SYNTHETIC DERIVATION OF INTERNAL TRIPS FOR SMALL CITIES

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A procedure is developed for estimating internal trip movements without interview surveys. A generalized trip generation model is based on analysis of generation characteristics of eight cities, three in Georgia. A method is proposed for determining gravity model travel time factors based on maximum trip length over the traffic assignment network. The procedure is evaluated by test application in four Georgia cities, and it satisfactorily duplicates observed traffic volumes.

•URBAN TRAFFIC CONGESTION is a problem of mammoth proportions that increases as population and trends toward urbanization and suburbanization increase. The rate of increase is such that construction and improvement programs cannot be needs oriented. For example, if a street is widened or a parallel facility is built or upgraded when traffic volumes on the street reach capacity, by completion of the project or soon thereafter the facility is loaded to capacity and the problem exists anew. There is a definite need to plan ahead, to have the new facilities or improved old facilities ready as the demand occurs, and to provide facilities that will return the maximum benefit for the scarce and sorely stretched funds available for that purpose. This can only be done through rational, systematic transportation planning on a comprehensive basis.

This need has been recognized, and for several years street and highway improvements in urban areas of over 50,000 population have been keyed to the results of comprehensive, continuing, cooperative transportation planning programs. In fact, such programs are required for construction projects using federal-aid highway funding. Attaining the required level of planning activity has necessitated the development of a new technology for urban transportation planning. This technology has provided the tools for the planner to make available to the decision-maker the information he needs to set priorities and establish a basis for fund requirements.

Most of the planning activity, however, has been in metropolitan areas of 50,000 or more population. This is logical, for these are the areas that are required to have comprehensive planning to qualify for federal aid for construction projects. Many of the urban area studies are being completed and are entering the continuing phase. Time is becoming available to be concerned with small urban areas with populations between 5,000 and 50,000 or even smaller. The question is arising of how much of the new technology should be used in transportation planning for the small urban area.

There are many answers to this question, ranging from none to all. The "none" answer is sometimes based on the assumption that small urban areas are economically unstable and that the gain or loss of a single manufactory or the development of a shopping center redirects traffic patterns so significantly that the expensive and time-consuming planning process is invalidated. Others disagree with this premise, believing that the comprehensive planning process that relies on mathematical models for trip generation, trip distribution, and traffic assignment has built-in mechanisms for maintaining the planning process in spite of unforeseen economic events. Other objections question the cost of comprehensive planning in time and money versus the benefit to small urban areas.

The time and cost requirements are valid points, not so much in terms of benefit, however arguable, as in terms of numbers. In Georgia there are 45 urban areas in the 5,000 to 50,000 population range. Experience gained in the conduct of comprehensive studies in five of these areas indicates that it takes 3 years to complete a study. Based on current and expected staff capabilities, no more than four new studies can be initiated each year, resulting in a 14-year period to complete studies in all current urban areas, and this does not consider new urban areas, updates for urbanized and urban areas, and new programs such as regional and statewide studies.

Seven steps are required to complete a comprehensive study:

1. Organization,
2. Data collection,
3. Data processing,
4. Model development,
5. Forecasting,
6. Systems analysis, and
7. Plan selection.

Of these seven steps, the fourth is the most critical, for it is on the models that subsequent activities, including updates in the continuing phase, are based. Because models are so critical, field data from which they are derived are also important. The importance of the field data is such that very rigid standards have been established to ensure adequate reliability. Data collection, including processing and editing to ensure this reliability, is one of the factors that adds significantly to the time and cost of a planning study. If a lesser degree of reliability can be accepted, then the time and cost of this phase can be reduced.

A great deal of research has been done to test the suitability of shortcuts in data collection. Such methods include small sample rates, cluster samples, and interviewed screen lines, among others, and have shown satisfactory results in many cases.

One of the primary assumptions, and apparently a valid one in transportation planning, is that certain relationships exist between travel demands and social, economic, and physical parameters and that these relationships are consistent over time. A logical extension of this assumption is that these relationships are also consistent over space. If this extended assumption is also valid, within limits, then it may be feasible to formulate models that can synthesize the results of field data collection and thereby completely eliminate the necessity for this expensive and time-consuming phase of transportation planning.

