An Evaluation of Simplified Procedures for Determining Travel Patterns in a Small Urban Area

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This report presents the results of research aimed at calibrating and testing the gravity model for a small urban area. The first part deals with application of the gravity model theory to travel patterns in Sioux Falls, S. Dak. (population 62,000). A gravity model trip distribution formula was calibrated from comprehensive information on the area's travel patterns and related characteristics. The ability of this model to simulate the trip distribution patterns was investigated by comparing the gravity model movements with movements obtained from a standard origin-destination survey. In addition, investigations were made to check the effects of balancing trip attractions (as is customary in all traffic forecasting procedures) and to determine how many purpose categories are required in a small city to simulate adequately the existing travel patterns with a gravity model.

The second part of the report deals with investigation into the minimum amount of data required to calibrate a gravity model in a small urban area. For the past three years small sample home interview data have been used increasingly for calibrating traffic models in urban areas. Sample sizes ranging from 0.1 to 1 percent have been used in several transportation studies. Users of these small samples feel that the data collected provide sufficient information about an area's travel patterns for calibrating traffic models. They believe that these data can be used to develop the total universe of trips in an area, as well as the percentage of trips for each of the several trip purpose and travel mode categories. Furthermore, they think that these data yield sufficient information concerning the lengths of urban trips, an important parameter in the development of traffic models. However, in developing a traffic model, specific information on the numbers and types of trips beginning and ending in each zone of the study area must also be known. This information cannot be obtained from a small sample home interview. Consequently, some assumption must be made as to how the total universe of trip productions and trip attractions distribute themselves on a zonal basis. This research examines the validity of these various assumptions. The ability of several sample sizes (as low as 200 home interviews) to provide the needed parameters for calibrating traffic models is investigated and the minimum sample size required is calibrated. The ability of simplified procedures to establish zonal productions and attraction values from areawide trip production values obtained from the small sample surveys is also investigated. The paper then reports the results of using the minimum sample size and the estimated production and attraction values to calibrate a gravity model for Sioux Falls. All validity tests are made using comprehensive home interview survey data of large sample size.

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•SINCE THE early 1940's transportation planning studies have been conducted in urban areas throughout the country in an increasingly comprehensive manner. In most of these areas basic data on travel patterns, social and economic characteristics of trip makers, and the uses of land have been collected, and the type and extent of transportation facilities have been determined. The interrelationships between these various kinds of data have in turn been analyzed to the point that today several theories on urban travel are emerging. These theories are in the form of traffic models, or equations, composed of the various parameters which influence the generation and distribution of urban trips as well as the routes which these trips will traverse. One of the most widely used theories on urban travel is the gravity model theory which utilizes a gravitational concept to describe the distribution of trips between various parts of an urban area.

With the advent of travel models, the theory has been advanced that the need for basic data on travel patterns may be less now than before these models were developed. In the past four years, interest has grown in the use of small sample home interview data for calibrating traffic models, particularly the gravity model, in urban areas. For example, the Hartford Area Traffic Study (1) collected travel data from only 200, or 0.1 percent, of the dwelling units within the study area. The Southeast Area Traffic Study (2) collected such data from 1,384 or 2.0 percent of the dwelling units within its study area. Several other studies (3, 4) have used similar sampling rates. Although theories have been advanced concerning travel patterns and the desirability of reducing the amount of travel data to be collected, little has been done to quantify their accuracy and validity.

This research had two principal objectives. The first was to examine the ability of a calibrated gravity model to reproduce the trip distribution patterns in a particular small urban area. To achieve this objective, full use was made of comprehensive origin-destination survey data in calibrating the gravity model for the urban area under study. The ability of this calibrated gravity model to simulate the area's trip distribution patterns was then investigated by comparing the gravity model movements against movements from the O-D survey.

The second objective was to evaluate simplified procedures for calibrating a gravity model trip distribution formula for the same urban area. Instead of calibrating with all the available data, only that trip information available from the external cordon survey and from a subsample of the original home interview survey was used. Simplified procedures were used to determine productions and attractions from detailed socio-economic data. The ability of this calibrated gravity model to simulate the area's travel patterns was then investigated by comparing the resultant gravity model movements against the movements obtained from the standard O-D survey of the area.

The small urban area selected for this research was Sioux Falls, S. Dak. (population, 62,000). In 1956, a comprehensive home interview O-D survey was conducted in 12.5 percent of the area's nearly 20,000 dwelling units (5), the rate recommended by the U.S. Bureau of Public Roads (6) for urban areas of this size. The standard external cordon and truck and taxi surveys (5) were also conducted, as were surveys of the land use and the type and extent of the area's transportation facilities. Unpublished data on the capacity and level of service characteristics of Sioux Falls transportation facilities, retail sales figures by zone, and certain employment and labor force statistics were supplied by the South Dakota Department of Highways. Also available were the results of a 1960 parking survey (9). The study area was divided into 74 traffic zones with 10 external stations. For summary and general analysis, these zones and stations were combined into 28 districts (Fig. 1).

GRAVITY MODEL THEORY

The gravity model theory, its mathematical statement, and the five parameters for calculating trip interchanges from this statement have been discussed in detail by Bouchard and Pyers (11, p. 2). However, the results of the present study indicate that there is no need for the application of the zone-to-zone adjustment factors, $K_{(i-j)}$, in the case of Sioux Falls. The need for these factors seems to be more pronounced

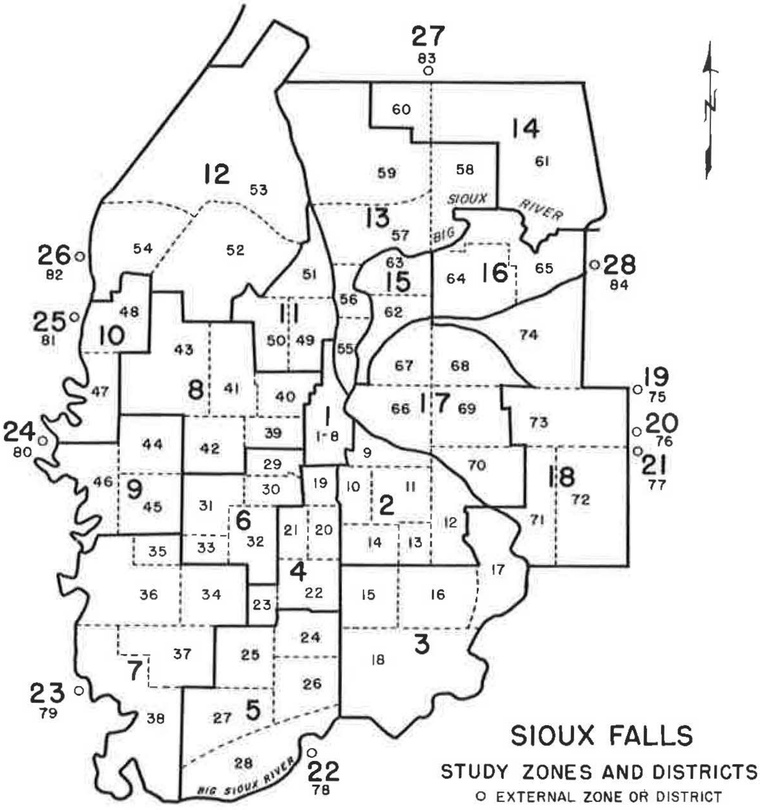


Figure 1. Zonal and district boundaries, Sioux Falls, S. Dak., study area, 1956.

in large urban areas where the range in various social and economic conditions of the residents is large.

TESTING THE GRAVITY MODEL THEORY FOR A SMALL URBAN AREA

This phase of the research deals with calibrating a gravity model from data obtained in the Sioux Falls O-D survey and testing the ability of this calibrated model to simulate the travel patterns found in the O-D survey. The steps involved in this phase were identical to those which have been completely documented in two recent publications by the U.S. Bureau of Public Roads (7, 8). These were essentially:

1. Processing basic data on the area's travel patterns and transportation facilities to provide three of the basic inputs to the gravity model formula, i.e., zonal trip production and attraction values and the spatial separation between zones;
2. Developing travel time factors, $F_{(t_{i-j})}$, to express the effect of spatial separation on trip interchange between zones;
3. Balancing zonal attraction factors, A_j, to assure that the trips attracted to each zone by the gravity model formula were in close agreement with those shown by the O-D survey data;
4. Examining these estimated trip interchanges to determine the need for adjustments to reflect various factors not directly accounted for in the model; and
5. Comparing the final gravity model trip interchanges with those from the home interview survey to test the ability of the model to simulate the 1956 travel patterns in the Sioux Falls area.

For this research, the total daily vehicular trips with either origins or destinations in the study area were used. Excluded from the study were trips which had neither their origins nor their destinations within the cordon (through trips) and all transit trips. The trips were stratified into the following categories: (a) home-based auto-driver work trips, (b) home-based auto-driver nonwork trips, and (c) nonhome-based vehicular trips.

The measure of spatial separation between zones (t_{i-j}) was composed of the off-peak minimum path driving time between zones plus the terminal time in the production and attraction zones connected with the trip. Terminal times were added to driving times at both ends of the trip to allow for differences in parking and walking times in the zones as caused by differences in congestion and available parking facilities.

Basic Data

All information from the home interview, external cordon, and truck and taxi surveys had previously been verified, coded and punched in cards. This information was made compatible as to meaning and location on the cards. The records were edited to insure that all pertinent information had been recorded correctly, and the edited records were then separated into the three trip purpose categories previously described. A table of zone-to-zone movements was then prepared for each trip purpose category. Each trip record was examined and all trips from each zone of production to every zone of attraction were accumulated. During this accumulation process the total number of trips produced by and attracted to each zone in the study area was also determined. These zonal trip production and attraction values were used to calculate trip interchanges with the gravity model formula. The zone-to-zone movements were subsequently used in testing the ability of the gravity model to simulate the 1956 travel patterns in Sioux Falls.

The data from the transportation facilities inventory had to be processed in the same way. This allowed the computation of the spatial separation between zones. Interzonal

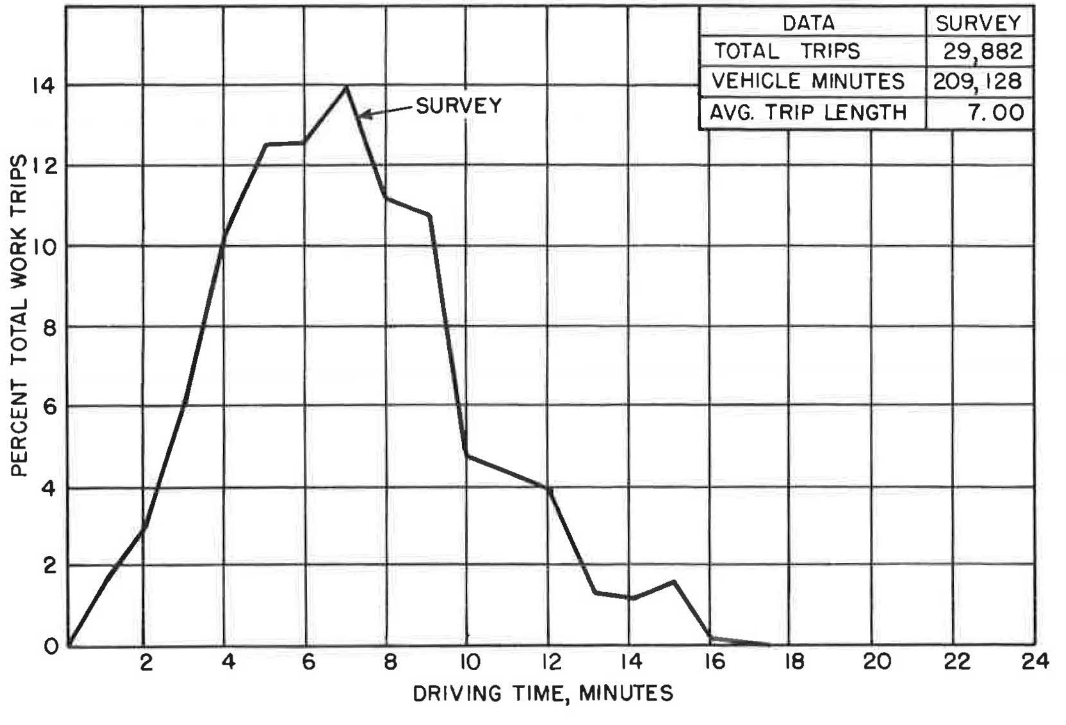


Figure 2. Trip length frequency distribution, home-based auto-driver work trips, Sioux Falls, 1956.

driving times were obtained from a description of the major street system in the area using a standard tree-building computer program. Intrazonal driving times were determined from an examination of the speeds on the highway facilities in each zone of the study area. Terminal times in each zone were determined by analyzing the results of the 1960 parking survey (9), which indicated to some extent the congestion and available parking facilities in each zone; central business district (CBD) zones were allocated 3 min and all other zones were allocated 1 min of terminal time.

Developing Travel Time Factors

The best set of travel time factors associated with each trip purpose was determined through a process of trial and adjustment. To determine travel time factors by this procedure, information is needed which reflects the effect of trip length on trip making. A useful summary of such information was obtained by determining the number and percent of trips for every minute of driving time for each trip purpose category. From the data on travel patterns, information was available on interzonal trips, and from the data on transportation facilities on driving times between zones. The trip length frequency distribution was obtained by combining the number of trips between each zone with the minimum path travel times between the zone pair, and repeating this process for all possible zone pairs. The resulting curve for work trips is shown in Figure 2. Table 1 summarizes this pertinent information for all trip purpose categories.

The procedure used was to assume a set of travel time factors for each trip purpose and to calculate trip interchanges using the gravity model formula, zonal trip productions and attractions and zonal separation information, obtained as previously described. The initial estimate of trip interchanges was then combined with the minimum time paths to obtain an estimated trip length frequency distribution for each trip purpose category. A comparison of the actual and the estimated trip length frequency distributions and the average trip length figures indicated close agreement. However, the discrepancies between the actual and the estimated figures were larger than desired by the research staff (±3 percent on average trip length with the frequency curves closely paralleling each other). Consequently, a revised gravity model estimate was made.

