North Carolina Procedure for Synthesizing Travel Movements

MARION R. POOLE AND JAMES T. NEWNAM, JR.

A procedure for synthesizing travel movements in small and medium-sized urban areas begun in 1961–1963 by the planning staff of the North Carolina Department of Transportation is described. Four methods are used, depending on the extent of travel surveys done as part of the transportation study. Method 1 uses data from an external-cordon, origin and destination (O-D) survey and small-sample, internal, O-D survey. Method 2 procedures are followed if only an external-cordon, O-D survey is done. Method 3 requires only travel data from an internal O-D survey. Method 4 is followed if no O-D surveys are done. All four methods require comprehensive traffic volume counts and comprehensive inventories of employment, commercial vehicles, and dwelling units. The North Carolina procedure has greatly reduced the time and cost required for the travel-modeling phase of transportation studies and has enabled more time and effort to be devoted to travel forecasting and transportation plan development and evaluation. A brief history of the evolution of the synthesis procedure is included.

If every land area had a sufficient variety of required natural resources; if people had uniformly adequate basic skills; and if people were satisfied with a relatively fixed level of goods, foods, and other benefits, there would be no need for travel. However, natural resources are not evenly distributed, and people have fundamental desires to increase their individual benefits and happiness. These factors have led people to specialize in various endeavors to increase productivity and benefits. This specialization or division of labor and increased benefits have increased the need to travel—in order to trade, work, play, and obtain required services. Today's complex urban society requires extensive travel to fulfill the needs of its population and its economic activity.

Prediction of future travel desires is a basic prerequisite for developing an adequate transportation plan for any urban area. Conventional techniques for travel forecasting have generally involved the development of a series of models that describe travel in terms of major components: *(a)* trip generation, *(b)* trip distribution, and *(c)* transportation system. From inputting of specific future assumptions about factors that create travel, the models produce estimates of future travel. The procedure for travel model development and travel forecasting has traditionally included inventories of travel, socioeconomic data, and transportation facilities; data validation; trip generation model development; transportation system coding and calibration of through-traffic assignment; trip distribution modeling; modal-split modeling; and projection of future travel through projection of future socioeconomic data and input of the data into the travel models. The process has been expensive and time-consuming, particularly in the inventory, data validation, and model development phases.

Planning and Research Branch, Division of Highways, North Carolina Department of Transportation, Raleigh, N.C. 27611.

The purpose of this paper is to describe the synthesis procedure developed by the planning staff of the North Carolina Department of Transportation over more than two decades to shorten, simplify, and reduce the cost of travel forecasting. In the following sections, evolution of the synthesis procedure and current methods of approach is described.

EVOLUTION OF SYNTHESIS PROCEDURE

The North Carolina experience in transportation planning began with the 1959 General Assembly and the enactment of general statutes requiring cooperative major street planning. These general statutes *(a)* required state and municipal development of a thoroughfare plan; *(b)* provided for state and municipal adoption of the plan; *(c)* required state and municipal agreement on street and highway responsibilities on mutual adoption of the plan; *(d)* defined state and municipal responsibilities; and *(e)* provided for mutual revision of the plan. The statutes applied to all municipalities, but did not affect counties because counties in North Carolina have no road construction or maintenance authority.

In 1958–1962, consultants were used for studies in the larger cities that generally included comprehensive internal-home-interview and external-cordon, origin and destination (O-D) traffic surveys. The basic techniques for projection of travel were the growth factor method *(1)* and the combination growth factor and modified gravity model *(2)*.

Beginning in 1961–1963, travel synthesis was initiated in smaller cities *(3, 4)*. The technique was based on the Iowa gravity model procedures *(5)* using data from a small-sample, home interview, O-D survey and employment data. An external-cordon traffic survey was done. All gravity model computations and traffic assignments were manual.

Following the enactment of the federal transportation planning regulation in 1962, comprehensive studies were required for cities over 50,000 population in the 1964–1971 period. The studies, which were expensive, included comprehensive O-D surveys, extensive gathering of land use and socioeconomic data, use of regression analysis techniques to develop estimating equations for trip productions and attractions, and use of the gravity model for trip distribution.

For smaller urban areas, during 1964–1976, the synthesis procedure for estimating travel was refined in an effort to reduce the cost of planning studies. The refinement included the standardization of procedures, building of a data bank for trip generation rates and trip length frequency curves from internal O-D surveys in 17 urban areas of various size, development of specialized computer programs, and research on procedures for synthesis of through-travel. The cost of internal O-D surveys was reduced in urban areas of less than 50,000 by reducing the sample size to 5 percent based on research by Horn et al. *(6)* and Parsonson and Horn *(7)*. In 1968, Cochrane *(8)* evaluated the ability of the synthesis approach to duplicate traffic volumes on the street system for Mooresville, North Carolina, and concluded the synthesis method had better duplicating ability than did a uniformly upgraded O-D survey. In 1971, Modlin *(9)* developed a method for estimation of external and through-travel that provided means for reducing costs associated with external-cordon traffic surveys. Studies for Marion, North Carolina *(10)*, and Ahoskie, North Carolina *(11)*, were the two earliest studies that used borrowed trip generation rates and trip distribution curves as means for modeling and synthesizing travel movements. A study for Wilkesboro-North Wilkesboro, North Carolina *(12)*, involved the first complete synthesis of all travel patterns—internal, external, and through.

During 1974–1984, dependence on the synthesis methodology and its application to urban areas over 50,000 population increased.

NORTH CAROLINA PROCEDURE FOR MODELING TRAFFIC MOVEMENTS USING A SYNTHESIS APPROACH

The steps involved in the North Carolina modeling procedure followed the conventional sequence of *(a)* study area and traffic zone definition, *(b)* inventory of existing conditions, *(c)* model development, and *(d)* model validation. Procedures varied depending on whether travel data were totally absent or partially available.

