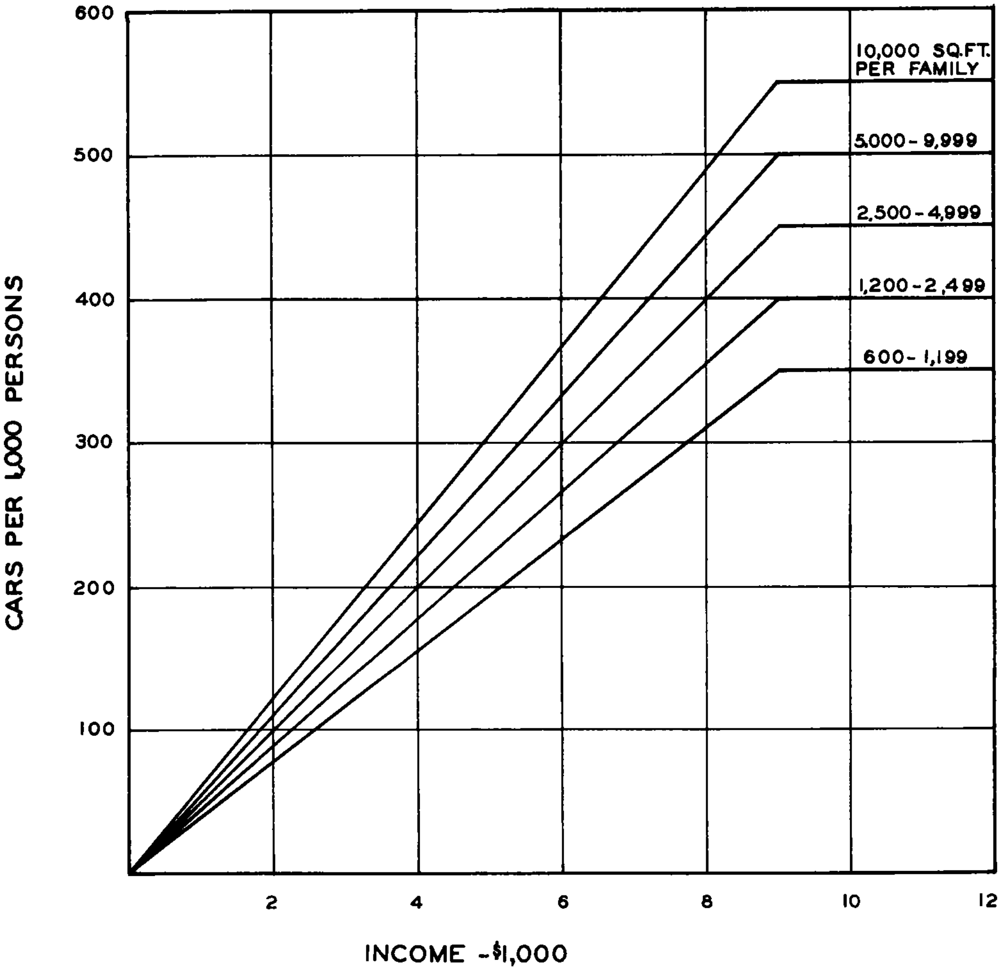

Figure 4. Car ownership ceilings for different residential densities.

SUMMARIZATION OF RESULTS

After the O-D computations had been completed, they were assigned to a desire leg network. Zone centroids were connected by desire lines as illustrated in Figure 5. Trips were assigned to the most direct route or series of desire legs between the O-D zones. Total volumes were accumulated on each desire leg by summing the zonal trips assigned to it. The results of this desire line summarization are illustrated in Figure 6. Desire line volume totals for 1959 and 1980 are included in Table 5.

One variation of this summarization process was to assign traffic to a freeway passing through the city. This was done by spotting the interchanges on the desire layout and adding desire legs between these points and connecting them to the desire pattern established earlier. Zonal movements that would be expected to use the freeway path may then be reassigned to this route and the volumes remaining on the original desire line network would have to be accommodated by the regular street system. Results of this type of assignment are illustrated in Figure 7.

The desire legs may be considered as the only streets available for the traffic desires between zones. Considering this, the future desire leg volume can be apportioned to the streets presently available for arterial traffic. After assigning each desire leg volume to the existing system, there can be a quick determination of where capacity problems may develop. More detailed study can be made of the composition of the traffic on each desire line by examining the zone-to-zone movements assigned to it.