To make a revised estimate, new sets of travel time factors were calculated for each trip purpose category. The percentage of survey trips occurring during each minute of driving time was divided by the percentage of gravity model trips occurring during the same time increment, and the results of this division were multiplied by the initial factor. An example of this procedure is given in Table 2. These new factors were then plotted on log-log graph paper for the appropriate 1-min intervals for each trip purpose category, as shown in Figure 3. A line of best fit was drawn (by judgment) through the plotted points to obtain a smooth curve for travel time factors (Fig. 3).

TABLE 1

DISTRIBUTION OF VEHICULAR TRIPS BY PURPOSE
SIOUX FALLS, 1956

Purpose	No. of Trips	Veh-Min of Travel	Avg. Trip Length
Home-based work	29,882	209,128	7.00
Home-based nonwork	65,759	404,749	6.15
Nonhome-based	63,280	360,736	5.70
Total	158,921	974,613	6.13

TABLE 2

TRAVEL TIME FACTOR ADJUSTMENT PROCESS, WORK TRIPS

Driving Time	Percent Trips (Actual)	Travel Time Factor 1	Percent Trips (Est. No. 1)	Adj. Travel Time Factor[a]	Travel Time Factor 2[b]
1	1.68	162	1.24	219	220
2	2.93	152	2.12	210	210
3	6.09	142	4.88	177	185
4	10.28	132	10.32	131	150
5	12.61	122	13.49	114	125
6	12.57	112	13.62	103	110
7	13.91	102	13.26	107	100
8	11.22	092	11.26	92	085
9	10.91	082	11.42	78	079
10	4.20	072	6.04	50	067
11	4.40	062	5.33	51	061
12	3.98	052	3.52	59	057
13	1.53	042	1.56	41	050
14	1.34	032	1.09	39	048
15	1.70	022	0.74	51	045
16	0.04	012	0.08	06	010
17	0.01	0	0.04	0	002
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0

[a]From $\frac{\text{\% trips (actual)}}{\text{\% trips (est. No. 1)}}$ x travel time factor 1.

[b]From Figure 3.

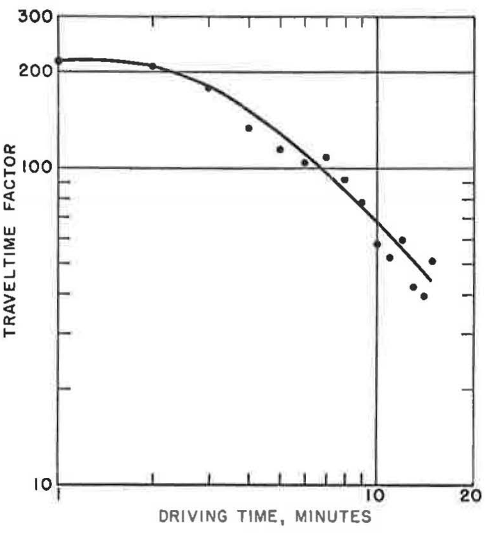


Figure 3. Determining revised travel time factors, work trips.

These new sets of travel time factors were then used in the same manner as in Calibration 1 to obtain a new estimate of trip interchanges with the model. New estimated trip length frequency curves, person hours of travel, and average trip length figures were developed and compared with the survey data. This comparison indicated that the gravity model estimates were within the established criteria. Consequently, the second estimate of travel time factors was judged to describe adequately the effect of spatial separation on trip interchange between zones in Sioux Falls. These final travel time factors are given for each trip purpose in Table 3.

Adjustment of Zonal Trip Attractions

The number of trips distributed by the gravity model to any given zone does not generally equal that shown by the O-D surveys as actually attracted to the zone,

TABLE 3

FINAL TRAVEL TIME FACTORS BY TRIP PURPOSE, SIOUX FALLS, 1956

Driving Time	Work	Nonwork	Nonhome-Based
1	220	280	300
2	210	260	270
3	185	220	210
4	150	160	120
5	125	130	100
6	110	090	080
7	100	085	070
8	085	070	060
9	079	060	055
10	067	050	044
11	061	039	038
12	057	035	032
13	050	027	030
14	048	025	026
15	045	021	023
16	010	016	014
17	002	000	005
18	000	000	000
19	000	000	000
20	000	000	000

because the gravity model formula does not have any built-in adjustment to insure such results. This variation in zonal attractions is a difficulty inherent in all currently available trip distribution techniques. Therefore, the trip attractions (A_j) for each zone were adjusted to bring the number of trips assigned to a given zone into balance with the trip attraction of that zone as determined by the survey.

Prior to balancing attractions, the estimated trip attractions resulting from Calibration 2 were compared with the actual attractions as shown by the survey to determine the differences. The two items of information for each zone were plotted for each trip purpose. An example for work trips is shown in Figure 4. A technique developed by Brokke and Sosslau (10) was used to judge the adequacy of the estimated figures. This earlier work established a reasonable approximation of the error that can be expected to result from O-D surveys of various sample rates, depending on the volume of trips measured. Curves developed to show the error in the survey volumes in terms of the root-mean-square (RMS) error, which is

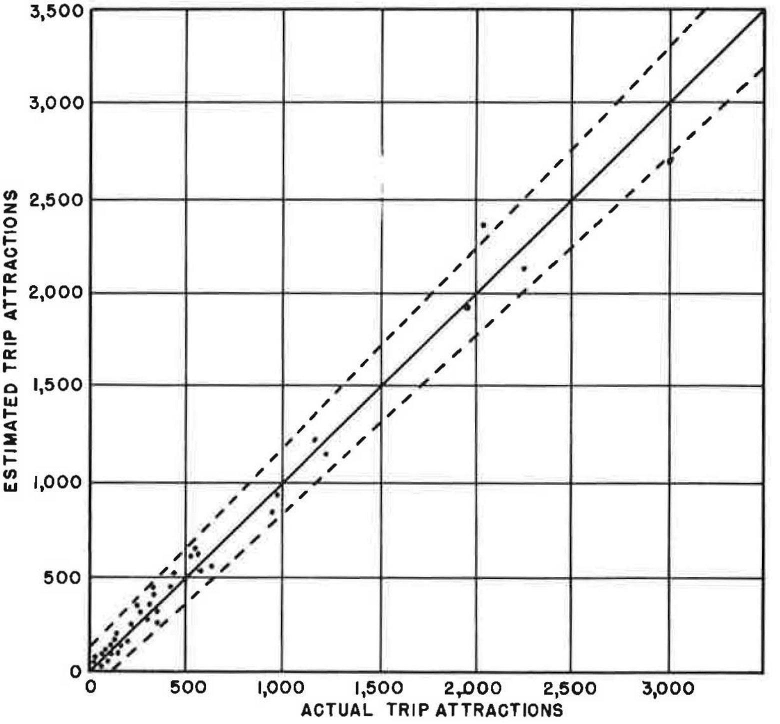


Figure 4. Comparison of work trip attractions, Calibration 2, Sioux Falls, 1956.

similar to the standard deviation, have been shown by Smith (16, Fig. 3). Two-thirds of the time (68.2 percent) the error in the origin-destination survey data, for a particular sample rate and volume group, will fall within one RMS error. Over 95 percent of the time, the recorded volumes will be within two RMS errors, and so forth. To determine the reliability (the degree of acceptability of the gravity model estimates) of the number of trips attracted to each zone in the study area, the RMS error for each volume group for the 12.5 percent sample rate was plotted as shown in Figure 4 and the points were connected by the dashed lines. If two-thirds of the points fall within these dashed lines, no adjustments are required. However, if less than two-thirds fall within these lines, all zonal attraction values should be adjusted. An examination of the results shown in Figure 4 indicated that the variations were small and entirely within the limits just described. The other two trip purposes showed similar results. Nevertheless, for purposes of this research, the zonal attraction values for each trip purpose were adjusted to obtain a more realistic measure of the error in the actual distribution of the trips. The adjustment was made by dividing the zonal trip attraction from the O-D survey by the trips attracted to each zone as developed by the gravity model and then multiplying the result by the original zonal trip attraction factor developed from the O-D survey. The amount of adjustment required for each trip purpose was relatively small. In most zones the adjustment was less than 10 percent and in no case was the adjustment greater than 20 percent. There was no discernible pattern in the required adjustment.

The gravity model interchanges were then recalculated using the adjusted zonal attraction values. The slight differences in this information between Calibrations 2 and 3 indicated that the zonal attraction factor adjustment had very little effect on the variation. Part of this, of course, can be explained on the basis of the rather small adjustments which were required to balance the zonal adjustment factors for each trip purpose. The results of this third and final calibration in terms of the trip length frequency distribution and the average trip length for work trips are shown in Figure 5.

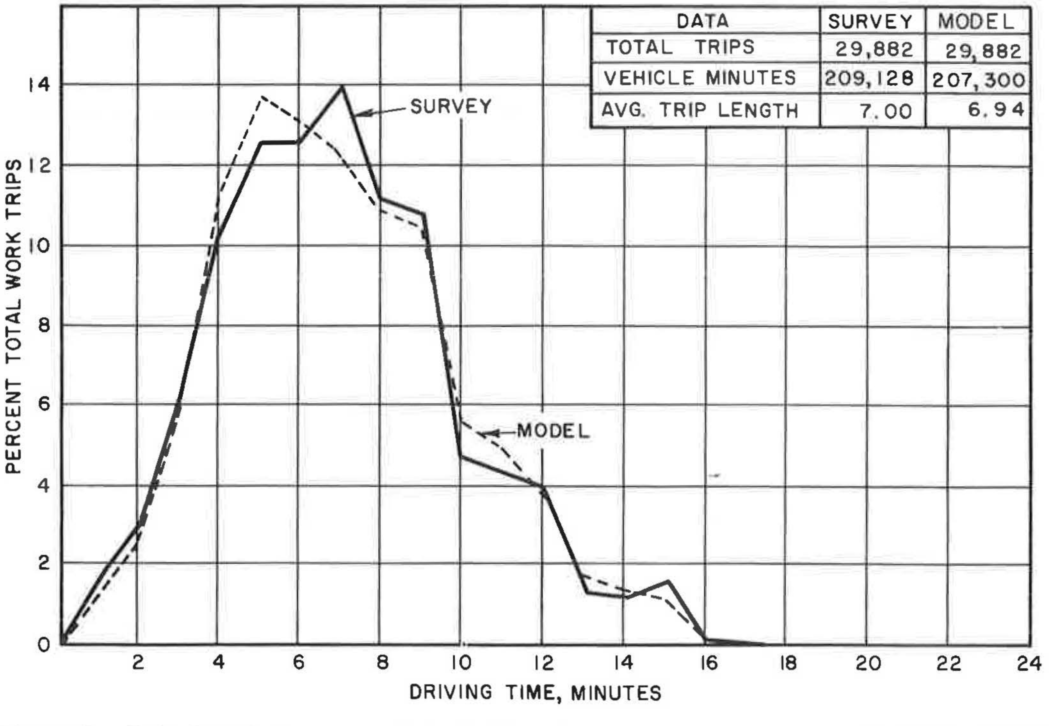


Figure 5. Trip length frequency distribution, home-based auto-driver work trips, Sioux Falls, 1956.

To investigate the effect of the zonal attraction factor adjustment on actual trip interchanges, the district-to-district movements were examined for both the second and third calibrations. District-to-district movements, rather than zone-to-zone movements were used in this analysis to obtain a more meaningful accumulation of trips. The results of this analysis for work trips, shown in Figure 6, were quite similar for the other two trip purposes although the dispersion was somewhat more pronounced. However, in no case was the dispersion greater than 15 percent. An examination of this information indicated that the attraction adjustment procedure had only a small effect on trip interchanges.

Checking Model for Geographical Bias

In using the gravity model, several researchers have discovered the need for various adjustment factors to account for special conditions within an urban area which affect travel patterns but are not accounted for in the model. For example, a recent study in Washington, D. C., indicated that the Potomac River had some influence on trip distribution patterns (11). A study in New Orleans, La., indicated similar problems connected with river crossings (12). A study in Hartford, Conn., indicated that toll bridges crossing the Connecticut River also had an effect on travel patterns (1). In each of these cases, the effects of these conditions were indicated to the gravity model by time penalities on those portions of the transportation system for which discrepancies in the model were observed. In addition, some studies have indicated geographical bias caused by factors other than topographical barriers. For example, the Washington, D. C., study showed the need for adjustment factors to account for a rather unique relationship existing in that area. Before incorporating the adjustment factors into the gravity model formula, the estimated trip interchanges were significantly biased in

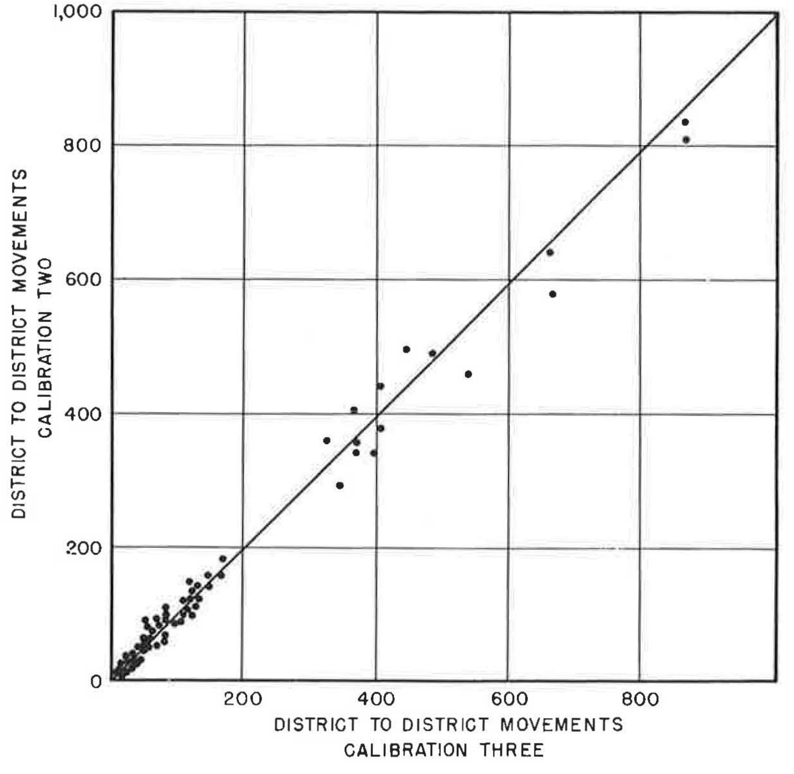


Figure 6. Comparison of district-to-district movements, home-based auto-driver work trips, Sioux Falls, 1956.

that the model did not adequately account for the fact that medium income blue collar workers residing in certain parts of the Washington area had no job opportunities within the central parts of the area. If work trips had been further stratified, perhaps the need for adjustment factors would have been reduced.