Study Area and Traffic Zones

Subdivision of the planning area into traffic analysis zones is the first step in segregation of travel into component parts for model development. Care in delineation of the planning area and zones minimizes potential problems in the synthesis procedure. It is important that the planning area boundary include all the land area that may become urban in character during the usual 20-year design period, that it follow easily defined topographic features, and that it be located so as to minimize the number of street crossings. If an external traffic survey is to be done, it is desirable to minimize the number of external stations to reduce survey cost, or to minimize analysis required if external and through-movements are to be synthesized. An external survey done previously in the area would also be considered.

Traffic analysis zones should define areas of similar lane use, be of regular shape, and contain an area not to exceed 1 mi^2. Typical urban areas have traffic zones that vary in size from 10–15 acres in densely developed areas to 500–600 acres in sparsely developed areas. Considerations in establishing traffic zone boundaries include census tract boundaries; local planning zone boundaries; topographic features; the existing and proposed street system; existing transit routes; and unique or significant travel generators such as airports, shopping centers, sports complexes, hospitals, schools, and universities. Because travel, from the standpoint of the travel forecast models, in theory originates and terminates at centroids of traffic zones, the analyst delineates zones considering the forecast models. The establishment of a large number of small zones means that traffic assignment models are more refined but that more error is likely in estimation of trip generation on a zonal basis. Contrariwise, larger zones produce greater confidence in trip generation estimates on a zonal basis, but less confidence in assignment model results.

One or two screenlines are normally defined that completely bisect the planning area. The screenlines are used to check and validate the travel models. They should follow natural topographic features, cut as few streets as possible to minimize travel inventories, and should be common to traffic zone boundaries.

Inventories

Travel inventories conducted to validate and assist in travel model calibration include *(a)* comprehensive traffic volume counts on segments of the major street network and at external-cordon and screenline stations; and *(b)* some vehicular classification counts at selected external-cordon and screenline stations. Traffic volume counts on street segments are usually taken by automatic traffic counters for minimum periods of 48 hr. Counts at external-cordon and screenline stations are preferably hourly machine counts taken over a 2-week period. Vehicular classification counts at selected screenline stations and external cordon stations are to determine trip distribution by hour of day and vehicle classification. Classification counts may be taken for 8-, 16-, or 24-hr periods.

A small-sample, internal, home interview, O-D survey or external-cordon O-D survey may be done depending on the scope of the study, funds available, and time constraints. An external-cordon traffic survey is usually avoided if at all possible because of the high cost and time required. A small-sample, internal survey of 400–600 dwelling units is needed occasionally to update information in the trip data bank on dwelling unit trip generation rates, trip purpose distribution, and trip length frequency.

Socioeconomic data inventories required for synthesis of travel are employment and number of dwelling units. The employment inventory consists of a survey of all employers in the planning area to determine number of employees and number of trucks, commercial automobiles, and taxis. The dwelling unit inventory identifies the number of dwelling units in each zone by five housing classes—excellent, above-average, average, below-average, and low. A sixth category of housing can be used to identify population in group quarters such as military bases and college campuses.

The employment survey is obtained by field survey by either city staff, state staff, or by temporary employment of a local person by the state or city. The last method has proved to be cost-effective. Two recent inventories were done using this approach for urban areas of 18,000 and 25,000 for less than $1,000 each.

Two procedures have been used to stratify dwelling units into the five housing classifications. If a recent tax assessment had been done for an area, property tax records and maps were used to determine dwelling unit numbers and classes in a cost-effective manner. Because tax reassessment is usually not frequent or recent, the most consistently used procedure for completing the dwelling unit inventory has been to do site inspections of all households and classify them based on specified criteria.

Travel Modeling

Travel modeling is accomplished by one of four methods depending on whether travel inventory data are obtained. The four methods are illustrated by the four flowcharts shown in Figures 1–4.

Method 1

Figure 1 shows the procedure followed if an external-cordon, O-D survey and a small-sample, internal, O-D survey are done as part of the transportation study. The internal O-D survey provides areawide information on dwelling unit trip generation rates, distribution of trips by purpose, and trip lengths. The external O-D survey provides a through-trip table, a summary of external-trip generation and attraction, a total number of internal trips generated by vehicles garaged outside the study area, and information on external trip length.

In Method 1, a multiple linear regression analysis is done to relate external trip attractions to employment and dwelling units. The usual regression form is

$$Y = a + bX_1 + cX_2 + dX_3 + eX_4 + fX_5 + gX_6 \quad (1)$$

where

Y = external trip ends,
X_1 = industrial employment,
X_2 = retail and wholesale employment,
X_3 = highway retail employment,
X_4 = office employment,
X_5 = service employment, and
X_6 = number of dwelling units.

The resulting equation is used as an estimator for external trip attractions and internal, nonhome-based (NHB) trip attractions and internal, other-home-based (OHB) trip attractions.

An internal data summary (IDS) computer program is a key program in the North Carolina synthesis procedure. Inputs to the program are *(a)* occupancy per dwelling unit class; *(b)* trip generation rates for dwelling unit classes; *(c)* trip generation rates for trucks, commercial automobiles, and taxis; *(d)* percentage of internal trips remaining inside the cordon; *(e)* percentage of home-based work (HBW), NHB, and OHB trips; *(f)* number of occupied dwelling units in each class in each zone; *(g)* number of trucks, commercial automobiles, and taxis in each zone; *(h)* total number of internal trips generated by traffic garaged outside the study area; and *(i)* trip attractions by zone. Trip attractions for HBW trips are total zonal employment. Trip attractions for other trips (NHB and OHB) are the factors from the regression equation. The IDS program does the following:

1. Computes total internal trips generated by dwelling units, trucks, commercial automobiles, and taxis for each zone.
2. Reduces the trips generated by the percentage of internal trips that cross the cordon.
3. Separates the remaining trips into HBW, NHB, and OHB trip purposes by zone.
4. Sums NHB trips and adds to internal NHB trips generated by external traffic.
5. Reallocates NHB trip productions to internal zones based on NHB trip attraction factors.
6. Factors HBW, NHB, and OHB attractions to equal productions.