Although it is doubtful whether synthetically derived models can duplicate the reliability of even the shortcut field methods, they may be reliable enough to serve as a valid tool for systems testing at significantly lower costs.

Hopeful that the synthetic approach would prove valid, the State Highway Department of Georgia developed synthetic trip generation and trip distribution models for the Waynesboro, Georgia, urban area (1, 9). These models were based on data from comprehensive studies in the Cedartown and Milledgeville, Georgia, urban areas. Application of the synthetic models in Waynesboro resulted in traffic assignments that compared very satisfactorily with observed volumes. The models were accepted for use in a Waynesboro study (9), but more detailed analysis and development were required to derive general models for use in any small urban area.

A research study was undertaken by the State Highway Department of Georgia in cooperation with the Federal Highway Administration to provide detailed analysis and developmental work (2). The purpose of the research was to develop and test a procedure for deriving models that synthesize internal trip movements in urban areas. With this procedure, a comprehensive systems-oriented planning study could be undertaken for small urban areas (under 50,000 population) without the need for expensive and time-consuming home interviews and model development phases of the traditional comprehensive planning process.

STUDY PROCEDURE

The study is empirical in that data from comprehensive planning studies in several small urban areas are analyzed to develop models that are then tested against data from other small studies. Requests were made to highway agencies in all the states and the District of Columbia and Puerto Rico and to the Federal Highway Administration for data from studies in the 5,000 to 50,000 population range. Of the 52 highway agencies, 12 had completed small area studies and 11 others had such studies in progress. A total of 16 studies had been completed, and 15 more were in process. This compares with 223 urbanized area studies in various stages of completion across the country. Data for possible use in the research study were received on 18 small urban areas. From these, nine were selected for use in the analysis.

Selection of studies for use in the analysis was based on three primary criteria:

1. The availability of common economic variables for trip generation analysis,
2. The availability of data for gravity model distribution, and
3. Observed volumes for comparison with network assignments.

All analysis was made to base year conditions. The study areas selected and the base year populations are as follows:

Area	Population
Albany, Georgia	85,000
Grand Forks-East Grand Forks, North Dakota	48,000
Maryville-Alcoa, Tennessee	41,000
Minot, North Dakota	34,000
Milledgeville, Georgia	33,000
Staunton, Virginia	32,000
Murray, Kentucky	15,000
Cedartown, Georgia	13,000
Waynesboro, Georgia	5,000

The procedure for trip generation and trip distribution is to develop a model from one study or group of studies and to test it by applying the model through traffic assignment and comparison with observed volumes. The groupings for each phase of analysis are given in Table 1.

The study areas selected for phase III are all in Georgia because assignment networks and observed volumes for these areas were available in a convenient form.

Some special mention is appropriate on the inclusion of Albany, Georgia, in the analysis. Its population of 85,000 is larger than the 5,000 to 50,000 range intended for the purposes of synthetic procedures. However, the study area includes much of one county and part of a second so that, based on cordon location, its population is very close to the 50,000 figure. In any event, it does provide an upper limit for the synthetic procedure. The Murray study should also be noted specifically because internal-internal data were derived by a 500-sample home interview.

This approach to synthetic derivation of internal-internal trips is based on two hypotheses.

1. The multivariant relationships that may be used to estimate productions and attractions for analysis zones are similar for all urban areas within general population ranges. This similarity is such that a single set of estimating equations may be developed for general use in urban areas of 5,000 to 50,000 population that will yield reliable enough estimates of zonal productions and attractions to be used in lieu of internal sample surveys and study-derived trip generation models.

2. The marginal propensity for trip-making that is represented in the gravity analogy distribution model by the spatial separation or F-factor is a rate that is consistent among urban areas, if adjusted for area size.

The derivation of these hypotheses is not completely arbitrary. Work done by other researchers (3, 4, 6) has indicated the consistency of trip generation characteristics. There is also an apparent trend in small city transportation studies toward the adaptation of generation and distribution models from similar cities for which comprehensive

Table 1. Groupings for each phase of analysis.