Several tests were conducted on the results of Calibration 3 to determine the need for adjustment factors such as those just described. One of these tests involved the Big Sioux River which bisects the Sioux Falls area as shown in Figure 1. For those trips crossing the Big Sioux River, the total trip interchanges as shown by the home interview survey were compared directly with the results of the gravity model. In addition, both of these items were compared with volume counts taken on all the bridges crossing this river. As indicated in Table 4, there is a very close agreement between these three sources of information; this indicates that the Big Sioux River is no barrier to travel.

Another test for geographical bias was conducted for trips to the CBD of Sioux Falls. Trips from each district to the CBD, by trip purpose, as shown in Calibration 3 of the gravity model were compared directly with the same information from the O-D survey. These results are shown in Figures 7, 8, and 9. An analysis of these figures indicates that no significant bias is present in the model and, furthermore, the gravity model estimates are close to the O-D survey.

Final Results

The total trips resulting from the final calibration of the gravity model and from the O-D survey were assigned to the transportation network. An examination of the results of these two assignments was made by comparing the number of trips crossing a very comprehensive series of screenlines. Figure 10 shows this comprehensive series of screenlines and also identifies each screenline. Table 5 compares the actual and estimated trips crossing each of these screenlines. An examination of the absolute and the percent differences between the actual and the estimated screenline crossings indicated only four differences larger than 10 percent and none which have absolute volume discrepancies large enough to affect design considerations.

One final test was made to determine the statistical significance of the differences between the gravity model estimates and the O-D survey data. The results of this test are given in Table 6. When these results were compared with the O-D survey error (10), the gravity model estimates had almost the same degree of reliability as the O-D survey data.

TABLE 4

COMPARISON OF TOTAL VEHICULAR TRIPS CROSSING BIG SIOUX RIVER, SIOUX FALLS, 1956

Facility	Trips (No.)		
	Vol. Count	O-D Survey	Gravity Model
Cherry Rock Ave.	1,511	1,640	1,660
Cliff Ave., S.	9,132	8,420	9,444
Tenth St.	14,842	16,296	16,648
Eighth St.	8,606	6,612	6,080
Sixth St.	3,864	2,900	3,576
McClellan St.	3,069	2,596	2,032
Cliff Ave., N.	4,699	4,156	3,904
Totals	45,723	42,620	43,344
Percent from Vol. Count	-	-6.8	-5.2
Percent from O-D Survey	+7.3	-	+1.7

The tests and comparisons shown in this section of the report indicate that the calibrated three purpose gravity model adequately simulates the trip distribution patterns shown by the O-D survey. Nevertheless, it is desirable to have a measure of the differences in the results which would have been obtained for lesser and higher degrees of trip stratification than the three purposes used in this research. To date, little has been done to investigate these differences. The analysis to be outlined is not conclusive, but it does shed considerable light on the subject.

The analysis procedure was as follows. Gravity models were calibrated for the following trip purpose stratifications:

1. One purpose model—total vehicular trips; and
2. Six purpose model—home-based auto-driver work trips, home-based auto-

driver shop trips, home-based auto-driver miscellaneous trips, home-based auto-driver social-recreation trips, nonhome-based vehicular trips, and truck and taxi trips.

The same techniques and the same number of calibration runs were made in these two models as were made in calibrating the three purpose model. The same tests were also performed on these models as on the three purpose model with about the same degree of accuracy. Table 5 gives the absolute and percentage differences between the model and survey trips crossing the comprehensive series of screenlines (Fig. 10) for one purpose, three purpose, and six purpose models. Results indicate that the three purpose model is better than the one purpose model, but the increased accuracy obtained with a six purpose model is only slightly greater than with a three purpose model.

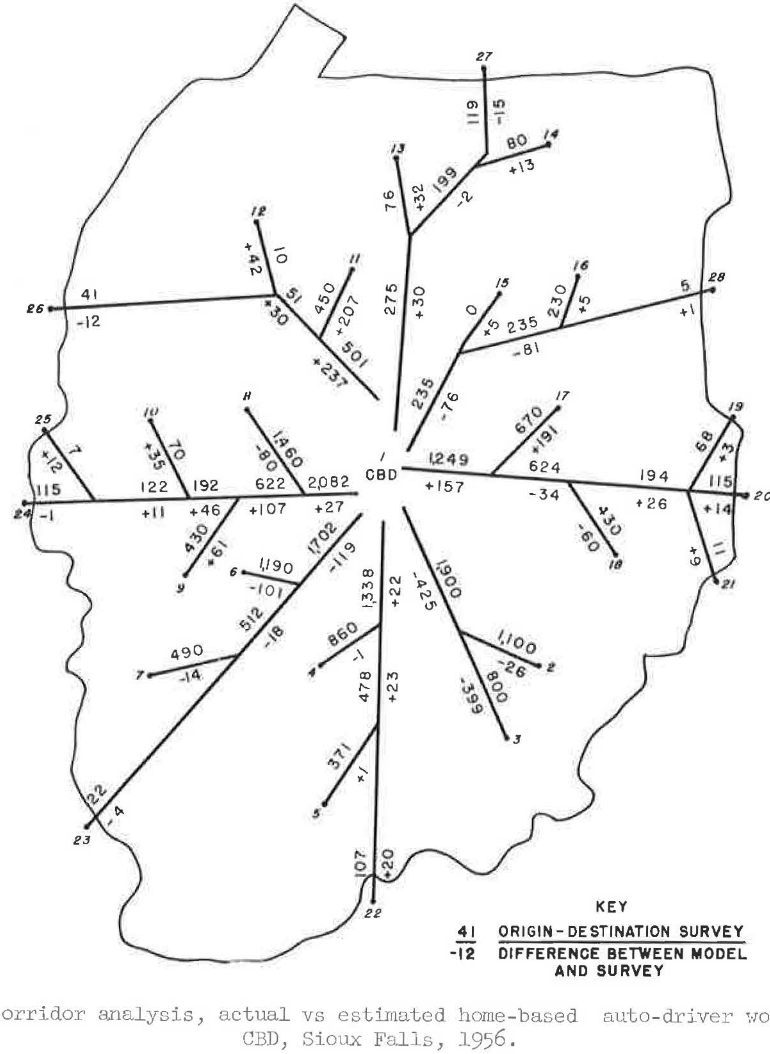


Figure 7. Corridor analysis, actual vs estimated home-based auto-driver work trips to CBD, Sioux Falls, 1956.

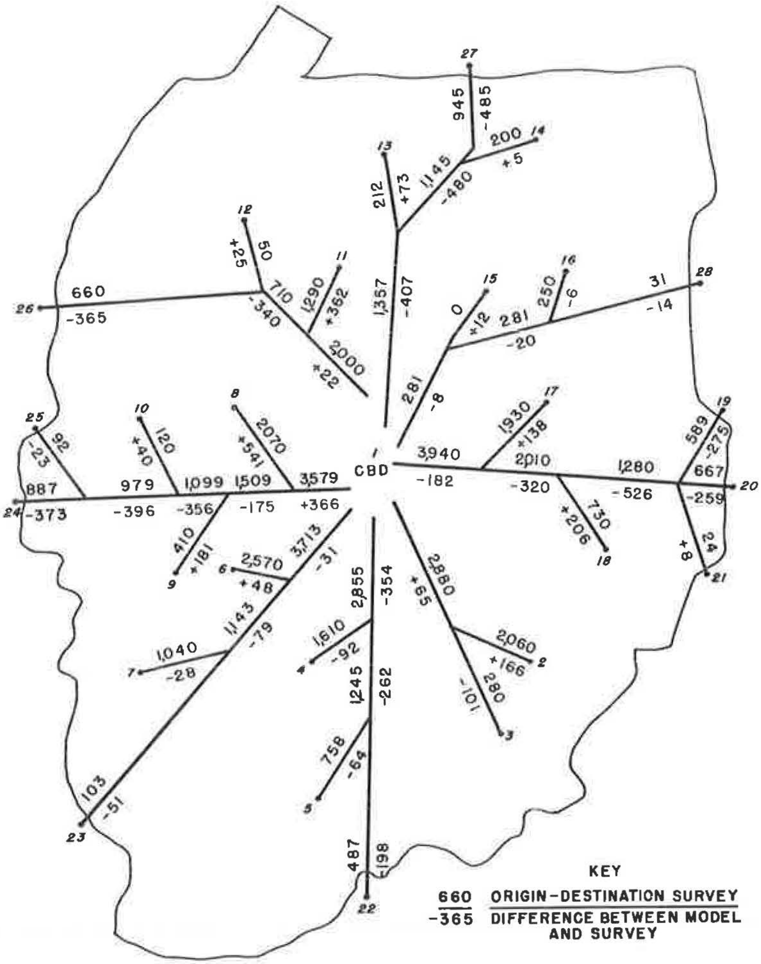


Figure 8. Corridor analysis, actual vs estimated home-based auto-driver nonwork trips to CBD, Sioux Falls, 1956.

USE OF SIMPLIFIED PROCEDURES FOR DETERMINING TRIP DISTRIBUTION PATTERNS IN A SMALL URBAN AREA

The previous phase of this research illustrated that the gravity model formula can be used to simulate trip distribution patterns in a small urban area when comprehensive home interview data are available for use in developing the model to fit the area's travel patterns. The research reported in this section examines the feasibility of reducing the amount of data necessary to develop the gravity model. Since in developing the gravity model for Sioux Falls, no significant geographical bias was observed, it was not necessary to make use of all the data available for the area. This led to an exploration of smaller samples of data for calibrating the gravity model. This phase of the research was accomplished in the following steps.

1. The minimum sample size of home interview survey required to provide the information necessary to develop the gravity model formula for Sioux Falls was determined. Since the previous phase of this research illustrated that information on zonal trip production and attraction and a trip length frequency distribution of trips, by trip

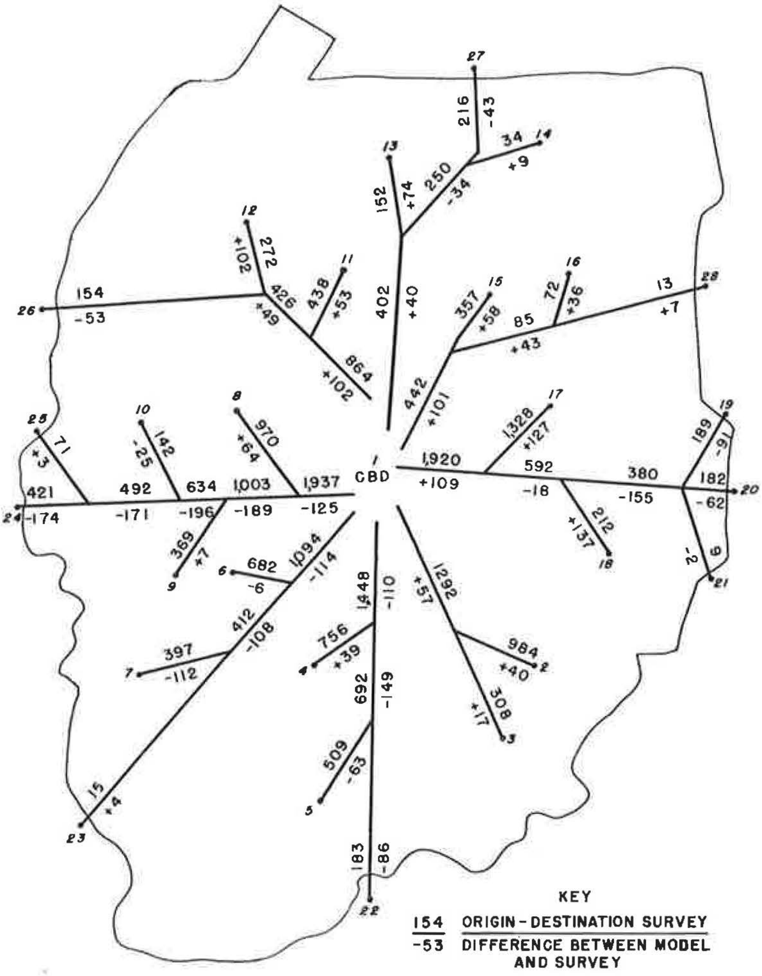


Figure 9. Corridor analysis, actual vs estimated nonhome-based vehicular trips to CBD, Sioux Falls, 1956.

purpose, was all that was required for a gravity model calibration, the small sample data must provide sufficient information to develop these parameters. This step involved an analysis of subsample data from several urban areas and the development of curves that could be used to determine the relative error which would occur for different size samples.

2. Zonal trip production and trip attraction values for each trip purpose were estimated using the total trips expanded from the small sample, their split among the various purposes, and certain social and economic characteristics of each individual zone. Zonal trip production and attraction values were developed in this manner because they are not available from small sample data, and they were compared directly with the data from a comprehensive O-D survey to determine the reliability of the techniques used.

3. Trip interchanges for each trip purpose were determined using the results of the previous two steps and the gravity model formula. The synthetic trip distribution patterns were then compared directly with the O-D survey results.