Outputs of the IDS program are *(a)* zonal totals of trip productions and attractions by purpose (HBW, NHB, and OHB), *(b)* zonal and areawide totals of trips; *(c)* zonal and areawide totals of population and employment; and *(d)* zonal and areawide totals of dwelling units, trucks, commercial automobiles, and trips.

Several checks for reasonableness are made on the output of the IDS program. The total trips generated by dwelling units divided by the total number of dwelling units should approximate the areawide trip generation rate. The distribution of dwelling units according to housing condition should be a normal and reasonable distribution. Population estimate totals within corporate limits or townships should be checked against Bureau of the Census data or other independent estimates.

In Method 1, trip data from the small-sample, internal, O-D survey and external-cordon survey are both processed through the trip length distribution (TDIST) computer program that assigns trip data to the existing street network and tabulates the number of trips occurring in each time increment. The output of the TDIST program is plotted and smooth curves are derived from the data.

Two programs in the FHWA battery of computer programs used to calibrate a gravity model and estimate internal and external trips are the gravity model calibration (GMCAL) program and the gravity model (GM) program.

The procedure requires the processing of data through these two programs and validation of the results through assignment of output trip tables to the existing street network.

The standard gravity model form is

$$T_{ij} = P_i A_j F_{ij} K_{ij} + \sum_{j=1}^{n} (A_j F_{ij} K_{ij}) \quad (2)$$

where

T_{ij} = trips produced at i and attracted to j;
P_i = total trip production at i (may be by purpose, mode, etc.);
A_j = total trip attraction at j (may be by purpose, mode, etc.);
F_{ij} = calibration term for interchange ij (travel time factor);
K_{ij} = socioeconomic adjustment factor for interchange ij;

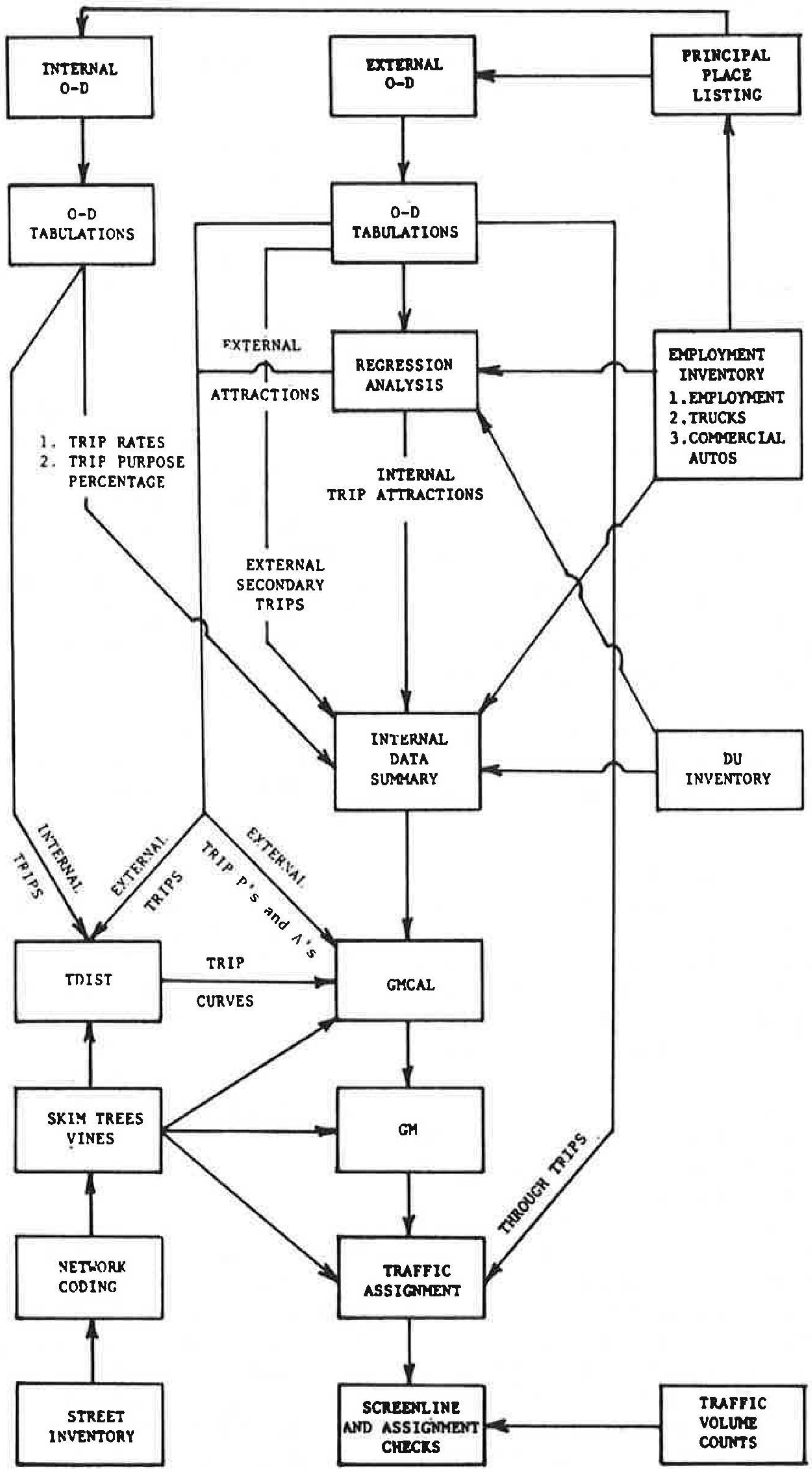

FIGURE 1 Synthesis of travel with small-sample, internal, O-D travel survey and external-cordon, O-D traffic survey.

i = origin zone number ($i = 1, 2, \ldots, n$);
j = destination zone number ($j = 1, 2, \ldots, n$); and
n = number of zones.