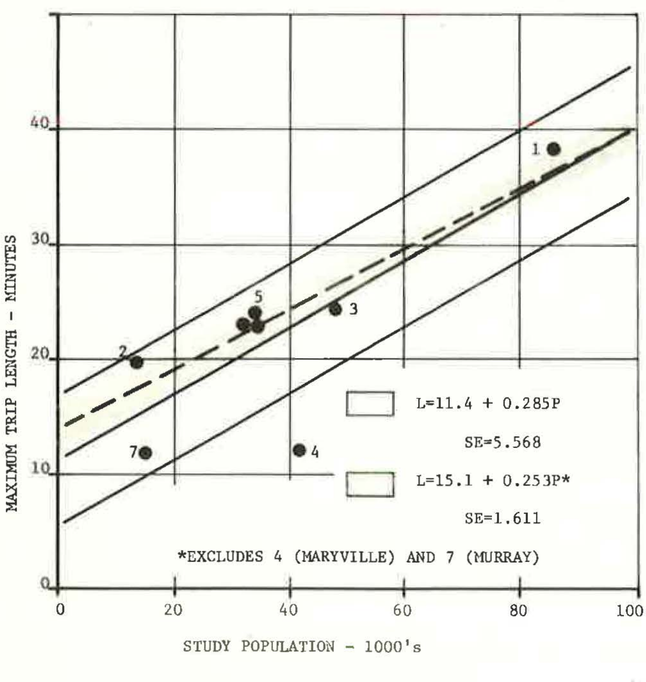
Phase	Process	Area
I, Trip generation	Development	Cedartown Grand Forks Maryville Staunton
	Testing	Albany Milledgeville Minot Murray
II, Trip distribution	Development Testing	Cedartown Albany Grand Forks Maryville Milledgeville Minot Murray Staunton
III, Test application		Albany Cedartown Milledgeville Waynesboro

Table 2. Significant data for analysis.

			Proportionality of Trips	
City	Population in Thousands	Maximum Work Trip Length	Internal-Internal	Internal-External
Albany	85	38	88.1	11.9
Cedartown	13	20	82.8	17.2
Grand Forks	48	25	92.9	7.1
Maryville	41	12	65.0	35.0
Milledgeville	33[a]	24	91.0	9.0
Minot	34	23	91.7	8.3
Murray	15	12	57.9	42.1
Staunton	32	23	71.6	28.4

[a]Includes approximately 11,000 resident state hospital staff and patients.

Figure 1. Maximum trip length as a function of population.



studies were performed (5, 7, 8). The adaptation procedure itself assumes at least a limited application of the hypotheses.

The purpose of this study was to verify these assumptions and to evaluate the reliability of their application. When it appeared that the hypotheses were valid or at least sufficiently approximated the results of normal trip interview surveys, procedures for their application in small urban areas were developed.

For this study three stratifications of trip purpose are considered: home-based work, home-based other, and non-home-based. Analysis is also made for total internal trips. Internal-external trips are not included in the synthetic analysis because external interview surveys will still be necessary for a synthetic urban study and the internal-external trip data will be available from inventory without synthesization.

Before the development of trip generation and distribution models is discussed, it is appropriate to examine the characteristics of the cities selected for inclusion, both to obtain some subjective verification for the basic assumptions on which the procedure development is based and to indicate whether any of the selected cities deviate from the general relationships and might therefore adversely affect the model development.

Three characteristics are examined: population, work trip length, and proportionality of internal-internal and internal-external trips. The values of these characteristics for eight of the nine cities are given in Table 2. Waynesboro is not included in this analysis because it was conducted as a synthetic study.

The relationship between maximum work trip length and study area population is shown in Figure 1. This relationship illustrates the consistency of the size of the study area in terms of the variable trip length, which is the significant parameter in the gravity model for trip distribution. From Figure 1 the consistent grouping of points with the exception of values for Murray and Maryville is easily observed. Murray is a relatively small area for which internal data were gathered by a 500-sample telephone survey; Maryville is a large population center with what appears to be a very close study cordon. When these two studies are excluded, the relationship shown in Figure 1 is highly consistent. However, there may be some bias introduced by the inclusion of the three Georgia studies. In Georgia, generally the practice is to extend the study cordon to include the projected urban area for the study design year. This practice tends to increase the maximum trip length without significantly increasing the population. However, the consistency shown by the three Georgia cities and Grand Forks, Minot, and Staunton indicates that any such bias is minimal.