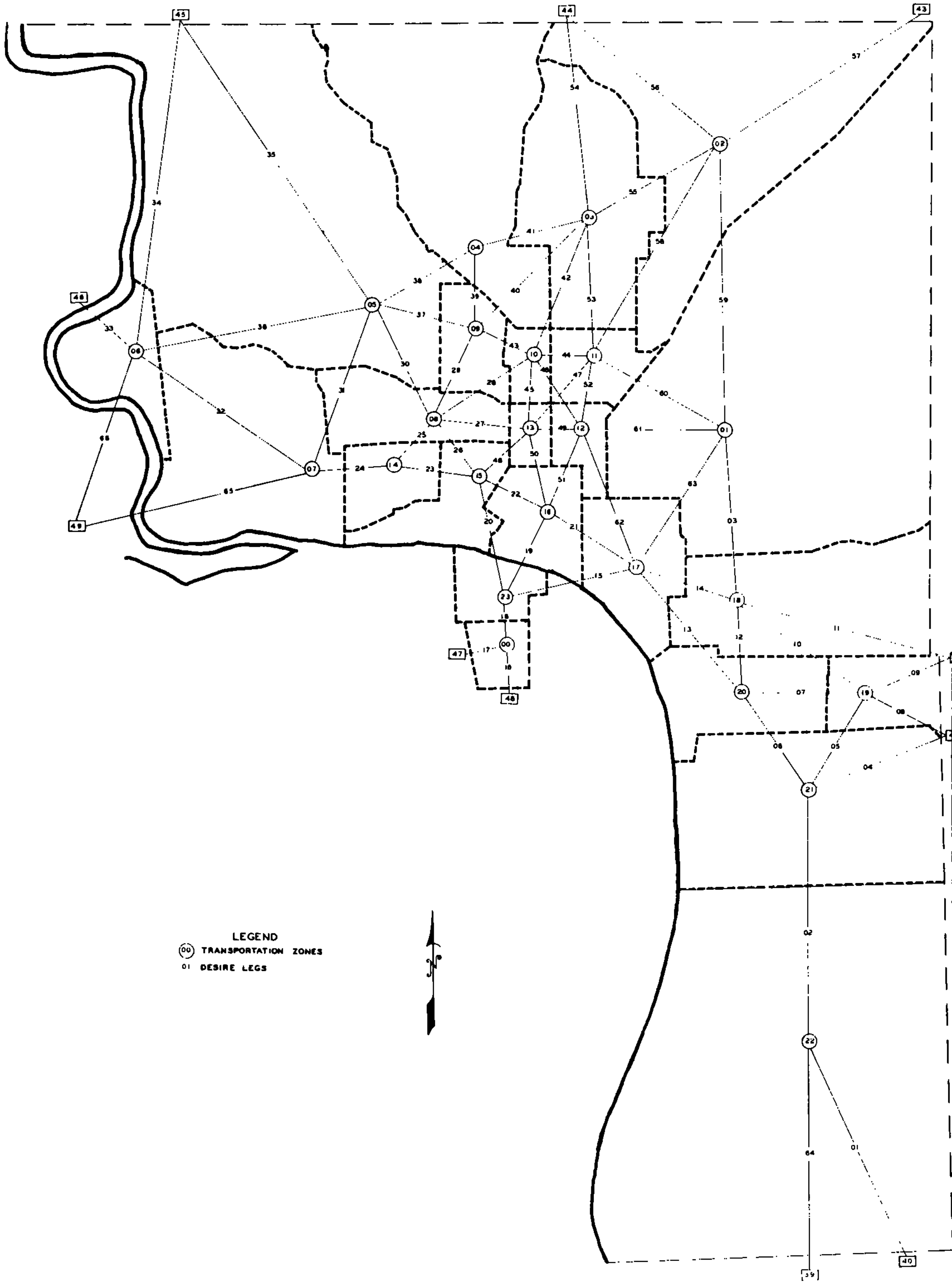

Figure 5. 1959 Sioux City area O-D traffic desire lines.