The GMCAL program repeatedly adjusts travel time factors (F_{ij}) until a satisfactory match is achieved between the desired areawide trip distribution curve and the output of the gravity model. Input to the program includes the zone-to-zone travel times (termed "skim trees" and "vines"), zonal productions and attractions from the IDS program, and trip length distribution for the trip purpose being analyzed. The user may also supply an initial trial set of F factors and specify the number of iterations desired. For proper operations of the GMCAL program, input must satisfy the following conditions for each trip purpose:

Total P trips = total A trips
= total trips in given distribution curve

One iteration of the GMCAL program involves

1. Computation of trip distribution based on given P and A trips, skim trees and vines, and given, or assumed, F factors.
2. Comparison for each time increment of trips distributed by gravity model to desired trips (input trip distribution).
3. Computation of adjusted F factors on basis of comparison.
4. Smoothing of adjusted F factors by fitting to a smooth curve using the least squares technique.
5. The smooth F factors are subsequently input to the second iteration.

There are opposing views as to whether F factors should conform to a smooth curve. For a large urban area with a large number of analysis zones and extensive transportation network, F factors can reasonably be expected to conform to a smooth curve; but, for smaller urban areas of the size typically found in North Carolina, this expectation may not be reasonable. Distortions in impedances resulting from network configuration or spatial location of travel generators tend to have a more significant effect in distorting impedances.

In North Carolina, the best procedure for accomplishing the GMCAL calibration phase has been to run three iterations of the GMCAL program and selected adjusted F factors from the best iteration for input to a second run of the program. A second run usually results in adequate calibration. F factors chosen should generally adhere to a decreasing number set with the exception of the first and second minutes.

The result of the GMCAL calibration process is a set of F factors for input to the GM program. The objective of the GM program is to produce trip tables that reasonably duplicate the travel patterns existing in the study area. Calibration is achieved in the GM program by holding F factors constant and making adjustments in input attraction factors (A's) until output trips attracted equal desired attractions. Input to the program includes the zone-to-zone travel times (skim trees and vines), zonal productions and attractions, and F factors derived from the GMCAL process.

One iteration of the GM program involves

1. Computation of trip distribution based on given P and A trips, skim trees and vines, and F factors.
2. Comparison by zone of actual trips attracted to desired input attractions.
3. Computation of adjusted attractions on basis of comparison for input to second iteration.

If socioeconomic adjustment factors K_{ij} are used, their need may first appear during the GM calibration phase. Unlike the F factor term, the K_{ij} term applies only to interchange i and j or other points specified. If used, it may be necessary to recycle through the GMCAL calibration phase. A 1972 FHWA manual *(13)* provides good documentation for using K factors.

Trip tables from the GM calibration and through trips are assigned to the existing street network and compared to actual volumes on the system as a check of the ability of the synthesis procedure to reproduce travel. Checks consist of both screenline comparisons and comparisons on an individual link bases. COMPARE, an FHWA computer program, may be used to make the link comparisons.

Some additional network calibration, that is, adjustment in speeds on various links, may be required at this stage. This additional network calibration may require that several of the steps in gravity model calibration be retraced because such changes result in changes in output of the skim trees and vines that is input to the calibration programs. Whether or not such retracing is required depends on the magnitude of changes made in the network.

Care must be exercised during the synthesis process to ensure that the models are not forced to duplicate givens too precisely during calibrations. Throughout the process it is important to remember that there are few if any absolute givens. For example,

1. O-D surveys are only estimates of existing travel;
2. Traffic volume counts and screenline counts are estimates of actual travel on the system;
3. Regression equations and trip rates provide estimates of attractions and productions; and
4. The gravity model provides estimates of travel patterns.

When discrepancies occur, data inputs as well as model performance must be examined before a decision is made as to what is in error.

Method 2

Figure 2 shows the procedure followed if only an external-cordon O-D traffic survey is done as part of the transportation study. The major difference between Method 1 and Method 2 is that borrowed trip generation rates and estimated percentage of internal trip purposes must be used as input to the IDS program. It is also necessary that estimated or borrowed HBW, NHB, and OHB trip distribution curves be used as input to the GMCAL gravity model program.

Average family income from the Bureau of the Census and areawide employment base is normally used as a guide in selecting trip generation rates and trip purpose distribution. The trip generation rates may need to be adjusted for changes in vehicle ownership, vehicle usage, and persons per dwelling unit if the borrowed rates are several years old. Adjustments to