In Figure 2 the relationship between the proportionality of internal-internal and internal-external trips is shown in comparison with study population. Logically, the more developed the study area is, the fewer trips will be reported as internal-external. Maryville and Murray again appear abnormal with the addition of Staunton. Upon examination it was found that a college campus is immediately outside the Staunton study area, which may account for the discrepancy. The consistency of the other five data sources is obvious, and indeed the consistency is not too adversely affected if Staunton is included.

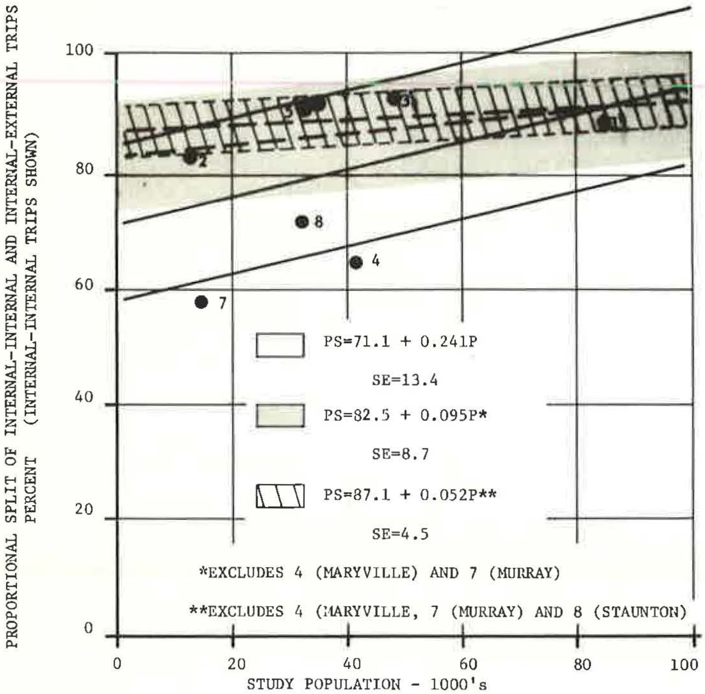
TRIP GENERATION

Data from four cities were used in the development of generation equations through linear regression analysis. Six economic indicators were entered as independent variables (population, dwelling units, motor vehicles, civilian labor force, employment, and school enrollment), and models were developed for four trip purposes (home-based work, home-based other, non-home-based, and total internal trips). Parallel development was carried out for procedures by using the sum of the three purposes and for the total internal model.

Models derived from the four cities were combined into a single set of equations and tested against all eight cities. The resulting equations are

$$\text{Home-based work productions} = 8 + 1.2 \text{ motor vehicles}$$

Figure 2. Proportionality of internal-internal and internal-external trips as a function of population.



Home-based work attractions = 54 + 0.9 employment

Home-based other productions = 18 + 2.7 motor vehicles

Home-based other attractions = 206 + 0.8 dwelling units + 0.6 employment + 0.3 school enrollment

Non-home-based productions = 67 + 0.1 dwelling units + 0.1 motor vehicles + 0.6 employment + 0.1 school enrollment

Non-home-based attractions = 67 + 0.5 dwelling units + 0.4 employment

Total internal productions = 164 + 4.2 motor vehicles + 0.4 employment

Total internal attractions = 221 + 2.3 motor vehicles + 2.3 employment

When the equations were applied for testing, attractions were set equal to productions (total) and the results were compared to survey data. Evaluation was made on the basis of three parameters:

$$\text{Percentage of error} = \frac{\text{mean calculated} - \text{mean observed}}{\text{mean observed}} \times 100$$

$$\text{Percentage of RMS error} = \frac{\sqrt{\frac{\Sigma(Vo - Vc)^2}{N}}}{\Sigma Vo} \times 100$$

$$\text{Mean ratio} = \frac{\Sigma(Vo/Vc)}{N}$$

where

Vo = zonal observed,
Vc = zonal calculated, and
N = number of zones.