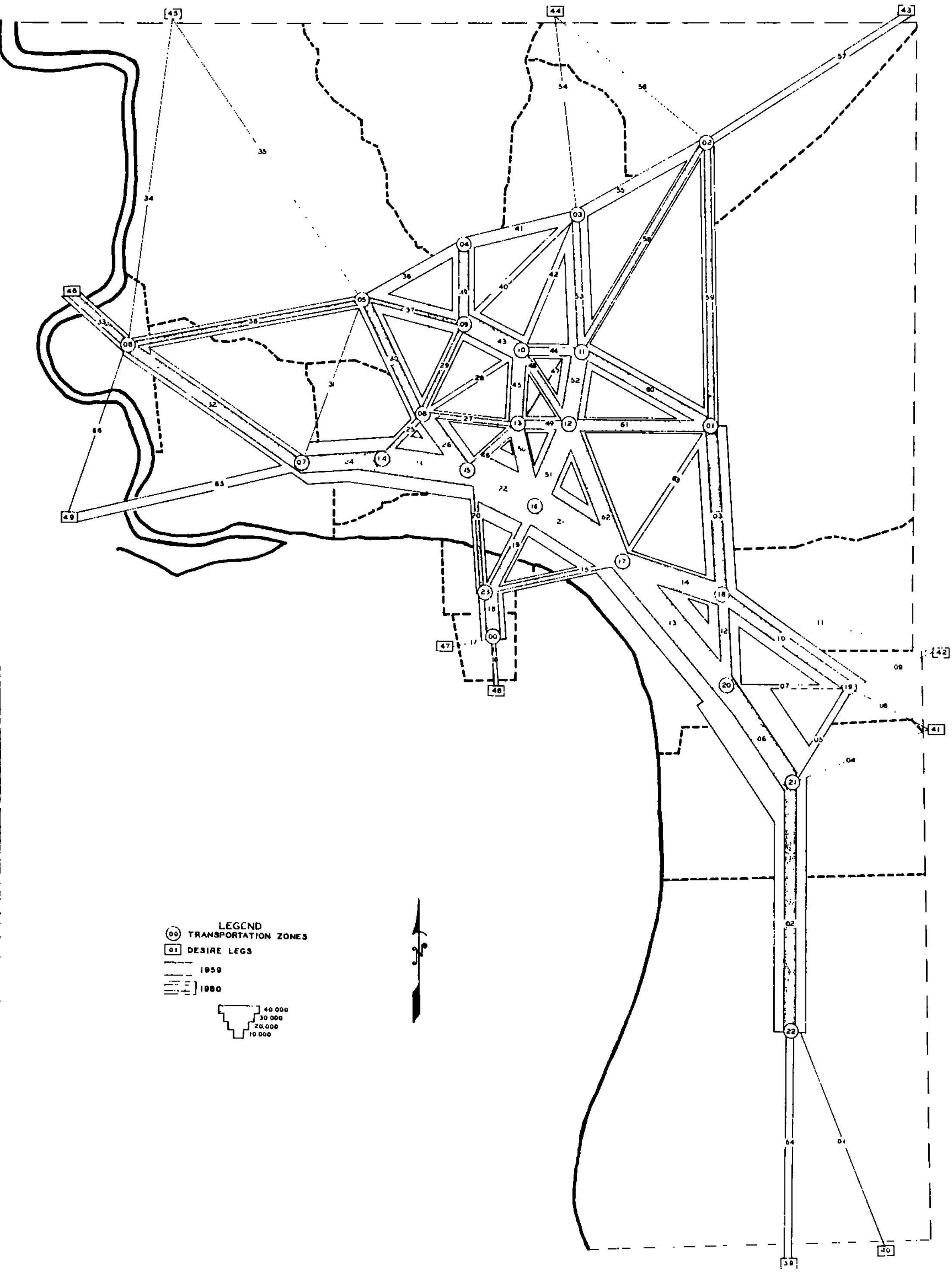

Figure 6. 1959-80 Sioux City area O-D traffic desire lines derived from land-use data, population figures and use of a gravity traffic model.