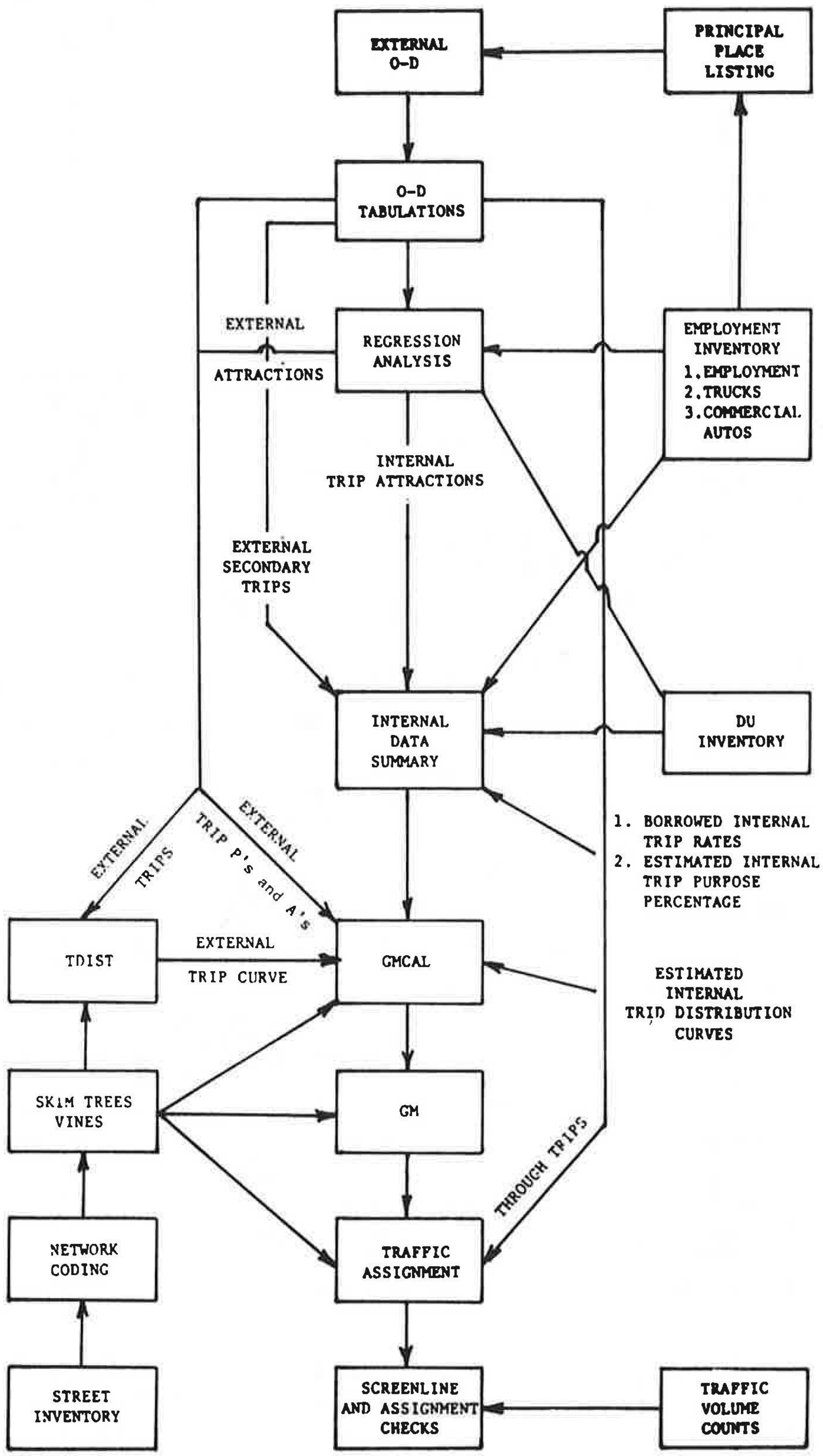

FIGURE 2 Synthesis of travel with an external-cordon, O-D traffic survey.