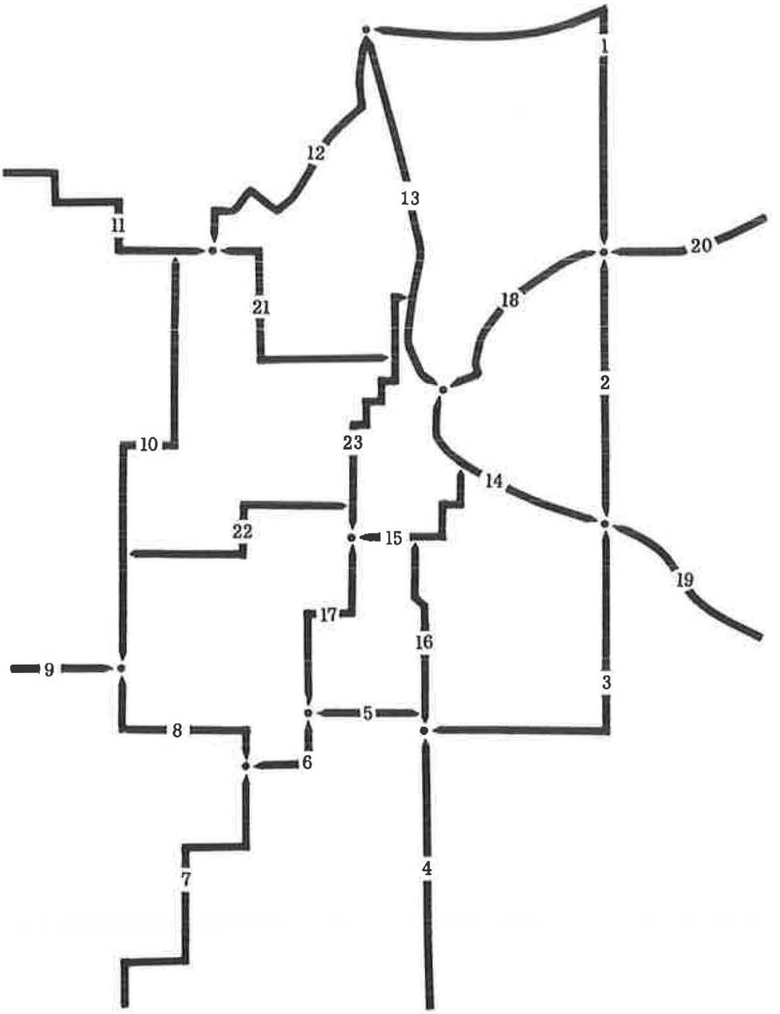


Figure 10. Location and identification of comprehensive series of screenlines, Sioux Falls, 1956.

Determining Overall Travel Characteristics from Small Sample

It has been reported by studies using small sample home interview surveys that the data collected in such surveys are adequate for calibrating a gravity model (1, 2). Those using small sample home interview surveys in the past have reported that the resulting data can be used to develop the total number of trips in the area, as well as the percentage of trips for each of the several trip purposes and travel mode categories. Furthermore, they indicated that these data gave sufficient information concerning the length of urban trips, an important parameter in the development of travel models.

There is some evidence available to substantiate these reports. For example, a recent study by the Connecticut Highway Department compared the total universe of trips as well as the percentages of trips for each of three trip purposes for subsamples of 153 and 592 home interviews. These subsamples were drawn from an original field sample of 1,384 home interviews taken in the Southeast Area Traffic Study. Some of the results of this study, given in Table 7, indicate that samples as low as 600 interviews may give approximately the same results for total trips by trip purpose as the

TABLE 5

TOTAL TRIPS CROSSING SCREENLINES, SIOUX FALLS, 1956

Screenline No.	O-D Survey Vol.	One Purpose Model		Three Purpose Model		Six Purpose Model	
		Vol.	Diff. from O-D (%)	Vol.	Diff. from O-D (%)	Vol.	Diff. from O-D (%)
1	7,952	6,996	-12.0	7,344	- 7.6	7,440	- 6.4
2	21,012	20,580	- 2.1	20,460	- 2.6	20,552	- 2.2
3	13,516	14,216	+ 5.2	13,900	+ 2.8	13,222	- 2.2
4	11,384	12,344	+ 8.4	12,060	+ 5.9	11,956	+ 4.2
5	9,744	9,332	- 4.2	9,252	- 5.0	9,336	- 5.0
6	8,784	9,500	+ 8.2	9,392	+ 6.9	9,444	+ 7.5
7	6,280	6,788	+ 8.1	6,824	+ 8.7	6,852	+ 9.1
8	6,568	6,984	+ 6.3	7,032	+ 7.1	7,152	+ 8.9
9	2,264	2,772	+22.4	2,676	+18.2	2,648	+17.0
10	17,448	17,808	+ 2.1	17,592	+ 0.8	17,668	+ 1.3
11	5,868	6,468	+10.2	6,532	+11.3	6,704	+14.2
12	5,592	6,484	+16.0	6,412	+14.7	6,392	+14.3
13	13,656	13,660	0.0	14,840	+ 8.7	13,924	+ 2.0
14	22,908	25,096	+ 9.6	23,040	+ 0.6	22,720	- 0.8
15	33,220	31,400	- 5.5	32,144	- 3.2	34,005	+ 2.4
16	10,032	10,736	+ 7.0	10,012	- 0.2	10,120	+ 0.8
17	13,424	14,016	+ 4.4	13,760	+ 2.5	14,012	+ 4.4
18	9,724	10,324	+ 6.2	10,276	+ 5.7	10,424	+ 7.2
19	10,060	11,352	+12.8	11,044	+ 9.8	11,092	+10.3
20	5,332	5,240	- 1.7	5,420	+ 1.6	5,556	+ 4.2
21	8,496	9,056	+ 6.6	9,136	+ 7.5	9,200	+ 8.3
22	13,332	14,612	+ 9.6	14,504	+ 8.8	14,672	+10.0
23	41,500	40,660	- 2.0	41,852	+ 0.8	39,995	- 3.6

1,384 interviews originally made in the field. The 1,384 sample, used as a base, is small and it must be realized that it contains inherent sampling error. This same study also compared the trip length frequency distributions and average trip lengths for the same trip purposes and sample sizes. The results for work trips (Fig. 11) show that the trip length frequency distributions and mean trip lengths are very similar for the 1,384 and 592 sample sizes, with the 592 interviews being about as adequate as the 1,384 interviews. The same data for the 153 samples show significant error.

A recent study in North Carolina (14) compared the total trips and trip percentages for three trip purposes for subsamples of 192, 196, 248, 383, and 742 home interviews drawn from an original field sample of 1,457 home interviews taken in Fayetteville, N.C. Some of the results of this study (Table 8) indicate that samples as low as 600 might give approximately the same results for total trips by purpose as the 1,457 original interviews. This study also compared the trip length frequency distributions (Fig. 12) and mean trip lengths. These figures were very similar for the 1,457 and 742 sample sizes. A sample size greater than 383 was necessary for an adequate mean trip length reproduction.

A similar study, recently completed by the Urban Planning Division of the U.S. Bureau of Public Roads, examined the variation in total trips, purpose split, average trip lengths, and trip length frequency distributions for subsamples of 2,021 and 404 interviews. These subsamples were from an original field survey of 16,169 home interviews taken during the Pittsburgh Area Transportation Study. Table 9 gives the total sample figures and the results of the comparisons of total trips and purpose split for each subsample. Figure 13 illustrates the trip length frequency distributions and the mean trip length figures for one of the six purposes in each of the sample rates tested. This information indicates that small samples yield adequate data on these overall travel characteristics, but the minimum sample rate shown by the Pittsburgh study appears to be around 2,000 interviews, as compared with about 600 interviews in the Connecticut and North Carolina studies. The Pittsburgh analysis used person

TABLE 6

COMPARISONS OF DISTRICT-TO-DISTRICT MOVEMENTS[a]

Volume Group	O-D Survey Trip		RMS Error	
	Mean	Freq.	Abs.	Percent
(a) Home-Based Auto-Driver Work Trips				
0- 99	21	400	17	80.95
100- 199	133	40	47	35.34
200- 299	259	13	87	33.59
300- 499	402	13	85	21.14
500-1,499	920	8	166	18.04
(b) Home-Based Auto-Driver Nonwork Trips				
0- 99	27	423	24	88.89
100- 199	136	53	83	61.03
200- 299	239	28	87	36.40
300- 499	380	22	112	29.47
500- 999	728	22	231	31.73
1,000-2,999	1,711	9	276	16.13
(c) Nonhome-Based Auto-Driver Trips				
0- 99	25	473	22	88.00
100- 199	144	62	63	43.75
200- 299	241	30	100	41.49
300- 499	385	33	101	26.23
500- 999	773	9	119	15.39
1,000-4,999	1,695	9	263	15.52

[a]1956 O-D survey data vs gravity model estimates, relative difference measured in terms of percent RMS error:

$$\text{Percent RMS error} = 100\left(\frac{\sqrt{\frac{\Sigma (d)^2}{n}}}{\bar{x}}\right)$$

where
d = difference between surveyed and estimated,
n = number of district-to-district movements, and
$\bar{x}$ = mean of surveyed trips.

trips, whereas the other two studies used auto-driver trips. The results appear consistent since the Pittsburgh analysis stratified trips six ways and the Connecticut and North Carolina analyses used only three trip stratifications.

Several subsamples of the Sioux Falls home interview data were also examined for their ability to yield accurate figures on total trip productions, average trip lengths, and trip length frequency distributions by trip purpose. The results of these analyses for 599 and 199 dwelling unit subsamples and the original 2,399 field samples appear in Table 10 and Figures 14, 15, and 16. These results reinforce the findings of the previously mentioned studies which indicate that samples as small in number as 600 can be used to determine the overall average characteristics of travel in a small urban area, when three trip stratifications are used.

The results for the Sioux Falls analytical subsamples were analyzed to see if general curves could be developed to approximate the error which would occur in mean trip length and total trips by trip purpose and trips per dwelling unit for various sample sizes. The curves which were developed from the relationship between the standard deviation of the mean and the square root of sample size are shown in Figures 17 and 18. They give the expected error which would occur in the indicated parameters for various sample sizes, based on the known variance in the trip data.

A statistical analysis of the ability of small samples to adequately estimate trip production and average trip length characteristics in the Pittsburgh, Pa., study area has also been made. The results of this analysis, shown in Figures 19 and 20, indicate the reliability of small sample home interview surveys in determining the overall travel characteristics of an urban area.

The research discussed in the next section of this report is based entirely on the sample size analyses. It utilizes the results of the 599 subsample of the Sioux Falls home interview survey and the standard external cordon survey in calibrating a synthetic gravity model.

Determining Zonal Trip Production and Attraction Values

As stated earlier, two of the basic parameters required to estimate trip interchanges by the gravity model formula are the number of trips produced by each zone and the number of trips attracted to each zone for each trip purpose category. This information cannot be obtained directly from a small sample home interview. Consequently, some assumption has to be made as to how the total number of trip productions and trip attractions distribute themselves on a zonal basis.

TABLE 7

COMPARISON OF TOTAL TRIP PRODUCTIONS FOR VARIOUS SAMPLE SIZES, SOUTHEAST AREA TRAFFIC STUDY, 1962

Trip Purpose	1,384 Sample[a]			592 Sample[b]			153 Sample[c]		
	Sample Trips	Percent Total Trips	Diff. (%)	Expanded Trips	Percent Total Trips	Diff. (%)	Expanded Trips	Percent Total Trips	Diff. (%)[d]
Home-based work	2,067	32.9	0	2,006	30.9	-3.0	1,936	32.6	-6.3
Other home-based	3,218	51.3	0	3,446	53.1	+7.1	3,139	52.9	-2.5
Nonhome-based	990	15.8	0	1,040	16.0	+5.1	859	14.5	-13.2
Total	6,275	100.0	0	6,492	100.0	+3.5	5,934	100.0	-5.4

[a]Sample rate, 2.4 percent.
[b]Sample rate, 1.1 percent.
[c]Sample rate, 0.3 percent.
[d]Percent difference from 2.4 percent sample.

The assumptions made and procedures used to obtain zonal trip production and attraction values in this research are very similar to previously reported synthetic procedures (1, 4). These procedures make use of detailed socio-economic data in developing productions and attractions for use with the gravity model trip distribution technique. For example, labor force can be used to indicate work trip production, employment can be used for work trip attraction, and retail sales for nonwork trip attraction.

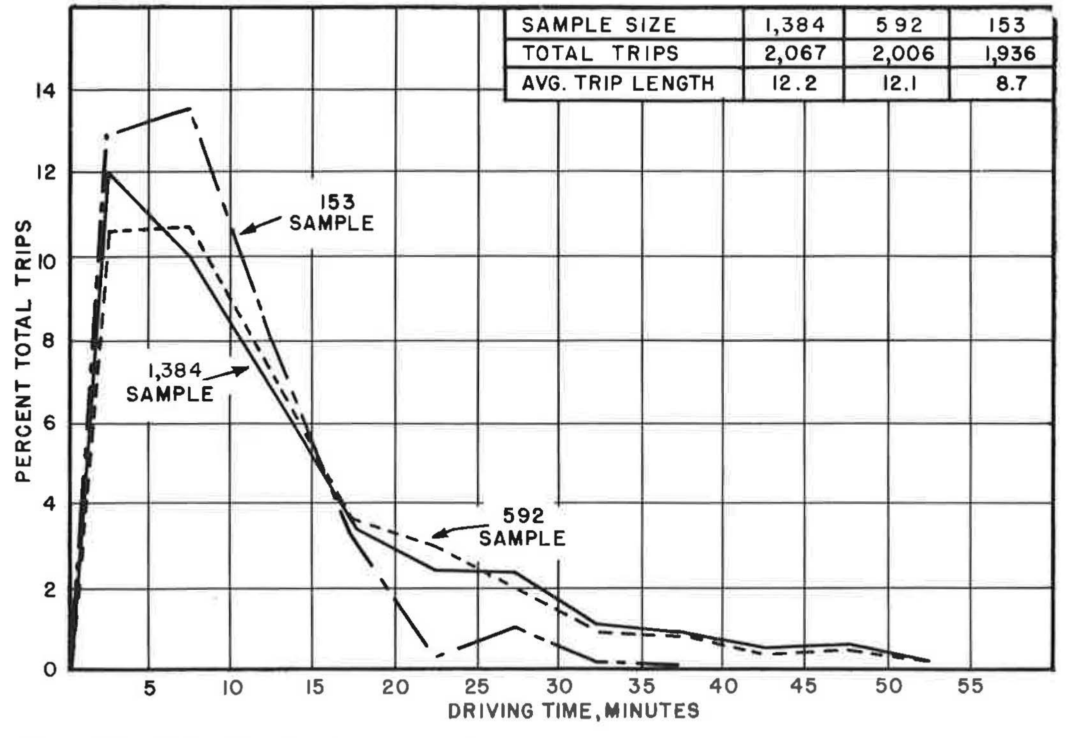


Figure 11. Trip length frequency distribution, home-based auto-driver work trips, southeast Connecticut, 1960.