TABLE 5

DESIRE LEG VOLUMES FOR SIOUX CITY ROAD STUDY TRAFFIC MODEL DATA

Leg	Volume 1959	Volume 1980	Volume 1980 with Freeway Assignments	Leg	Volume 1959	Volume 1980	Volume 1980 with Freeway Assignments
01	2,065	2,882	2,882	44	7,595	13,856	13,672
02	12,126	29,260	15,551	45	13,476	19,730	20,935
03	11,389	28,603	27,174	46	7,081	11,764	12,264
04	144	359	359	47	2,674	3,779	4,172
05	2,122	7,366	7,366	48	7,104	12,420	11,422
06	20,177	67,783	54,074	49	9,560	16,277	15,450
07	3,162	4,088	4,088	50	16,385	18,225	19,262
08	1,462	1,449	1,449	51	21,625	32,228	32,479
09	700	1,550	1,550	52	16,473	29,560	30,373
10	11,180	13,909	13,909	53	7,355	24,586	24,586
11	2,191	3,559	3,559	54	554	763	763
12	10,110	28,367	26,938	55	3,600	11,326	11,117
13	23,696	52,184	39,904	56	98	162	162
14	21,024	27,202	27,202	57	3,961	7,244	7,244
15	4,607	10,559	7,349	58	6,404	10,778	10,569
16	2,824	5,156	5,156	59	6,115	13,512	13,512
17	2,250	4,517	4,517	60	9,328	21,776	20,963
18	13,416	29,189	29,189	61	10,955	15,250	14,806
19	8,044	13,553	13,553	62	13,625	22,756	21,937
20	3,996	11,878	9,005	63	4,509	6,078	7,138
21	36,440	57,767	44,308	64		7,015	000
22	43,435	70,458	53,735	65		8,749	000
23	26,053	51,180	31,202	66		563	000
24	16,522	43,409	27,638				
25	5,655	12,750	12,683				
26	15,708	30,102	30,446				
27	4,656	9,076	9,076	70			9,312
28	2,823	5,513	5,169	71			16,648
29	5,009	12,129	12,750	72			17,864
30	7,943	18,826	18,826	73			14,477
31	508	3,816	2,676	74			18,745
32	11,367	20,846	12,684	75			13,709
33	7,346	13,419	13,419	76			7,015
34	48	80	80	77			9,694
35	555	1,029	1,029	78			6,674
36	5,296	12,000	12,263	79			3,058
37	4,064	9,505	9,505	80			2,520
38	2,355	11,188	10,311	81			6,244
39	10,721	20,889	21,166	82			4,268
40	1,617	5,170	5,170	83			11,860
41	2,718	12,254	11,654	84			11,440
42	2,336	6,295	6,686	85			6,083
43	18,239	31,414	31,070				

CONCLUSIONS

The techniques described in this paper were used to delineate 1980 arterial street systems in Iowa's seven largest cities. Time and money were not available to permit use of an O-D interview method and these methods were employed to overcome these obstacles.

Total cost of the traffic model forecasting work in Iowa was approximately $22,500. This figure includes work on statewide O-D research in addition to the seven cities studied. The salaries of the local officials who provided most of the basic data are not included. About $5,000 was expended on development of computer programs to handle the traffic distribution and summarization aspects of the work. Average total cost per study was a little less than $3,000. Contrast this to the cost of an interview operation. The cost of an Iowa external-internal cordon line survey made in 1959 was twenty cents an interview. Total costs of the 100,000 interview study was $20,000.

After completing the seven-city study, it was felt that some sample interviewing in each city would have improved the results of the gravity model. The factors derived from the Cedar Rapids home-interview data were applied to the other six cities with some trip production adjustments. Data from a few home interviews would have indicated more precisely what modifications were in order.

The 1960 census data would have been very helpful in providing basic information on