There were no rigid acceptance-rejection criteria used in evaluating the results of these tests. A principal evaluation was the calculation of the sample size indicated by the magnitude of the RMS error as given by the expression

$$Y = \frac{1,624}{(X^{0.4884})\ DUS}$$

where

Y = expected RMS error,
X = volume of occurrence, and
DUS = sample rate.

For RMS error values equal to $\pm 1/3$ of those calculated, ranges of indicated sample size were estimated. From this analysis indicated, sample sizes in the general range of 3 to 6 percent for production equations and 1 to 3 percent for attraction equations were determined. Because these figures were in the general range for small sample interview surveys, the generation model was accepted.

TRIP DISTRIBUTION

Travel time or F-factors for input into gravity analogy trip distribution are usually obtained through trial and error by assuming a relationship

$$\text{Log (factor)} = \log (a) + b \log (\text{travel time})$$

If the hypothesis is valid, the probable equilibrium point is the average trip length. If this is so, then for any two cities

$$\text{Log}\ (a_1) + b \log (ATL_1) = \log (a_2) + b \log (ATL_2)$$

and if values are known for a_1, ATL_1, and ATL_2,

$$\text{Log (factor)} = \log (a_1) + b[\log (ATL_1) - \log (ATL_2) + \log (t)]$$

and a travel time factor can be determined for any value of t = time.

The significant characteristic that is needed, given a set of F-factors and the average trip length for one city, is the average trip length for the city for which factors are desired. A review of data from several cities showed a consistent relationship between average and maximum trip lengths for each trip purpose. This relationship is expressed as a ratio:

Purpose	Ratio
Home-based work	0.362
Home-based other	0.317
Non-home-based	0.282
Total internal	0.314

Experimentation with varying values of these factors yielded no change in the resulting F-factor estimates.

By using Cedartown F-factors as a base and solving the equation above for 1-minute increments to a value 5 minutes greater than the longest minimum path tree for the other cities, we estimated F-factors and made gravity distributions. The average trip lengths derived differed from the survey-derived data by 2.34 minutes on the average. The shapes of the trip length frequency curves were very similar to the survey-derived distributions.

TEST APPLICATION

The synthetic procedures were applied in four Georgia cities: Albany, Cedartown, Milledgeville, and Waynesboro. Both sum-of-purpose and total model tests were made. Internal trip tables derived by synthetic procedures were added to external trip tables from the roadside cordon interviews, and the resulting total table was assigned to the network. The assigned link volumes were compared to observed volumes, and errors were observed (Table 3). The errors observed are greater than would be accepted for survey-derived results, but not significantly so.

Because a determinable error was observed and because this error is attributable to the synthetically derived internal data, the internal data can be adjusted and the magnitude of the error can be reduced. The adjustment factor used was based on the trip interchange volumes and the error in assigned volumes and was calculated by

$$\text{Factor} = \frac{\dfrac{\text{total trips}}{\text{error}/100} - \text{external trips}}{\text{internal trips}}$$

where the error is $\dfrac{\text{total assigned volume} - \text{total observed volume}}{\text{total observed volume}}$. The values for internal trips, external trips, error used in computing adjustment factors, and the factors derived are given in Table 4.

The factors were applied to all internal trip interchanges, and the external trips were added to obtain new total trip tables. These were then assigned to the networks, and comparisons were made. The errors observed in these assignments are given in Table 5.

EVALUATION OF PROCEDURE

The synthetic procedures appear to adequately reproduce observed conditions and after adjustment indicate system errors no larger than those for traditional survey techniques. The value of the synthetic procedure in providing a quick, inexpensive approach cannot be understated, and with this procedure staff capabilities for four comprehensive studies on 36-month schedules can be increased to capabilities for 10 synthetic studies on 15-month schedules. Synthetic procedures provide significant increases in staff capabilities and do not require significantly greater effort than external-oriented "bypass" studies that exclude internal movements. When conducted as shown by the flow chart in Figure 3, synthetic procedures offer a valuable tool for urban transportation planning.