TABLE

COMPARISON OF TOTAL TRIP PRODUCTIONS FOR SELECTED SAM

Trip Purpose	1,457 Sample			742 Sample			196 Sample	
	Expanded Trips	Percent Total Trips	Diff. (%)a	Expanded Trips	Percent Total Trips	Diff. (%)a	Expanded Trips	Percent Total Trips
Home-based work	26,207	38.9	0	25,781	38.6	-1.6	26,080	39.0
Other home-based	27,760	41.2	0	27,887	41.7	+0.5	27,101	40.5
Nonhome-based	13,437	19.9	0	13,194	19.7	-1.8	13,720	20.5
Total	67,404	100.0	0	66,862	100.0	-0.8	66,901	100.0

[a]Percent difference from total sample.

Table 11 indicates that there was a total of 7.18 trips made for every car owned by the persons who were interviewed; 1.36 of these were work trips, 2.84 were nonwork trips, and 2.98 were nonhome-based trips. By applying these rates to the total number of automobiles in the area, a total number of trips, by trip purpose, can be obtained. The total number of automobiles in the study area can be obtained from several sources such as census data (only for the census year), state, county, or city auto registration records, or special surveys. In this study the information was obtained from the 1956 comprehensive home interview survey. The resulting estimates of total trip production for each trip purpose are given in Table 12. Since total trip productions for the

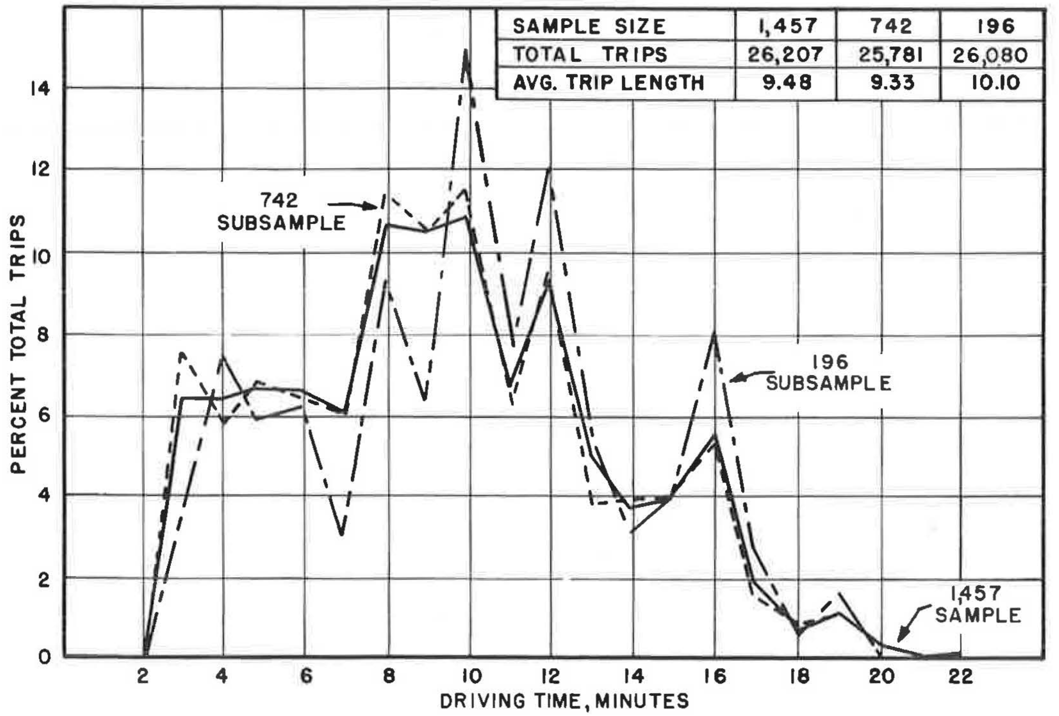


Figure 12. Selected trip length frequency distributions, home-based auto-driver work trips, North Carolina study, 1963.

8

PLE SIZES, NORTH CAROLINA RESEARCH PROJECT N, 1963

	383 Sample			248 Sample			192 Sample		
Diff. (%)a	Expanded Trips	Percent Total Trips	Diff. (%)a	Expanded Trips	Percent Total Trips	Diff. (%)a	Expanded Trips	Percent Total Trips	Diff. (%)a
-0.5	24,382	38.5	-7.0	25,920	40.0	-1.1	27,498	39.3	+4.9
-2.4	27,983	44.2	+0.8	27,896	43.0	+0.5	26,637	38.1	-4.0
+2.1	10,991	17.3	-18.2	11,053	17.0	-17.7	15,802	22.6	+17.6
-0.8	63,356	100.0	-6.0	64,869	100.0	-3.8	69,937	100.0	+3.8

entire study area must equal total trip attractions for the entire study area in each trip purpose category, estimates of total trip attractions are also available from this procedure and are given in Table 12.

Home-Based Auto-Driver Work Trips. —As one might suspect, work trips are closely associated with labor force and employment; these were the basic socio-economic data used to determine zonal production and attraction values for this trip purpose.

Zonal Trip Productions. —These values for the 74 internal zones for this trip purpose were derived from zonal information on the labor force. Labor force data are generally available from sources such as census reports, labor statistics, and reports. In this research, the information for each zone was taken from data available for Sioux Falls. From studies in other areas (1, 4), it has been found that there are about 0.80 daily work trips produced (one-way) for each person in the labor force. This figure differs from 1.0 work trips (one-way) because some persons in the labor force are unemployed, on vacation, walk to work, etc. An examination of the survey data in the Sioux Falls area indicated similar trip rates. Consequently, to determine the total number of work trip productions by auto and transit in each zone, the labor force in each internal zone was first multiplied by 0.80.

To determine transit usage, the information given in Table 13 was used. This information was developed from survey data in Chicago, Ill. By entering this table with the zonal information on car ownership and net residential density, an index of transit usage is obtained. The resulting zonal indices were then totaled and equated to the work trip transit usage for the Sioux Falls study as determined from the small sample home interview survey. A correction factor was developed which, when applied to the

TABLE 9

COMPARISON OF TOTAL TRIP PRODUCTIONS FOR VARIOUS SAMPLE SIZES, PITTSBURGH, PA., 1958

Trip Purpose	16,169 Sample[a]			2,021 Sample[b]			404 Sample[c]		
	Expanded Trips	Percent Total Trips	Diff. (%)d	Expanded Trips	Percent Total Trips	Diff. (%)d	Expanded Trips	Percent Total Trips	Diff. (%)d
Home-based work	796,195	34.1	0	792,576	33.9	-0.5	765,480	33.3	-3.9
Home-based other	425,074	18.2	0	440,784	18.8	3.7	436,920	19.0	2.8
Home-based soc-rec.	288,047	12.3	0	293,752	12.6	2.0	311,280	13.5	8.1
Home-based shop	286,883	12.3	0	276,416	11.8	-3.6	289,640	12.6	1.0
Home-based school	232,875	10.0	0	218,264	9.3	-6.3	191,920	8.4	-17.6
Nonhome-based	306,915	13.1	0	318,688	13.6	3.8	303,520	13.2	-1.1

[a]Sample rate, 4.0 percent.
[b]Sample rate, 0.5 percent.
[c]Sample rate, 0.1 percent.
[d]Percent difference from 4 percent sample.

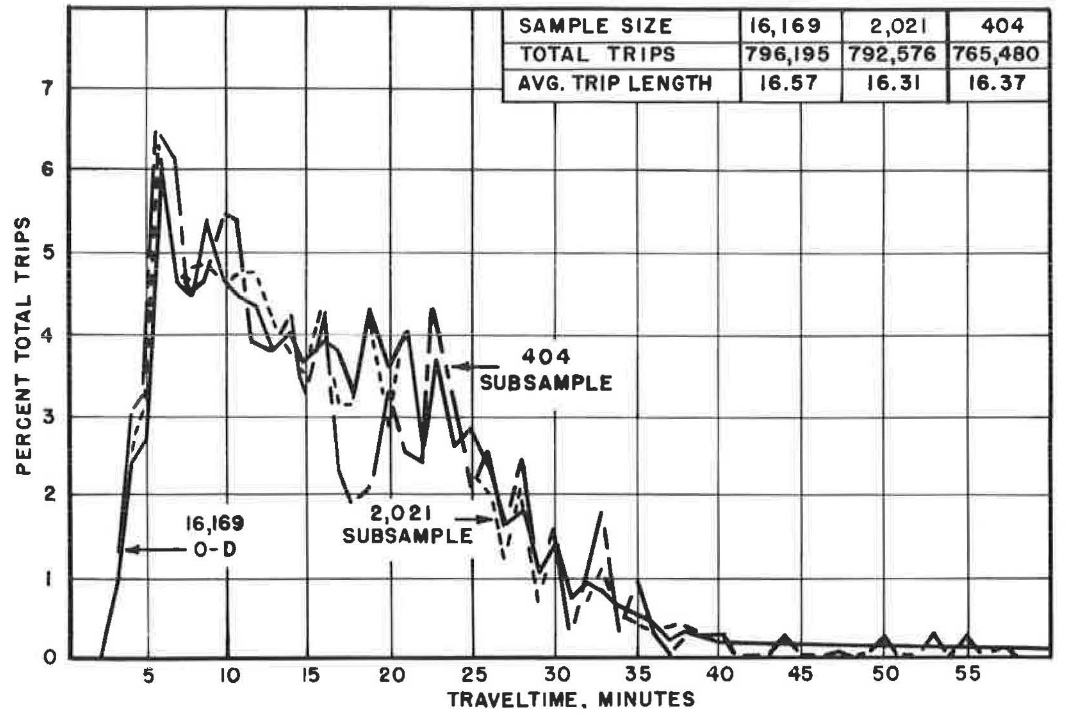


Figure 13. Trip length frequency distributions, home-based person work trips, Pittsburgh, Pa., 1958.

previously developed indices, would yield figures on zonal work trip transit usage; these figures, when totaled, would agree with that shown for the total study area by the small sample. The application of this correction factor was based on the assumption that a three-dimensional plot of the characteristics of variation in transit usage would maintain the same form and shape from one city to another. This correction factor for Sioux Falls was 0.5, and when applied to the zonal indices, it brought the total estimated work transit trips into agreement with the total from the small sample. The number of person work trips made by auto for each zone was then obtained by subtracting

TABLE 10

COMPARISON OF TOTAL TRIP PRODUCTION FOR VARIOUS SAMPLE SIZES, SIOUX FALLS, 1956[a]

Auto-Driver Trip Purpose	2,399 Sample[b]			599 Sample[c]			199 Sample[d]		
	Expanded Trips	Percent Total Trips	Diff. (%)[e]	Expanded Trips	Percent Total Trips	Diff. (%)[e]	Expanded Trips	Percent Total Trips	Diff. (%)[e]
Home-based work	25,161	24.2	0	26,564	24.4	5.6	26,292	26.4	4.5
Home-based nonwork	50,782	48.9	0	53,848	49.4	6.0	47,232	47.4	-7.0
Nonhome-based	27,924	26.9	0	28,516	26.2	2.1	26,040	26.2	-6.8
Total	103,867	100.0	0	108,744	100.0	4.6	101,496	100.0	-2.4

[a]These figures are from internal home interview person trip data only and do not include information available from the truck, taxi, and external cordon survey. Auto-driver trip data from both of these sources were used in developing trip interchanges synthetically as described in text and given in Table 12.
[b]Sample rate, 12.5 percent.
[c]Sample rate, 3.1 percent.
[d]Sample rate, 1.0 percent.
[e]Percent difference from 12.5 percent sample.

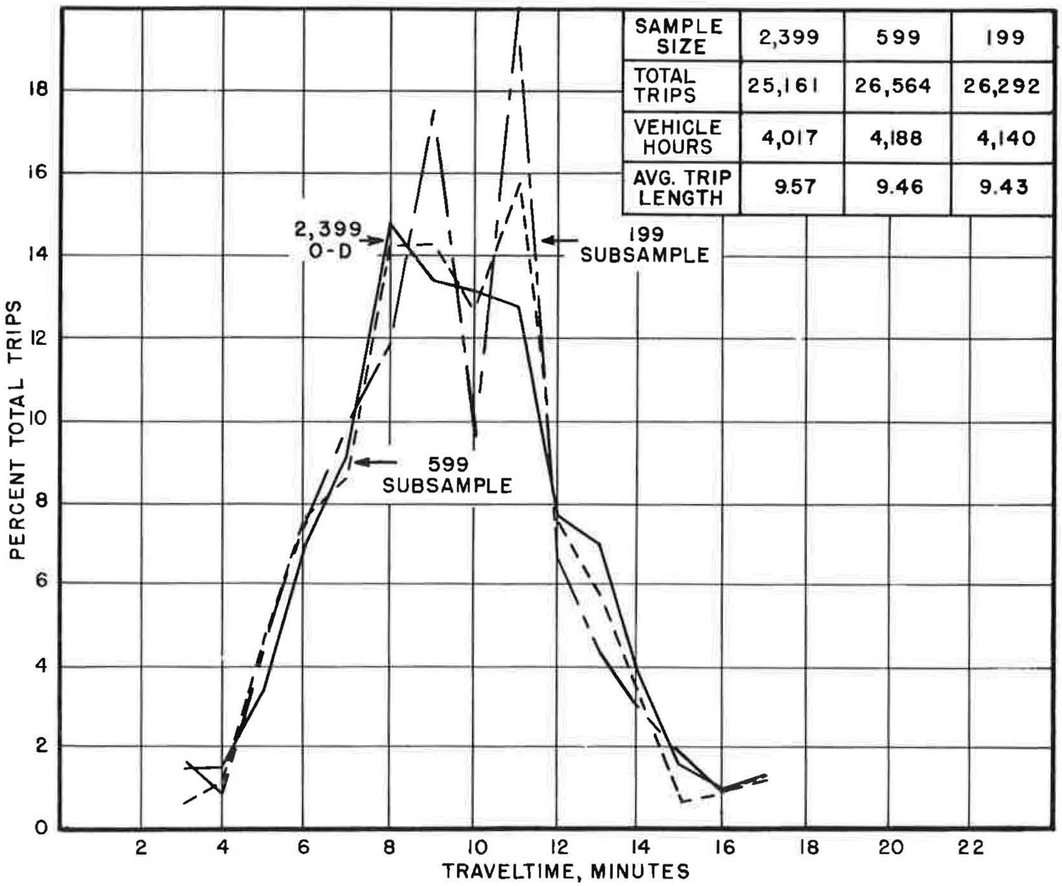


Figure 14. Trip length frequency distributions, home-based auto-driver work trips, Sioux Falls, 1956.

these transit work trips from the total person work trips for each zone. To correct for car occupancy and to arrive at auto-driver work trips, the information from Table 14 was applied to the total automobile work trips previously developed for each zone. Table 14 shows the relationship between car ownership and car occupancy, as developed from data in the Chicago area. Assuming that the relationship between car occupancy and car ownership is relatively stable from urban area to urban area, the information in Table 14 is also usable in Sioux Falls.