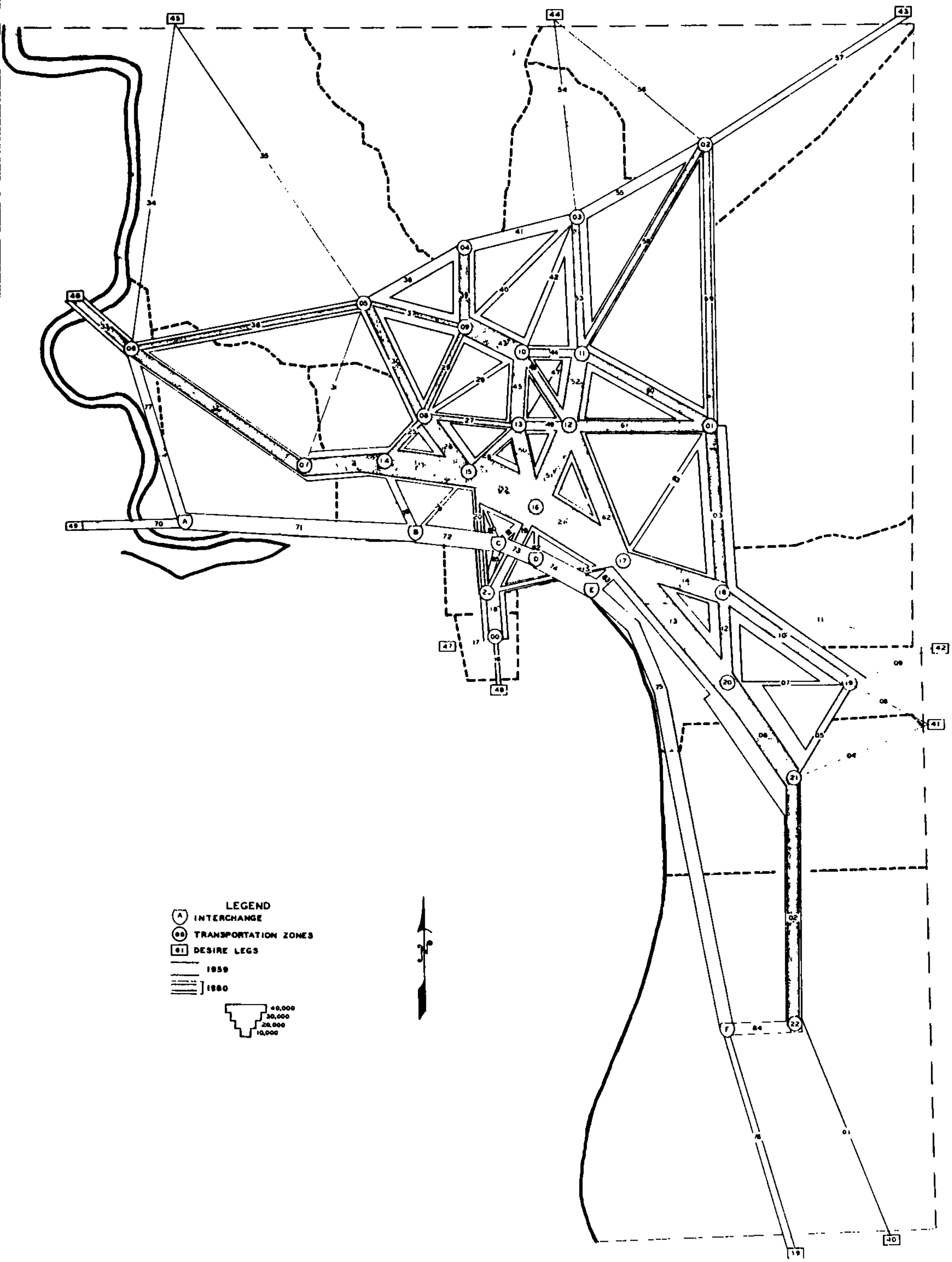

Figure 7. 1959-80 Sioux City area O-D traffic desire lines derived from land-use data, population figures and use of a gravity traffic model.

population labor force and car ownership Local officials provided estimates of these characteristics for use in the traffic model studies. Some areas had no city planning departments and the estimates were made hurriedly and of necessity by people unfamiliar with these characteristics. Current census data would very likely have improved the results in these areas.

Methods outlined here are relatively simple and by using a computer, results can be obtained quickly. In forecasting, alternate land-use plans and the resulting impact of traffic desires could be easily evaluated. The costs of applying the techniques are relatively low. With these things in mind, it is difficult to overlook the potential value of the mathematical approach to traffic synthesis.

REFERENCES

1. Iowa State Highway Commission in cooperation with the U.S. Bureau of Public Roads, "Cedar Rapids-Marion Urban Area Origin and Destination Traffic Study."
2. Voorhees, A.M., and Morris, R., "Estimating and Forecasting Travel for Baltimore by Use of a Mathematical Model." HRB Bull. 224.
3. Heald, K.L., "Discussion of the Iowa Gravity Model Traffic Distribution Program Computing Center, Iowa State Highway Commission, 25 pp., mimeo.
4. Brokke, G.E., and Sosslau, A.B., "Appraisal of Sample Size Based on Phoenix O-D Survey Data." HRB Bull. 253.
5. Curran, F.B., and Stegmaier, J.T., "Travel Patterns in 50 Cities." HRB Bull. 203.
6. Hansen, W.G., "How Accessibility Shapes Land Use." API Journal, 25:2 (May 1959).

Appendix

SAMPLE COMPUTATIONS

Travel frequency factors were derived empirically from the Cedar Rapids-Marion home-interview data. They describe the effect of travel time on trip frequency between zones. Factors derived from the Iowa data for three trip purposes are included in Table 6. The accessibility index of a zone is equal to the sum of the products of the attraction factor in each of the other zones, times the respective frequency factor for the travel time linking the zones. This is clarified by Table 7.