It is therefore recommended that the synthetic procedures described be adopted for standard use as a planning methodology in urban and suburban areas of 25,000 to 50,000 population. FHWA internal memorandum 50-3-69 specifically authorized the use of synthetic procedures in the latter grouping as an alternate to a small sample survey. FHWA requires no specific consideration of internal trip movements in areas of 5,000 to 15,000 population. However, with the synthetic procedures internal movements can be considered and systems-oriented planning can be carried on with little additional effort.

The use of the synthetic procedure will be expedited by the supplemental processes for travel time analysis, traffic assignment network preparation and assignment analysis used by the Urban Planning Section of the Georgia Department of Transportation. Computer programs for synthetic processing designated as SYNTH 1 and SYNTH 2 are also on file with that agency.

Table 3. Comparison of error resulting from unadjusted synthetic procedures with error resulting from interview surveys.

	Resultant Error (percent)				
Procedure and Study Area	Vehicle-Miles of Travel	Vehicle Hours of Travel	Total Volume	Procedure Average	Total Weighted Network
Interview survey					
Albany	-13.1	-16.8	-10.3		58.4
Cedartown	-7.8	-8.4	-0.8		33.3
Milledgeville	+1.9	+0.4	+1.8		54.8
⅓ Σ/error	7.6	8.5	4.3	6.8	48.8
Synthetic, sum of purposes					
Albany	+2.7	-6.2	+1.8		75.4
Cedartown	+20.3	+19.9	+25.9		40.5
Milledgeville	+17.1	+15.7	+19.3		66.7
Waynesboro	-21.1	-4.5	-13.9		37.5
¼ Σ/error	15.3	11.6	15.2	14.0	55.0
Synthetic, total model					
Albany	+22.7	+13.1	+21.3		88.4
Cedartown	+24.5	+24.3	+31.0		41.4
Milledgeville	+18.5	+17.1	+20.4		66.5
Waynesboro	-20.5	-3.9	-13.1		36.9
¼ Σ/error	21.3	14.6	21.5	19.1	58.3

Table 4. Computation of adjustment factors.

City	Model	Internal	External	Total	Error	Factor
Albany	Sum	131,063	27,385	154,448	101.8	0.949
Cedartown	Sum	42,127	19,647	61,774	125.9	0.698
Milledgeville	Sum	51,625	15,527	67,152	119.3	0.790
Waynesboro	Sum	18,850	8,003	26,853	86.1	1.230
Albany	Total	170,011	27,385	197,396	121.3	0.796
Cedartown	Total	42,339	19,647	61,986	131.0	0.654
Milledgeville	Total	50,202	15,527	65,729	120.4	0.778
Waynesboro	Total	19,311	8,003	27,314	86.9	1.213

Table 5. Comparison of error resulting from adjusted synthetic procedures with error resulting from interview surveys.

	Resultant Error (percent)				
Procedure and Study Area	Vehicle-Miles of Travel	Vehicle Hours of Travel	Total Volume	Procedure Average	Total Weighted Network
Interview survey					
Albany	-13.1	-16.8	-10.3		58.4
Cedartown	-7.8	-8.4	-0.8		33.3
Milledgeville	+1.9	+0.4	+1.8		54.8
⅓ Σ/error	7.6	8.5	4.3	6.8	48.8
Synthetic, sum of purposes					
Albany	+1.3	-7.5	-0.7		74.3
Cedartown	-9.3	-10.3	-4.1		30.2
Milledgeville	+8.5	+7.0	+8.7		59.8
Waynesboro	-13.4	+5.3	-4.6		43.0
¼ Σ/error	8.1	7.6	4.5	6.7	
Synthetic, total model					
Albany	+10.1	+0.8	+8.6		78.2
Cedartown	-9.2	-10.2	-3.8		29.4
Milledgeville	+10.9	+9.4	+10.0		61.1
Waynesboro	-12.4	+6.5	-3.3		42.2
¼ Σ/error	10.7	6.7	6.4	7.9	52.7