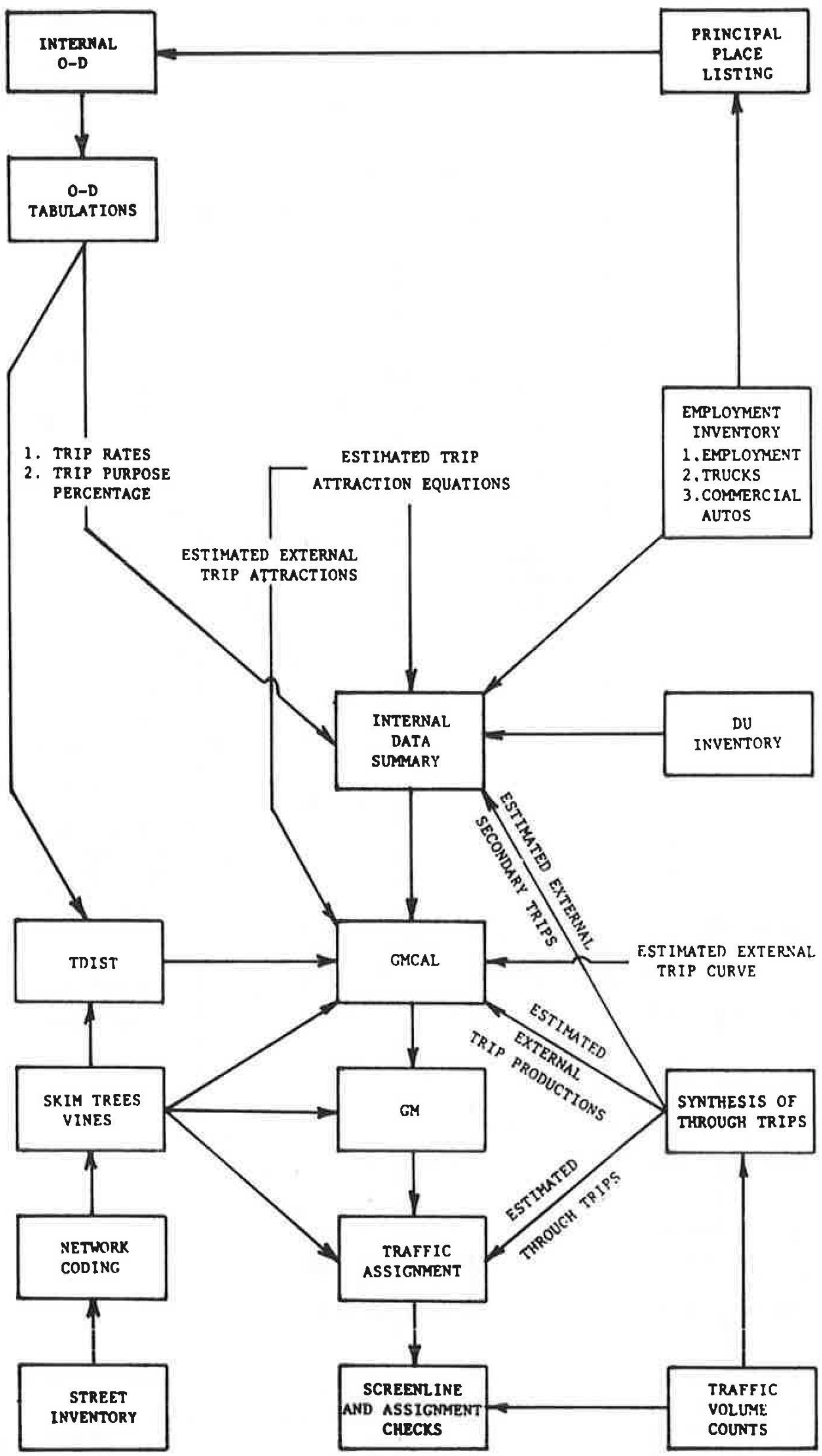

FIGURE 3 Synthesis of travel with a small-sample, internal, O-D travel survey.

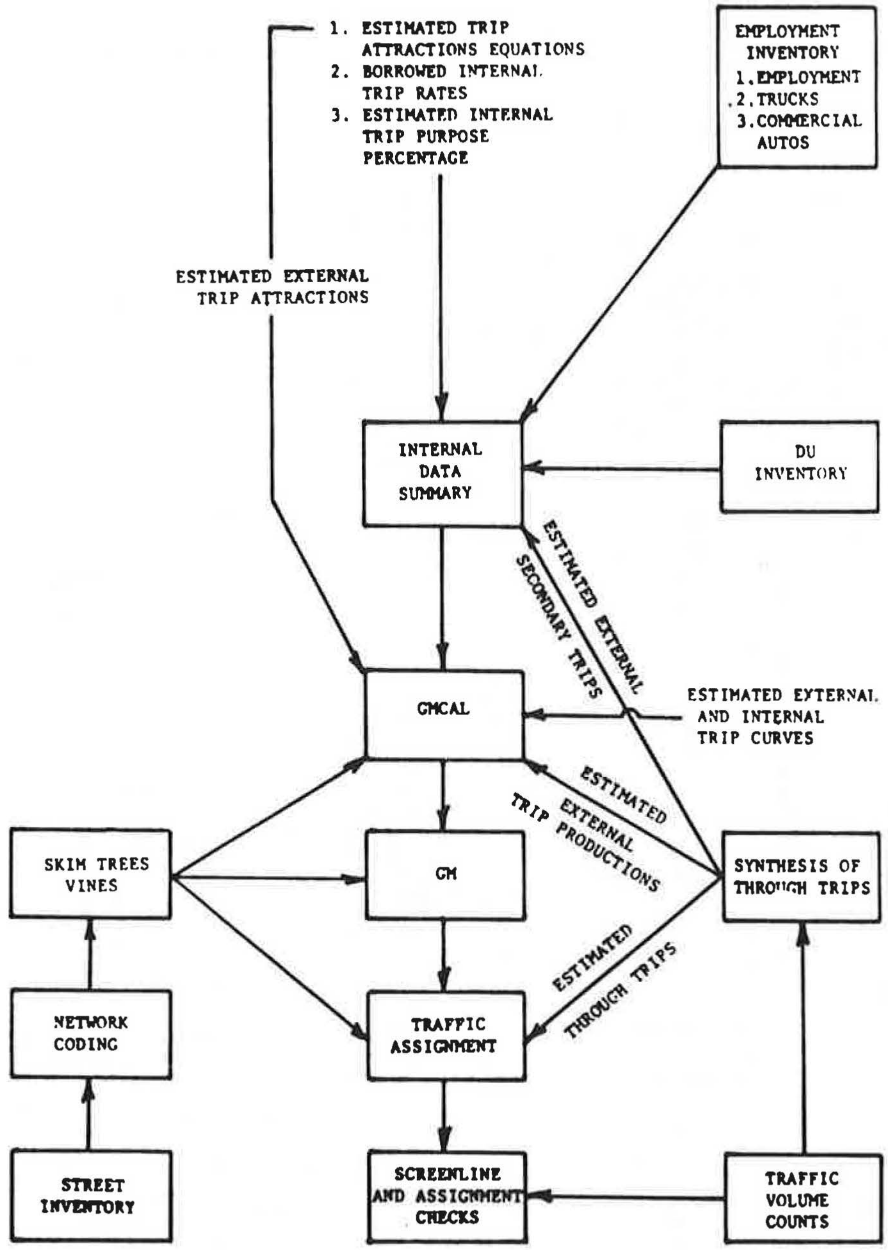

FIGURE 4 Synthesis of travel with no O-D travel surveys.

rates are made by factoring the areawide average and adding the incremental difference to each rate category.

The remainder of the synthesis procedure under Method 2 follows in a manner similar to Method 1. However, it is important in Method 2 to carefully examine the first iteration trip generation curve output of the GMCAL program. Because the internal trip distribution curves have been borrowed, they may not adequately represent the travel patterns of the area under study. The first-iteration output of the GMCAL program sometimes signals that adjustments may be needed in the trip distribution curves.