In calculating a theoretical growth quantity for each zone, the employment accessibility index, I_n, was multiplied times the additional holding capacity, C_n, in 1950. The actual growth for each zone was plotted over the products of I_nC_n and an exponent was derived which described population growth in terms of I_nC_n. Figure 8 illustrates the slope of the hand-fitted curve for the Cedar Rapids study. The exponent, x, for this study was equal to 0.6. Thus the term, $(I_nC_n)^x$, describes the theoretical growth of each individual zone relative to the others. The total population growth for all zones is then distributed to each of the zones by the ratio of $\frac{(I_nC_n)^x}{\Sigma(I\ C)^x}$. The resulting theoretical growth quantity is divided into the actual growth observed and the quotient indicates the size or "weight" of factors other than available land and accessibility to employment which influence the growth rate of urban zones. These calculations are given in Table 8, from which

$$F = \frac{\text{Population growth of all zones}}{\Sigma(IC)^{0.6}} = \frac{16,780}{2,156} = 7.78.$$

After obtaining new estimates of employment distribution and travel times, employment accessibility indexes for 1980 were calculated in the same fashion as those for 1959. Sample calculations are given in Table 9.

TABLE 6

TRIP FREQUENCY FACTORS

ravel Time (min)	Relative Trip Frequency, by Purpose: Work	Non-Home Base	Other-Home Base
1	2.00	3.00	5.00
2	2.00	2 25	3 66
3	2.00	1 80	2 20
4	1.50	1 40	1.45
5	1.25	1.15	1 20
6	1.10	1.00	1 00
7	1.00	0 90	0.90
8	0 93	0 80	0 80
9	0 87	0.70	0 70
10	0 84	0 62	0 62
11	0 80	0 56	0 56
12	0 76	0 49	0.50
13	0 72	0 43	0.45
14	0 68	0 38	0 41
15	0 64	0 34	0 38
16	0 61	0 30	0 35
17	0.58	0 27	0.32
18	0 55	0.24	0.30
19	0 52	0 22	0.27
20	0.49	0 20	0.25
21	0.47	0 18	0.23
22	0.45	0 16	0 21
23	0 43	0.14	0.19
24	0 41	0 12	0.17
25	0 39	0 10	0 15
26	0.37	0 09	0 13
27	0.35	0 08	0 11
28	0 33	0.07	0 10
29	0.31	0 06	0 09
30	0.29	0 05	0 08
31	0.27	0 04	0 06
32	0.25	0.03	0 04
33	0 23	0 02	0.03
34	0.21	0 01	0.02
35	0.19	0 01	0 01
36	0.17		
37	0 15		
38	0.14		
39	0.13		
40	0.12		
41	0 11		
42	0.10		
43	0 09		
44	0 08		
45	0.07		
46	0.06		
47	0.05		
48	0 04		
49	0.04		
50	0 04		
51	0 03		
52	0.03		
53	0 02		

TABLE 7

COMPUTATION OF EMPLOYMENT ACCESSIBILITY INDEX FOR ZONE 00

To Zone	(A) Present Employment	Present Travel Time	(B) Work Trip Frequency Factor	AB
00	61	1	2 00	122
01	10,260	14	0 68	6,977
02	445	12	0 76	338
03	381	7	1.00	381
04	1,294	11	0 80	1,035
05	54	9	0.87	47
.	.	.	.	.
.	.	.	.	
.	.	.	.	.
39	00	4	1.50	00
			Index (I_{00}) =	ΣAB

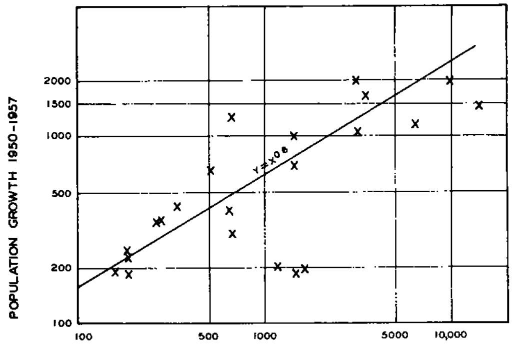

Figure 8. Relation between population growth and accessibility and additional holding capacity.

Using the 1980 employment accessibility index, I, and the holding capacity, C, available now for additional population growth, new values of $(I\,C)^{0.6}$ can be computed. These values are taken times the future weights or growth ratios estimated by the local planners and the products are used to distribute the total anticipated population growth for the urban area. Remembering that future growth cannot exceed present holding capacity, adjustments must be made in the distribution calculations so as not to "overfill" any zone with population. Succeeding approximations must be made of the "F" factor in distributing the population to satisfy the restraint of zone holding capacities. Table 10 illustrates the procedure in distributing estimated population growth. Only zones with additional holding capacity in 1959 are included in this table.