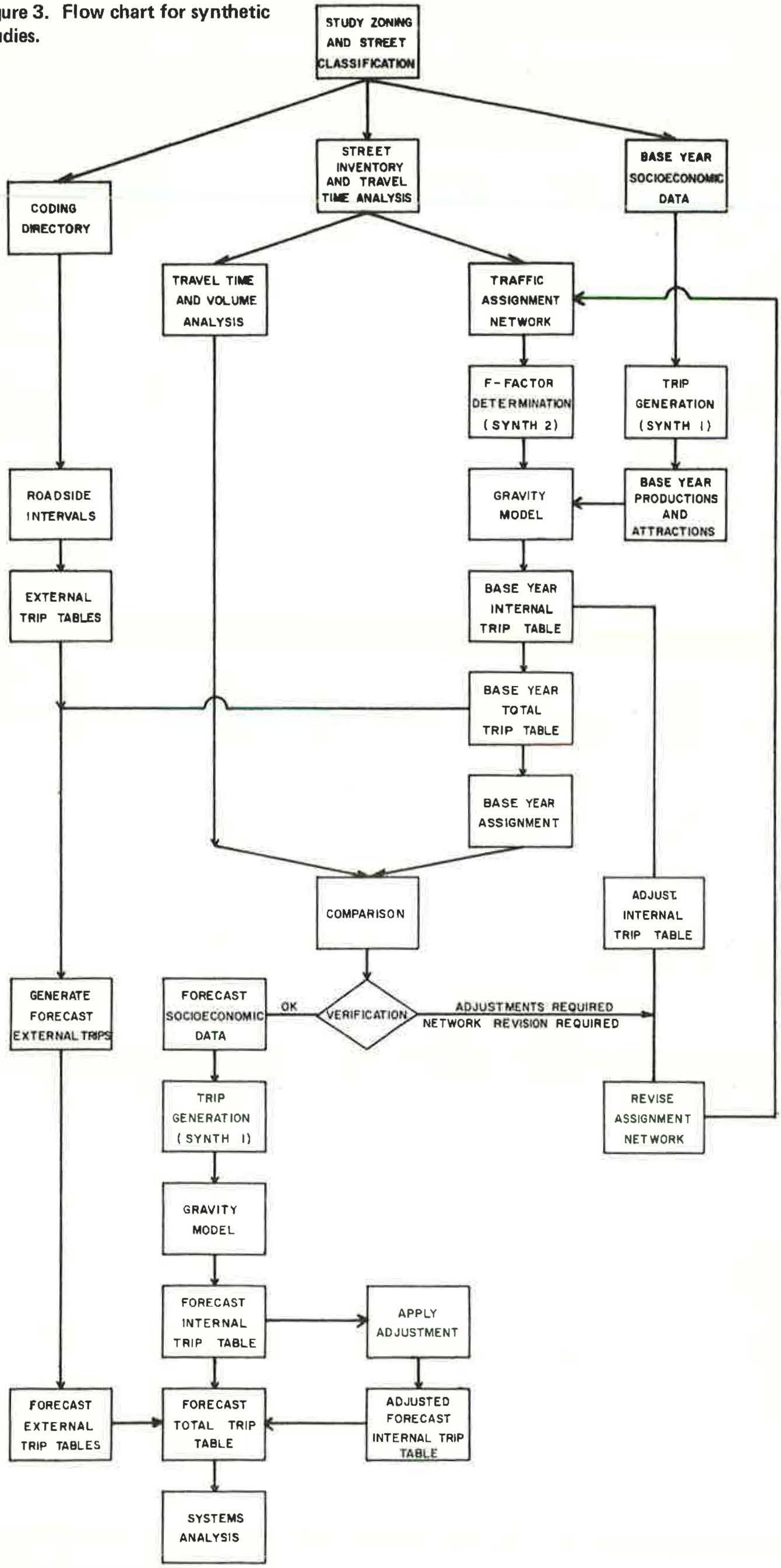


Figure 3. Flow chart for synthetic studies.

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