For each of the 10 external stations in Sioux Falls, the number of automobile work trips produced by each station was estimated as a percentage of the adjusted total trips for all purposes recorded at all stations during a standard external cordon survey. The adjusted total trips for all stations were obtained by deducting the through trips from the total external station trips and analyzing the remaining trips. The adjusted total station trips consisted of auto and taxi trips between the external stations and the zones. The percentage of automobile work trips produced by the 10 external stations was determined to be 20 percent of this adjusted external station volume.

To determine the accuracy of these procedures, the auto-driver work trip productions estimated for each zone were compared with those shown by the 1956 comprehensive O-D survey. The results are shown in Figure 21. These comparisons were also analyzed using the RMS error criteria described earlier, and the analysis indicated very close agreement between the actual and the estimated values. The limits of one RMS error are shown as dashed lines in Figure 21.

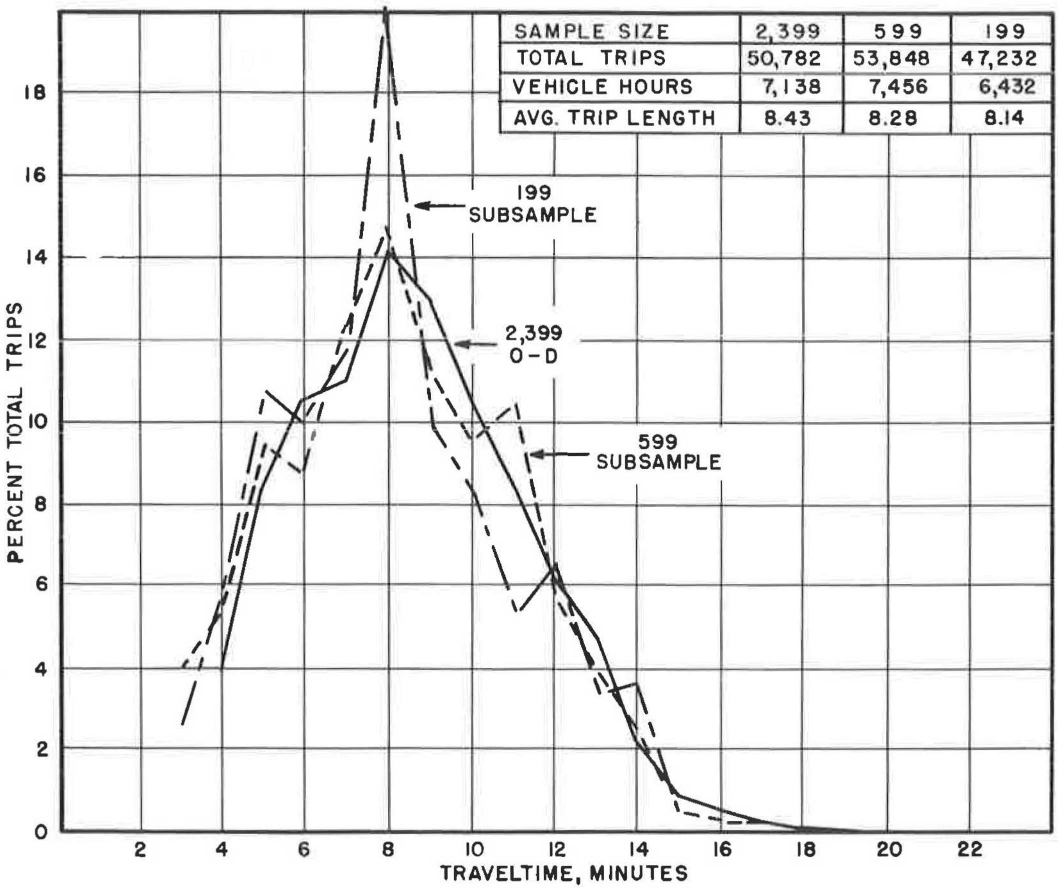


Figure 15. Trip length frequency distributions, home-based nonwork trips, Sioux Falls, 1956.

Zonal Trip Attractions.—These values for each of the 74 internal zones were developed from zonal employment information. Information on the number of people employed in each zone was available from employment statistics and also from information collected in a special survey by the Sioux Falls Chamber of Commerce. From an analysis of the data, it was determined that each employee in Sioux Falls attracted about 0.83 person work trips per day. The remaining employees were not recorded as making work trips because of illness, vacations, and walk to work trips. Consequently, to obtain an estimate of the total person work trips attracted to each zone, zonal employment figures were multiplied by 0.83. Corrections were then made for transit usage and car occupancy by using the information in Tables 13 and 14, as previously described for work trip productions, to arrive at auto-driver work trip attractions. In addition to these two corrections, a control figure for work trips to the CBD was also applied. Essentially, the estimated auto-driver work trips to the CBD were factored to meet the number indicated by the small sample and the external survey. All non-CBD zones were then factored in a similar manner so that the total auto-driver work trips remained the same.

For each of the 10 external stations, auto-driver work trip attractions were determined in the same manner as external station auto-driver work trip productions. The percentage of total station auto-driver trips (minus through trips) which were attracted by the external stations was determined to be 6.0 percent.

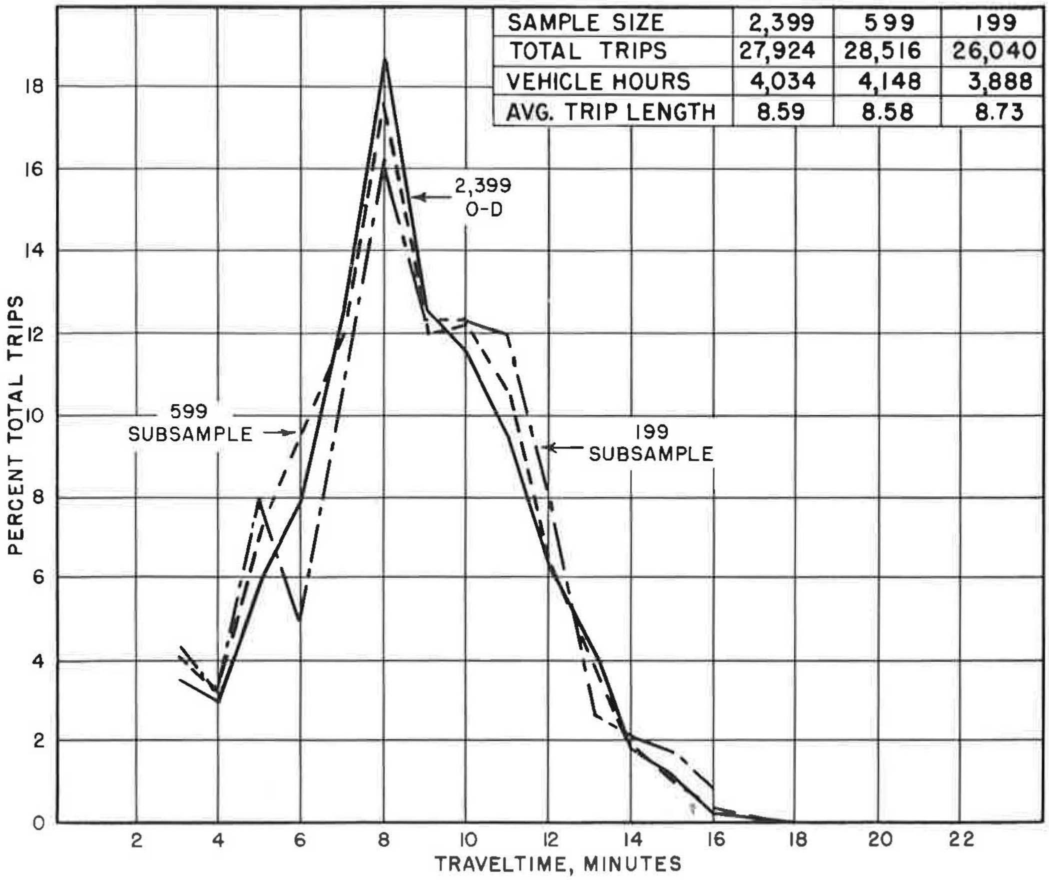


Figure 16. Trip length frequency distributions, nonhome-based trips, Sioux Falls, 1956.

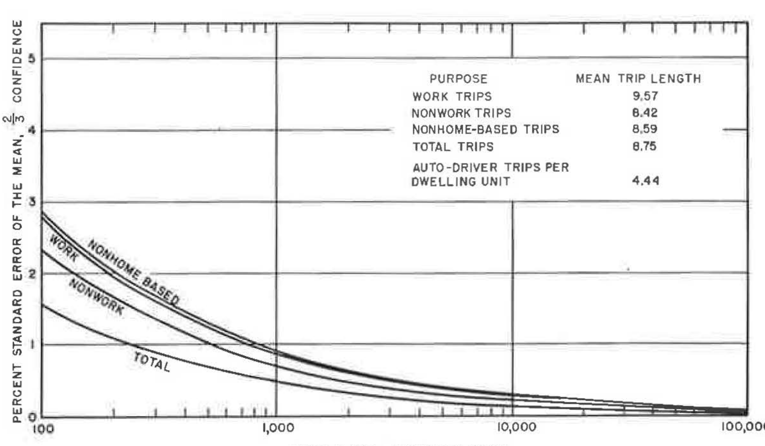


Figure 17. Percent standard error of mean trip length vs sample size in dwelling units, Sioux Falls, 1956.

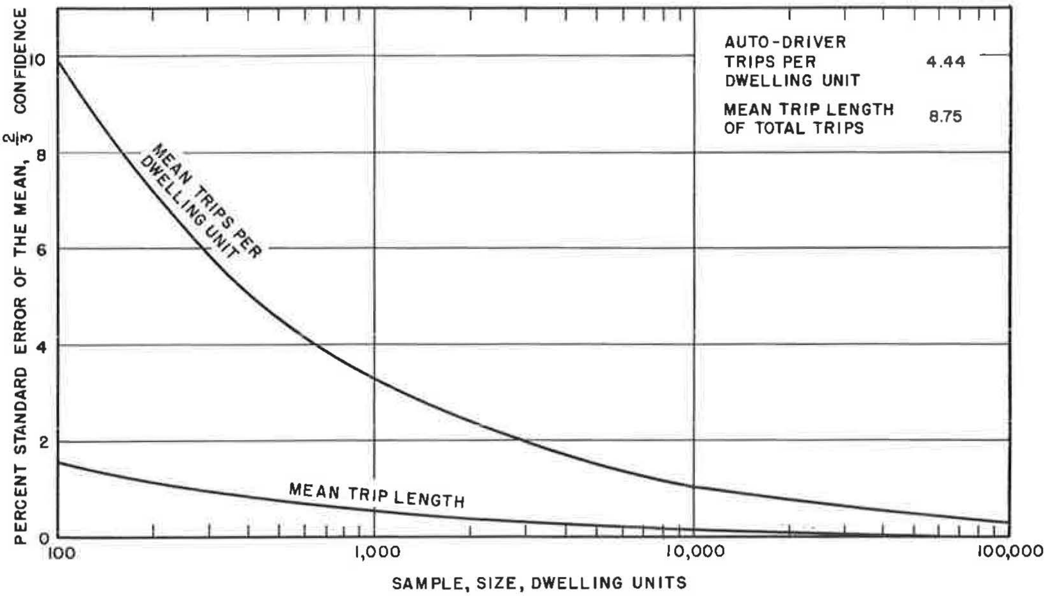


Figure 18. Percent standard error vs sample size in dwelling units for mean trip length and trips per dwelling unit, Sioux Falls, 1956.

To determine the accuracy of these procedures, the auto-driver work trip attractions estimated for each zone were compared with those shown by the 1956 comprehensive O-D survey. The results are shown in Figure 22. These comparisons were analyzed in the same manner as the work trip productions and the analysis indicated very close agreement between the actual and the estimated values.

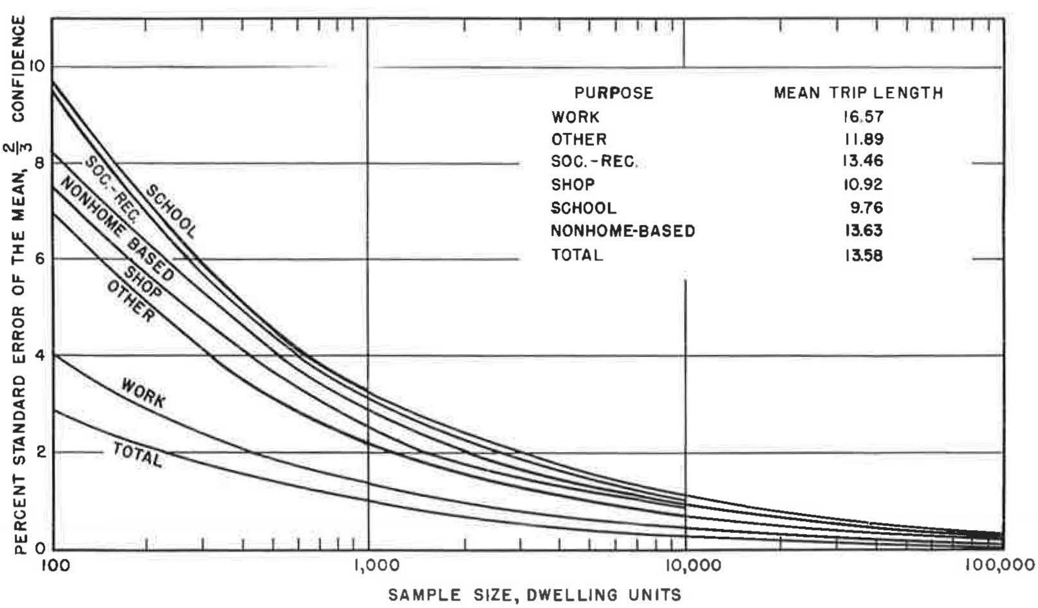


Figure 19. Percent standard error of mean trip length vs sample size in dwelling units, Pittsburgh, Pa., 1958.