As discussed previously, the number of cars presently owned in each of the zones was expanded by a factor of 1.5 which reflected the anticipated increase in real income by 1980. This expansion was restrained by the ceiling ownership level associated with the residential zone as illustrated in Figure 4. Figure 9 illustrates the relation between 1959 car ownership patterns in five Iowa cities and the residential density where they were located. Cars were added for each zone's increased population at the ceiling rate of applicable to the residential density of the zone. Sample car ownership computations are given in Table 11.

TABLE 8

CALCULATION OF POPULATION DISTRIBUTION WEIGHTS

Zone	ΣAB=I Employment Accessibility Index	Additional Holding Capacity, C, 1950	IxC	$(IC)^{0.6}$	Theo. Growth $F(IC)^{0.6}$	Actual Growth 1950-1957	Ratio, Actual Theo.
00	0.568	2,600	1,477	80	622	700	1.1
01	1.105	55	61	12	93	55	-
02	0.809	102	83	14	109	102	0.9
03	0.744	13,132	9,770	248	1,929	1,932	1.0
04	0.765	243	186	23	179	243	1.4
05	0.777	660	513	42	327	660	2.0
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
39	0.671	1,760	1,181	70	545	200	0.4
All				2,156		Pop. growth =16,780	

TABLE 9

COMPUTATION OF 1980 EMPLOYMENT ACCESSIBILITY INDEX FOR ZONE 00

To Zone	(A) 1980 Employment	1980 Travel Time	(B) Work Trip Frequency Factor	(AB)
00	275	1	2.00	550
01	13,440	14	0.68	9,139
02	482	7	1.00	482
03	3,411	5	1 25	4,264
04	1,332	11	0.80	1,066
05	59	8	0.93	55
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
39	107	4	1.50	161
			1980 Index, I = ΣAB	