Method 3

Figure 3 shows procedures that are followed if only a small-sample, internal, O-D survey is done as part of the transportation study. In this procedure, a borrowed trip attraction equation is used to estimate trip attractions for NHB, OHB, and external trips. If an external-cordon, O-D survey was done for the area in prior years, it would serve as a basis for synthesis of through-travel movement and external-travel productions. If information on through- and external-travel data is totally absent, the synthesis procedure for estimation of through-travel, developed and updated by Modlin *(9, 14)*, is used to estimate through- and external-travel productions. An estimated or borrowed external trip distribution curve must be used in the GMCAL program in this method.

Method 4

Figure 4 shows the procedure followed if neither an external-cordon nor internal, home interview, O-D survey is done as part of the transportation study. The only inventoried data used

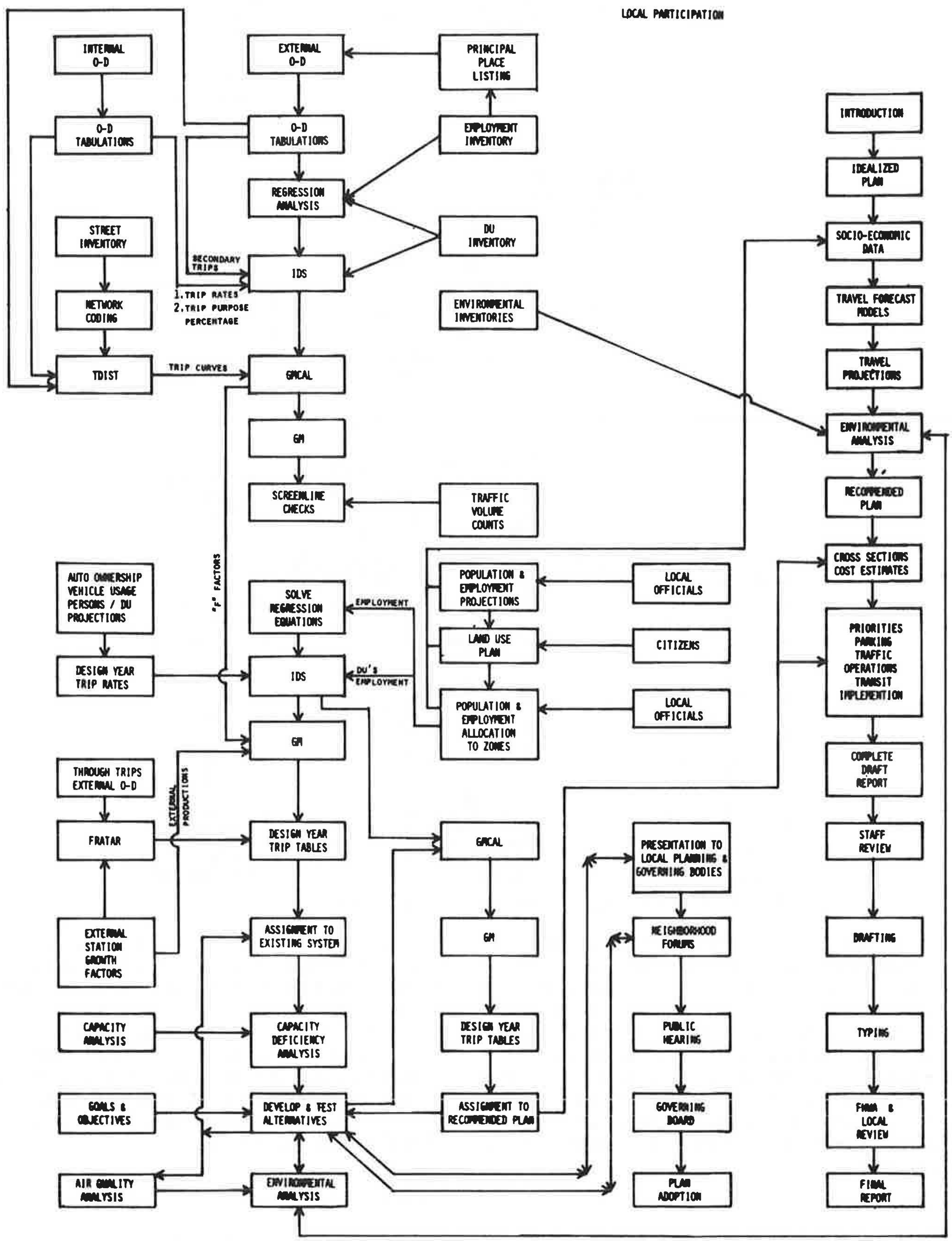

FIGURE 5 Transportation plan development flowchart.

in the synthesis process in this procedure are data from employment and dwelling unit inventories, and from traffic counts. Borrowed or previously developed trip attraction equations must be used to estimate trip attractions for NHB, OHB, and external trips. Estimated trip generation rates and estimated percentage of internal trip purposes must be used as input to the IDS program. It is also necessary that estimated or borrowed HBW, NHB, and OHB trip distribution curves be used as input to the GMCAL gravity model program. Through and external travel must be estimated generally as described in Method 3.

Method 4 requires careful checks on reasonableness of data and output at each step of the process because assumptions are much more extensive in number.

SELECTION OF SYNTHESIS METHOD

Since the early 1960's, North Carolina has completed 69 studies applying one of the four synthesis procedures. Currently, selection of one procedure over an alternative depends on *(a)* perceived transportation problems, *(b)* extent of prior studies completed for the area, *(c)* study time constraints, *(d)* cost, and *(e)* staff availability. In general, Method 4 typically requires 1–3 months to complete traffic counts and the employment and dwelling unit inventories, and 2–4 months to complete the synthesis of travel. If a small-sample, internal O-D survey is done as in Method 3, an additional 3–6 months are needed to plan, conduct, and tabulate the survey data. Methods 1 and 2 have typically required 12–18 months to plan, complete, and tabulate data from O-D surveys.