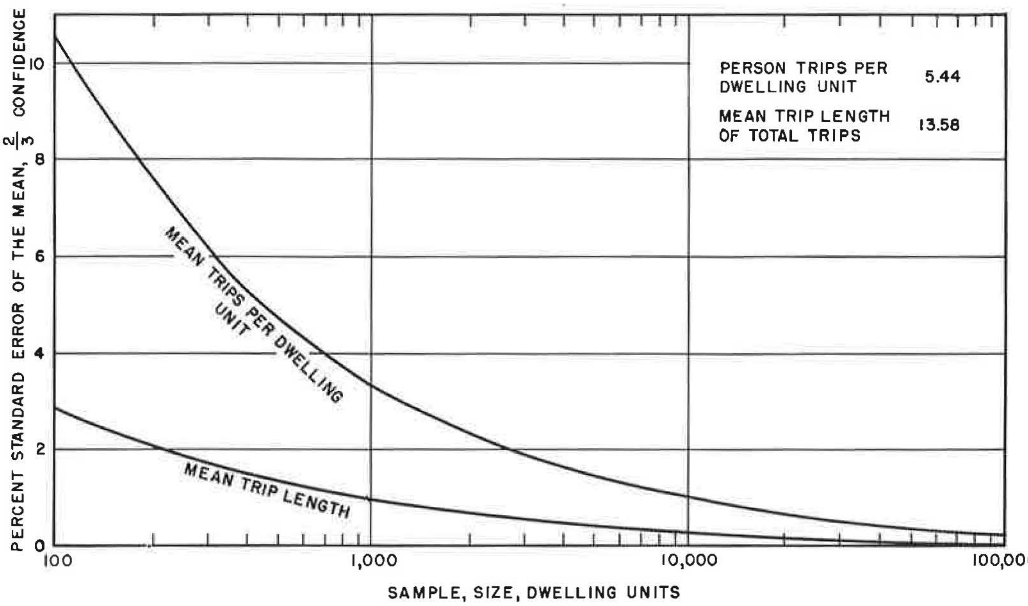


Figure 20. Percent standard error vs sample size in dwelling units for mean trip length and trips per dwelling unit, Pittsburgh, Pa., 1958.

TABLE 11

TOTAL INTERNAL VEHICULAR TRIP PRODUCTION RATES BY TRIP PURPOSE, SIOUX FALLS, 1956[a]

Trip Purpose	Trips per Car
Home-based work trips	1.36
Home-based nonwork trips	2.84
Nonhome-based trips	2.98
Total vehicular trips	7.18

[a]Information included in this table includes travel data from both the 599 home interview sample and the truck and taxi surveys.

Home-Based Auto-Driver Nonwork Trips. —Zonal trip productions for the 74 internal zones for this purpose of trip were derived from zonal data on car ownership obtained from the O-D survey. As previously pointed out, however, car ownership data are also generally available from several other sources. Table 11 indicates that there are 2.84 home-based auto-driver nonwork trips per car. This figure was applied to the number of cars owned by the residents of each of the internal zones to determine trip production values for this trip purpose. For the 10 external stations, the nonwork trip

TABLE 12

TOTAL VEHICULAR TRIP PRODUCTIONS AND ATTRACTIONS BY TRIP PURPOSE, SIOUX FALLS, 1956

Trip Purpose	Productions			Attractions		
	Internal[a]	External[b]	Total	Internal[a]	External[b]	Total
Work	27,475	2,175	29,650	28,212	1,438	29,650
Nonwork	57,219	8,010	65,229	60,123	5,106	65,229
Nonhome-based	59,966	4,956	64,922	59,847	5,075	64,922
Total	144,660	15,141	159,801	148,182	11,619	159,801

[a]These figures obtained by multiplying trip rates given in Table 11 by total cars owned by residents of study area.
[b]These figures from standard external cordon survey.

TABLE 13

PERCENTAGE OF ALL WORK TRIPS MADE BY TRANSIT (17)

Cars per 1,000 Persons	Work Trips by Transit (%)					
	Net Land per Family					
	10,000 Sq Ft	5,000 Sq Ft	2,500 Sq Ft	1,200 Sq Ft	600 Sq Ft	300 Sq Ft
500	5	7	11	19	33	65
450	7	9	13	21	35	67
400	9	11	15	23	37	69
350	11	13	17	25	39	71
300	13	15	19	27	41	73
275	14	16	20	28	42	74
250	15	17	21	29	43	75
225	16	18	22	30	44	76
200	17	19	23	31	45	77
175	18	20	24	32	46	78
150	19	21	25	33	47	79
125	20	22	26	34	48	80

productions were obtained in the same manner as described for external station auto-driver work trip productions. Nonwork trip productions were determined to be 30 percent of the total station volume. To test the accuracy of these procedures, the auto-driver nonwork trip productions estimated for each zone were compared with those shown by the 1956 comprehensive O-D survey. The results are shown in Figure 24. These comparisons were analyzed and the results indicated very close agreement between the actual and the estimated values.

Zonal trip attractions for the 74 internal zones for this trip purpose were derived from zonal data on population and retail sales. By dividing the total internal auto-driver nonwork trip attractions into the total population of the area, the population per attraction for this purpose was obtained. By repeating this process for the total retail sales in the area, the unit of sales per attraction was also obtained. By dividing the larger of these rates (population) by the smaller (retail sales) it was found that 1.69 units of retail sales were required to attract each nonwork trip, whereas 1.00 units of population were required to attract each nonwork trip. By using this technique a weighting factor equal to population + 1.69 × retail sales was established as an indicator of the auto-driver nonwork trip attractions in each zone. Consequently, the total number of attractions for this purpose were prorated to the zones using this weighting factor. As in the case of the auto-driver work trip attractions, nonwork trip attractions were factored to insure that the CBD attraction values are equal to those shown by the

TABLE 14

RELATIONSHIP BETWEEN CAR OCCUPANCY AND CAR OWNERSHIP FOR TOTAL WORK TRIPS (17)

Cars per 1,000 Persons	Persons per Car
500	1.20
450	1.23
400	1.27
350	1.30
300	1.33
250	1.40
200	1.46
150	1.52
100	1.65

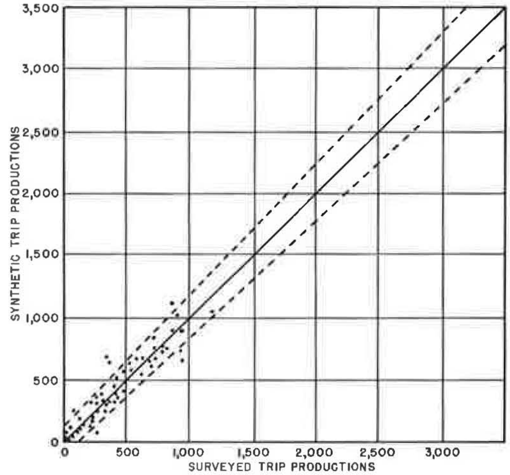


Figure 21. Synthetic vs surveyed auto-driver home-based work trip productions, Sioux Falls, 1956.

small sample survey data. The non-CBD attractions were then adjusted accordingly to keep the total attractions the same as shown by the small sample.

For the 10 external stations, trip attractions for this trip purpose were obtained in the same manner as described for external station auto-driver work trip productions. The percentage of total station auto-driver trips (minus the through trips) which were nonwork trips was determined to be 20 percent.

To test the accuracy of these procedures, the auto-driver nonwork trip attractions estimated for each zone were compared with those shown by the 1956 comprehensive O-D survey. The results, shown in Figure 24, were analyzed and indicated reasonable agreement between the actual and estimated values.

Nonhome-Based Auto-Driver Trips. —Several studies have reported that auto-driver nonhome-based trip production is associated with car ownership (1, 4). Because by definition the trip productions are equal to trip origins and trip attractions are equal

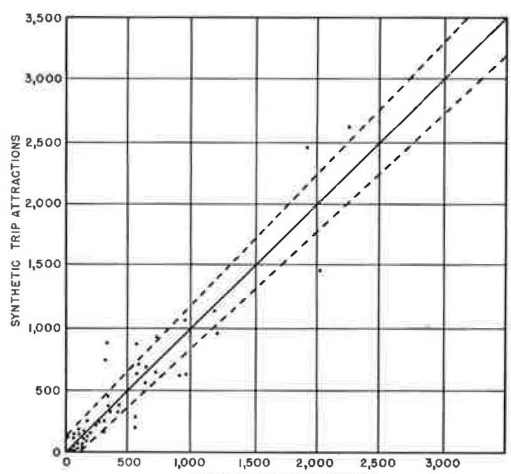


Figure 22. Synthetic vs surveyed auto-driver home-based work trip attractions, Sioux Falls, 1956.

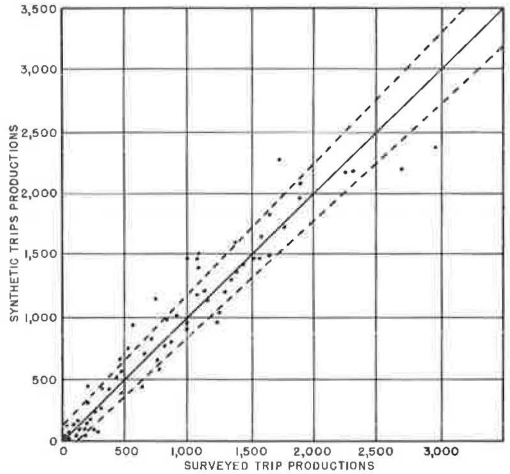


Figure 23. Synthetic vs surveyed auto-driver home-based nonwork trip productions, Sioux Falls, 1956.

to trip destinations for nonhome-based trips, production and attraction values should be equal on a zonal basis as well as on a study area basis. Since origins should closely agree with destinations on a zonal basis during the 24-hr day, productions must also agree closely with attractions. This information was used in determining zonal trip productions and attractions for nonhome-based auto-driver trips in this research project. Zonal trip productions and attractions for the 74 internal zones for this trip purpose were derived from zonal data on car ownership, which in this research was obtained from the origin-destination survey. Table 11 indicates that there are 2.98 nonhome-based vehicular trips per car. This figure was applied to the number of cars owned in each internal zone to determine trip production values for this trip purpose.

For the 10 external stations, trip productions and attractions were obtained in the same manner as described for external station auto-driver work productions. The percentages which were nonhome-based auto-driver productions and attractions were determined to be 18.5 and 19.0, respectively.

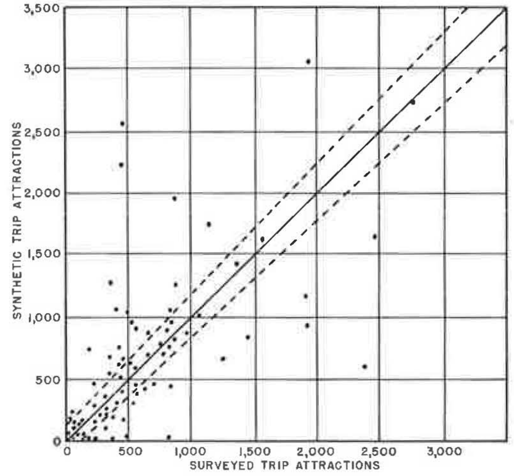


Figure 24. Synthetic vs surveyed auto-driver home-based nonwork trip attractions, Sioux Falls, 1956.

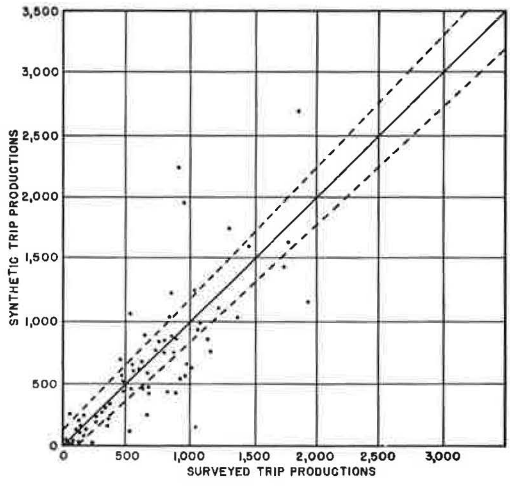


Figure 25. Synthetic vs surveyed nonhome-based vehicular trip productions, Sioux Falls, 1956.

To test the accuracy of these procedures, the auto-driver nonhome-based trip productions and attractions estimated for each zone were compared with those shown by the 1956 comprehensive O-D survey. An analysis of the results shown in Figures 25 and 26 indicated rather poor agreement between the actual and estimated values. An examination of the internal nonhome-based trip productions and attractions from other studies showed similar agreement for these values.