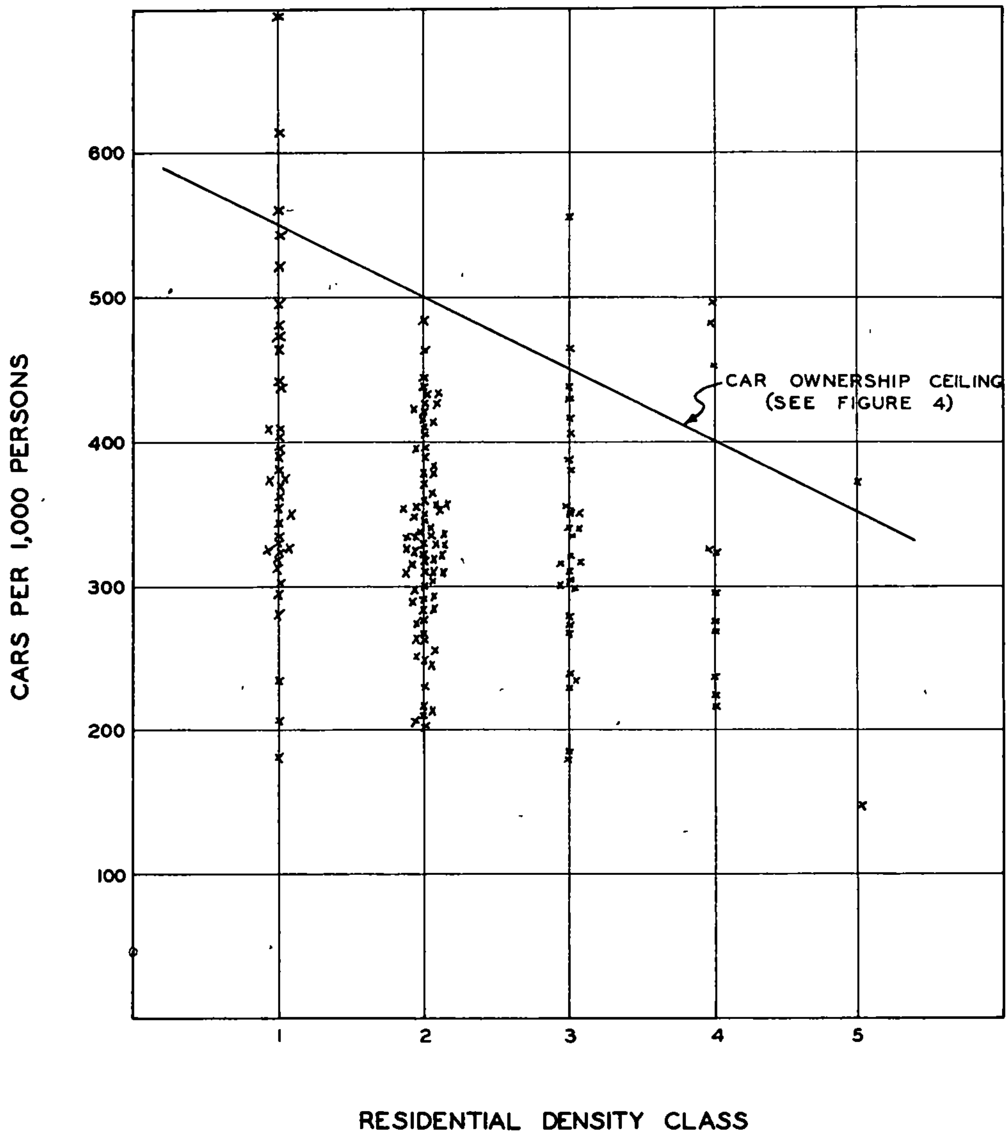

Figure 9. Car ownership related to residential density in five Iowa cities.

TABLE 10

1980 POPULATION DISTRIBUTION COMPUTATIONS
(Additional Population to Be Distributed—40,000)

Zone	1980 Access. Index, I	Present Add Holding Capacity, C	$(IxC)^{0.8}$	Future Weight, W	$\left(\frac{(A)}{W(IC)^{0.8}}\right)$	Population Growth A(F) 1st Est	A(F_1) 2nd Est	A(F_2) 3rd Est	Present Population, P	A(F_2) + P 1980 Population
00	0.377	1,900	52	1.0	52	1,788	2,164	1,900*	1,597	3,497
03	0.541	11,200	186	1.0	186	6,397	7,739	7,881	3,994	11,875
06	0.481	2,240	66	2.0	132	4,539	2,240*	2,240*	4,571	6,811
12	0.457	1,680	54	0.8	43	1,479	1,789	1,680*	1,850	3,530
14	0.419	3,360	78	0.8	62	2,132	2,580	2,627	5,283	7,910
20	0.372	8,960	130	0.8	104	3,577	4,327	4,407	3,310	7,717
21	0.446	19,040	228	1.0	228	7,841	9,487	9,660	6,006	15,666
26	0.477	2,800	75	1.5	113	3,886	2,800*	2,800*	3,389	6,189
32	0.418	2,240	61	0.3	18	619	749	763	1,494	2,257
33	0.448	3,920	88	0.3	26	894	1,082	1,102	48	1,150
34	0.425	1,120	40	1.5	60	2,063	1,120*	1,120*	2,335	3,455
35	0.360	300	17	1.0	17	585	300*	300*	264	564
36	0.311	140	10	2.0	20	688	140*	140*	3,499	3,639
37	0.311	1,120	33	1.0	33	1,135	1,120*	1,120*	1,258	2,378
38	0.391	700	29	1.0	29	997	700*	700*	1,095	1,795
39	0.437	1,560	50	0.8	40	1,376	1,664	1,560*	-	1,560
					1,163			40,000	39,993	79,993

$F = \frac{40,000}{1,163} = 34.39$

$F_1 = \frac{31,580}{759} = 41.61$

$F_2 = \frac{26,440}{624} = 42.37$

	Present Population, P	1980 Population
Population in zones with no growth	50,787	50,787
Total population	90,780	130,780

*Zones limited in growth by present additional holding capacity

TABLE 11

CALCULATION OF 1980 CAR OWNERSHIP

Zone	(A) Present Population	(B) Cars/Person Ceiling	(C) Ceiling Total Cars (AxB)	(D) Present Cars Owned x1.5	(E) Population Added by 1980	(F) Added Cars For New Pop. (BxE)	Total Cars 1980 (D+F)
00	1,597	0.50	799	834	1900	950	1,749*
01	1,544	0.35	540	338	-	-	338
02	1,361	0.45	612	548	-	-	548
03	3,994	0.55	2,197	2,019	8500	4675	6,694
04	2,196	0.50	1,098	1,145	-	-	1,098*
05	1,735	0.50	868	831	-	-	831
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.

*Expanded car ownership (Col. D) exceeded car ceiling (Col. C) for this zone. Total cars 1980 = Col. C + Col. F.