In some cases, locally preconceived ideas as to the cause of the transportation problem may dictate the synthesis method used. For example, it may be perceived locally that the major travel problem is through traffic. In this case, it may be desirable to include a partial or full, external, O-D survey to obtain hard data on through traffic. In another situation, local officials may feel internal travel characteristics of the area are significantly unique, or have changed. In this case, it may be necessary to schedule a small-sample, home interview, O-D survey as a part of the study to ensure local confidence in the study.

The extent of travel data obtained in a prior study, problems encountered in prior travel modeling, and the type of travel modeling used in a prior study may influence the decision on which procedure to use. In most instances, if O-D surveys have been done earlier for an area, Method 4 is the preferred procedure for travel synthesis for an update study.

In recent years, cost and staff availability have been controlling factors in the decision process. Staff and monies have just not been available for conducting O-D surveys. In 1985, a thoroughfare planning study was completed for Reidsville, a city in north-central North Carolina with an estimated planning area population of 23,700. Method 4 was used in the study and the total study cost was $24,000. If a small-sample, internal, O-D survey was done, an estimated additional cost of $10,300 would have been incurred. If an external-cordon, O-D survey was done, the estimated additional cost would have been $68,000.

SUMMARY

The North Carolina procedure for synthesis of travel discussed herein is but one part of several sequential steps involved in the transportation plan development process (Figure 5). Historically, considerable time and monies have been expended in data inventories and travel modeling. The North Carolina procedure has greatly reduced the time and cost required for this part of the transportation study and allowed more time and effort to be devoted to travel forecasting and plan development and evaluation.

The procedure was developed for use in small- to medium-sized cities where transit has not been a major consideration. In urban areas where it has been desirable to consider transit, procedures developed by Modlin et al. *(15)* have been used to estimate transit travel and its impact on automobile driver travel.

A data bank of information on trip generation rates, trip attractions, trip purpose distribution, and trip length frequency is needed to apply the synthesis procedure. In North Carolina, this information was gathered over a number of years. Method 1 procedures that included an external-cordon, O-D survey and a small-sample, internal, home interview, O-D survey were widely used in the 1960s. Today, Method 4, which involves no O-D surveys, is the procedure used almost exclusively. Method 3, which entails a small-sample, internal, O-D survey, is occasionally followed in order to add to the data bank new information on trip generation rates, trip purpose distribution, and trip length frequency.

The synthesis procedure requires detailed inventories of dwelling units, employment, and traffic counts. No substitute has been found for a comprehensive inventory of employment numbers, trucks, and commercial automobiles. Attempts at using alternative sources for employment data have proved to be inefficient, costly, time-consuming, and inadequate.

REFERENCES

1. *Masters Thoroughfare Plan, Fayetteville Urban Area.* Harland Bartholomew and Associates, Memphis, Tenn., 1962.
2. *A Master Transportation Plan, Charlotte Metropolitan Area.* Wilbur Smith and Associates, New Haven, Conn., 1960.
3. *Salisbury-Spencer Major Thoroughfare Plan.* Advance Planning Department, North Carolina State Highway Commission, Raleigh, N.C., 1962.
4. *Major Thoroughfare Plan for the Rocky Mount Urban Area.* Advance Planning Department, North Carolina State Highway Commission, Raleigh, N.C., 1963.
5. *Gravity Model Procedures Used by Iowa Planning Survey.* Region Five, Bureau of Public Roads, U.S. Department of Commerce, Kansas City, Mo., 1962.
6. J. W. Horn, D. B. Stafford, E. W. Houser, B. T. Brothers, and P. S. Parsonson. *Examination and Comparison of ADT Gravity Models.* Project ERD–110–X, Part II. Highway Research Program, North Carolina State University, Raleigh, N.C., 1966.
7. P. S. Parsonson and J. W. Horn. *Comparison of Techniques for Estimating Zonal Trip Production and Attractions.* Supplement to Project ERD–110–X Final Report. Highway Research Program, North Carolina State University, Raleigh, N.C., 1966.
8. C. T. Cochrane. *An Evaluation of a Synthetic Gravity Model in a Small Urban Town.* M.S. thesis, North Carolina State University, Raleigh, N.C., 1968.
9. D. G. Modlin, Jr. *Synthesis of Through Trip Patterns in Small Urban Areas.* Ph.D. dissertation, North Carolina State University, Raleigh, N.C., 1971.
10. *Marion Thoroughfare Plan.* Advance Planning Department, North Carolina State Highway Commission, Raleigh, N.C., 1964.
11. *Ahoskie Thoroughfare Plan.* Advance Planning Department, North Carolina State Highway Commission, Raleigh, N.C., 1969.

12. *Wilkesboro-North Wilkesboro Thoroughfare Plan.* Planning and Research Branch, Division of Highways, North Carolina Department of Transportation, Raleigh, N.C., 1976.
13. *Urban Transportation Planning, General Information and Introduction to System 360.* FHWA, U.S. Department of Transportation, 1972.
14. D. G. Modlin, Jr. Synthesizing Through-Trip Table for Small Urban Areas. In *Transportation Research Record 842*, TRB, National Research Council, Washington, D.C., 1982, pp. 16–20.
15. D. G. Modlin, L. E. Mooring, and J. T. Newnam, Jr. *Quick Response Transit Impact Analysis.* Technical Report 6. North Carolina Urban Transportation Planning Information System, Planning and Research Branch, Division of Highways, North Carolina Department of Transportation, Raleigh, N.C., 1981.

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