Determining Trip Distribution Pattern

The previously described procedures provided zonal trip production and attraction values for each of the trip purpose categories. However, before interchanges can be calculated using the gravity model formula, some measure of spatial separation between the zones must be developed. For the purpose of this phase of the research, the minimum path driving times between zones, the intrazonal times, and the terminal

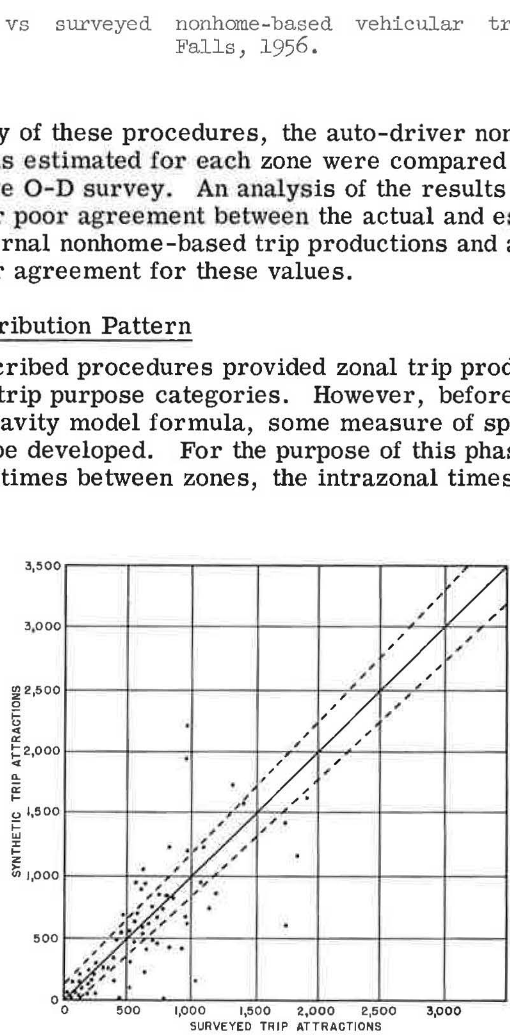
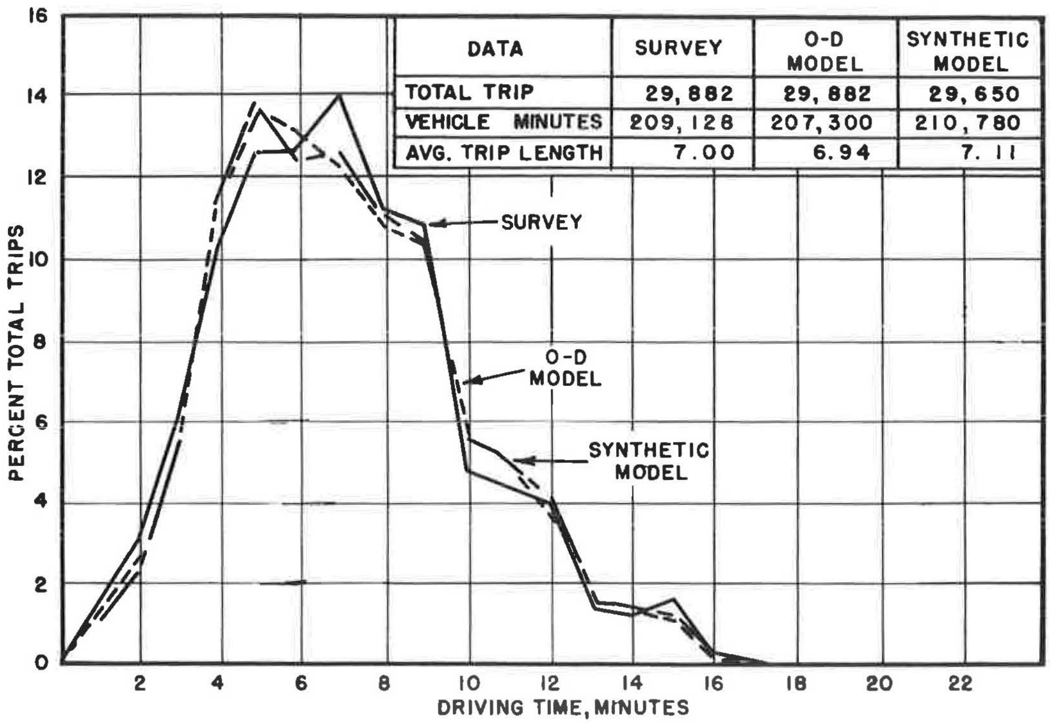


Figure 26. Synthetic vs surveyed nonhome-based vehicular trip attractions, Sioux Falls, 1956.



DATA	SURVEY	O-D MODEL	SYNTHETIC MODEL
TOTAL TRIP	29,882	29,882	29,650
VEHICLE MINUTES	209,128	207,300	210,780
AVG. TRIP LENGTH	7.00	6.94	7.11

Figure 27. Trip length frequency distributions, home-based auto-driver work trips, Sioux Falls, 1956.

times used were as developed for the previous phase of this work. In addition, some measure of the effect of this spatial separation on trip interchange between zones, $F_{(t_{i-j})}$, is also required. In this phase of the research, full use was made of the travel time factors already developed for each trip purpose during the previous phase

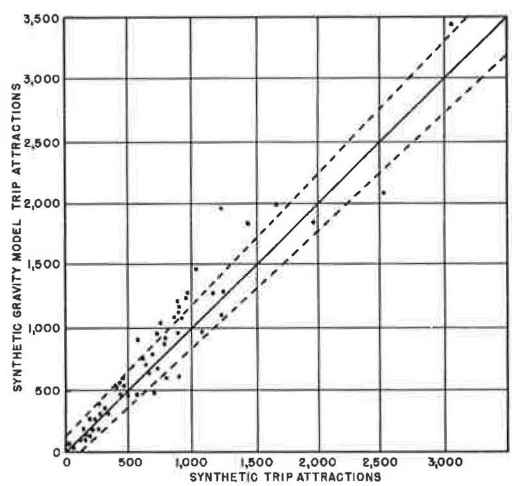


Figure 28. Synthetic vs synthetic gravity model home-based auto-driver nonwork trip attractions, Sioux Falls, 1956.

TABLE 15

COMPARISON OF TOTAL VEHICULAR TRIPS CROSSING BIG SIOUX RIVER, SIOUX FALLS, 1956

Facility	Vol. Count	O-D Survey	Syn. Gravity Model
Cherry Rock Ave.	1,511	1,640	1,512
Cliff Ave., S.	9,132	8,420	9,208
Tenth St.	14,842	16,296	16,832
Eighth St.	8,606	6,612	6,752
Sixth St.	3,864	2,900	4,564
McClellan St.	3,069	2,596	1,972
Cliff Ave., N.	4,699	4,156	2,048
Totals	45,723	42,620	42,888
Percent Diff. from Vol. Count		-6.8	-6.2
Percent Diff. from O-D Survey	+7.3		+0.6

of the research. This was done because the trip length frequency curves for the 599 subsample were so similar to those for the total sample which was used to develop the travel time factors. The values of these factors are shown in Table 3.

With all the required parameters available, the gravity model calculations were made to obtain a synthetic trip distribution pattern. This pattern was then compared to the O-D survey data to determine the accuracy and, consequently, the ability of the simplified procedures described in this report to supply the necessary information for adequately simulating trip

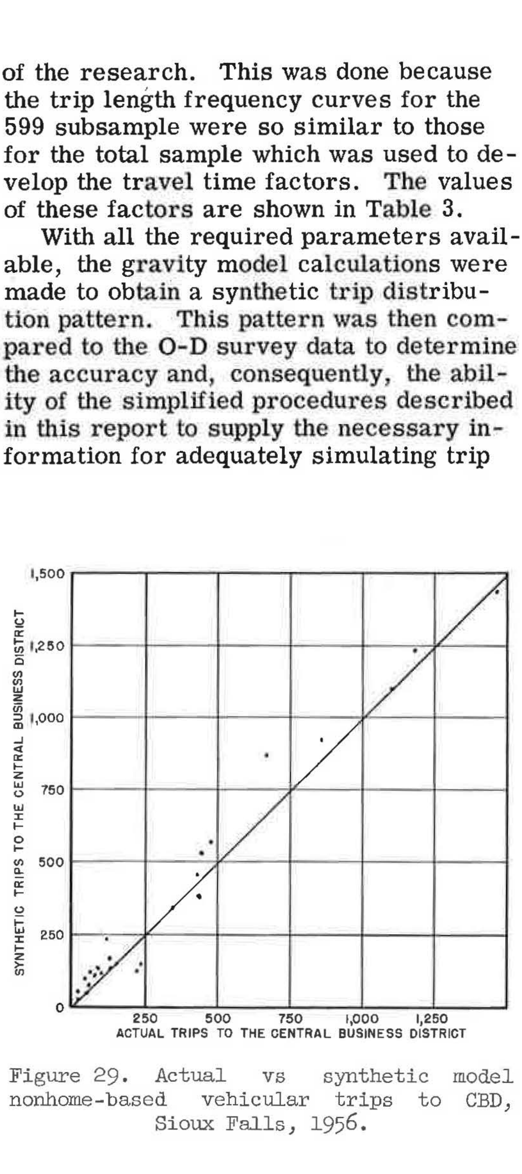


Figure 29. Actual vs synthetic model nonhome-based vehicular trips to CBD, Sioux Falls, 1956.

TABLE 16

TOTAL TRIPS CROSSING SCREENLINES, SIOUX FALLS, 1956

Screenline No.	O-D Survey Vol.	Syn. Gravity Model	
		Vol.	Diff. from O-D (%)
1	7,952	7,280	-8.5
2	21,012	21,120	+0.5
3	13,516	13,224	-2.2
4	11,384	10,428	-8.4
5	9,744	8,516	-12.6
6	8,784	8,440	-3.9
7	6,280	6,520	+3.8
8	6,568	6,100	-7.1
9	2,264	1,980	-12.5
10	17,448	18,420	+5.6
11	5,868	4,836	-17.6
12	5,592	3,872	-30.8
13	13,656	15,280	+10.6
14	22,908	23,584	+2.9
15	33,220	33,204	0.0
16	10,032	10,996	+9.6
17	13,424	14,220	+5.9
18	9,724	12,200	+25.5
19	10,060	10,720	+6.6
20	5,332	5,476	+2.7
21	8,496	8,364	-1.5
22	13,332	14,192	+6.5
23	41,500	41,468	-0.1

distribution patterns. Several tests were involved in the comparisons.

First, the synthetic trip length frequency distributions and average trip lengths were compared with those from the O-D survey for each trip purpose category. The results for work trips are shown in Figure 27; the other two purposes also exhibit very close agreement. The results of this test indicated that the decision to use the travel time factors from the previous phase of this research was a correct one. If an initial set of travel time factors had been assumed and the normal trial and adjustment process utilized, the final result would have been travel time factors identical to those shown in Table 3.

Tests were made comparing the trips attracted to each zone by the gravity model with those shown by the synthetic procedures for each trip purpose. The results for all purposes indicated an accuracy within one RMS error. Figure 28 shows the results for nonwork trips which had the largest scatter.

Another test was made of the number of synthetic trips crossing the Big Sioux River. These figures were compared with

TABLE 17

COMPARISONS OF DISTRICT-TO-DISTRICT MOVEMENTS[a]

Volume Group	O-D Survey Trip		RMS Error	
	Mean	Freq.	Abs.	Percent
(a) Home-Based Auto-Driver Work Trips				
0- 99	21	400	20	95.24
100- 199	133	40	58	43.61
200- 299	259	13	119	45.95
300- 499	402	13	98	24.38
500-1,499	920	8	186	20.22
(b) Home-Based Auto-Driver Nonwork Trips				
0- 99	27	423	28	103.70
100- 199	136	53	83	61.03
200- 299	239	28	103	43.10
300- 499	380	22	166	43.68
500- 999	728	22	282	38.74
1,000-2,999	1,711	9	343	20.05
(c) Nonhome-Based Auto-Driver Trips				
0- 99	25	473	24	96.00
100- 199	144	62	82	56.94
200- 299	241	30	122	50.62
300- 499	385	33	157	40.78
500- 999	773	9	289	37.39
1,000-3,999	1,311	8	457	34.86

[a]1956 O-D survey data vs synthetic gravity model estimates, relative difference measured in terms of percent RMS error (see footnote to Table 6).

those from the O-D survey and again, the differences were small (Table 15).

Synthetic trips to the CBD, for each trip purpose, were also compared with the same movements from the total sample. The results for work trips (Fig. 29), indicate that there is no geographical bias present in the synthetic interchanges and that the discrepancies between the two sets of information are quite small.

Synthetic trip interchanges for total trips were then assigned to the minimum path driving time network. The expanded trips from the full O-D sample were also assigned. These two sources of information were then compared by analyzing the differences over the comprehensive series of screenline crossings shown in Figure 10. The results of the comparisons are given in Table 16.

Finally, a statistical comparison of the actual and the estimated trips was made for each trip purpose (Table 17). An analysis of the comparisons indicated acceptable results for all purposes when compared with similar studies (12, 13, 15) and with the comparisons resulting from the first phase of this research (Table 6).

SUMMARY AND CONCLUSIONS

The application of the gravity model theory in a particular small urban area was investigated and, because it was the theory of the gravity model which was being tested, the model was developed using all of the travel information normally collected during a comprehensive O-D survey obtained by using the dwelling unit sample size recommended in the Public Roads Home Interview Manual (6). The home interview survey provided the data on trip production, trip attraction, and trip length distribution needed for developing the model, as well as information on the zonal trip interchanges used to test the gravity model results.

A three purpose gravity model was calibrated following the procedures outlined in this paper but more fully detailed previously (8). The calibrated gravity model was then thoroughly tested against the O-D trip distributions and volume counts. These tests revealed that the gravity model formulation adequately simulated trip distribution patterns for the Sioux Falls area.

Having determined that the three purpose model was adequate, when based on the data from the full O-D survey, we then investigated the question of reducing the O-D survey sample necessary to develop the model. To determine the appropriate sample sizes to investigate, the results of studies of small samples in other cities were collected and analyzed. Comparisons were made with the full field sample, by trip purpose, of total trips, average trip lengths, and trip length frequency distributions for each of several subsamples. From the tests made in Sioux Falls and from an analysis of other studies, it was determined that about 600 home interview samples in combination with the standard external cordon survey provided adequate data for obtaining, by purpose, total trips, trip length frequency distributions, and average trip lengths.

Since a small sample does not yield stable data on zonal trip productions and attractions by trip purpose, these items of information must be obtained by other techniques. Synthetic procedures based on detailed socio-economic data were used for this purpose. The results of the synthetic procedures were compared to the O-D survey productions and attractions, and the procedures were shown to be satisfactory for computing productions and attractions for Sioux Falls.

Finally, the synthetic productions and attractions were combined with the travel time factors that reflected the 599 home interview sample to determine a trip distribution pattern for each trip purpose. The results were compared with the O-D survey distribution and the patterns agreed closely.

With these separate analyses completed, the following conclusions appear warranted:

1. The gravity model formula provided an adequate framework for determining trip distribution patterns for Sioux Falls.
2. A three purpose trip stratification of home-based work, nonwork, and nonhome-based trips was sufficient in the small urban area.
3. For Sioux Falls, a 599 home interview sample used in combination with detailed socio-economic data and the standard truck, taxi, and external cordon surveys provided sufficient data for a three purpose gravity model calibration. Sioux Falls is a self-contained urban area with a single center and no strong travel linkages to other urban areas. This city does not exhibit any social or economic factors which might have a significant effect on travel patterns, and which might require adjustments to the gravity model trip distributions. The findings for Sioux Falls may not apply to cities exhibiting different characteristics.
4. The synthetic procedures used in this research to compute zonal trip productions and attractions are satisfactory for this small urban area when used in combination with detailed socio-economic data and with limited travel data from a small sample survey.

Further research should be conducted to determine if the findings for this small urban area can have wider application.

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