Inexpensive Travel Demand Techniques

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16. ABSTRACT

Conventional urban travel demand models, which are data-hungry, costly and mainly meant for large cities and metropolitan areas are not suitable for small urban areas with a population of 50,000 or less. These small urban areas generally lack the staff, expertise and budget to operate the conventional models. This report examines the applicability of simplified travel demand models suitable for small urban areas. The scope of this research is limited to simplified travel demand forecasting techniques that make use of routinely collected traffic ground counts. A total of thirteen methods are examined, of which four are discussed in detail, by applying them in a common setting. Their input requirements and usability are examined. Contacts with selected MPOs, COGs, Planning Commissions in the State of Washington reveal that such methods will be useful in small urban areas considering the staff, expertise, and budget limitation available. Currently, these small urban areas use unproven heuristic methods. The use of methods described in this report will considerably help small urban areas to forecast travel demands using traffic ground counts and socioeconomic data.

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INEXPENSIVE TRAVEL DEMAND TECHNIQUES

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Abstract

Conventional urban travel demand models, which are data-hungry, costly and mainly meant for large cities and metropolitan areas are not suitable for small urban areas with a population of 50,000 or less. These small urban areas generally lack the staff, expertise and budget to operate the conventional models. This report examines the applicability of simplified travel demand models suitable for small urban areas. The scope of this research is limited to simplified travel demand forecasting techniques that make use of routinely collected traffic ground counts. A total of thirteen methods are examined, of which four are discussed in detail, by applying them in a common setting. Their input requirements and usability are examined. Contacts with selected MPOs, COGs, Planning Commissions in the State of Washington reveal that such methods will be useful in small urban areas considering the staff, expertise, and budget limitation available. Currently, these small urban areas use unproven heuristic methods. The use of methods described in this report will considerably help small urban areas to forecast travel demands using traffic ground counts and socioeconomic data.

Summary

This study examines various travel demand forecasting techniques proposed by researchers and a few used by practitioners in recent years, which have the characteristics of being simple, inexpensive and suitable for small urban areas with population 50,000 or less. Thirteen of these techniques are considered which make use of routinely collected ground counts and which have a potential for such use.

The objectives of the research are : 1) to study recent reports, articles, papers, and evaluations on inexpensive travel demand techniques used across the country, using routinely collected traffic ground counts; 2) to contact selected MPOs, COGs, and cities on their experiences with inexpensive travel demand techniques; and 3) to synthesize this information in a summary report.

A survey of recent reports and articles, and contacts with the MPOs and COGs across the State of Washington reveal several commonalities among various simplified travel demand techniques proposed for use in small urbanized areas. There are, however, individual differences which are unique. It appears that researchers have been working on model simplification for at least a decade for coming up with quick forecasting techniques.

After examining thirteen travel demand forecasting techniques through a set of criteria designed with the special characteristics of small urban areas in mind, four of these techniques are selected as the most promising for application. These techniques are then applied in a common setting to determine how they work, the ease of their application and their comparative advantages. Step-by-step procedures are shown for each of these techniques using a hypothetical city road network.

The four techniques finally chosen can easily be applied to small urban areas with

much advantage. In particular, the techniques would prove most applicable in modeling small urban areas, especially those that are free-standing in rural regions, and possibly those that are extensions of large metropolitan areas. Also, cities where transportation system management analysis is needed, and where qualified full-time transportation planners are not available on the planning staff will find benefits in applying these methods.

In order to make use of a simplified travel demand technique, a city or small urban area should have the following data base as a minimum requirement :

1. Transportation network characteristics, including network configuration, link speed and operating rules.
2. Representative base year traffic volumes based on ground counts, throughout the network.
3. Volumes and patterns of trips with one or both ends outside the area under study. Information about these external trips may be gathered from an interview survey conducted on the periphery of the study area.
4. Patterns and intensities of land use development in the base year as well as in the horizon year. At the very least, this must include population or dwelling units and employment by zone. Additional breakdowns, for example, population by income or automobile ownership level, or employment by industrial, commercial, or other categories, may also be recorded, if possible. The most recent census data can be used to obtain this information for the base year. For the horizon year, economic analysis and social studies conducted for the area can be used. If such studies have not been done, simple trend analysis figures could be used.

Conclusions

1. Urban travel demand models, which are data-hungry, costly and mainly meant for large cities and metropolitan areas are not suitable for small urban areas. These small urban areas generally lack the staff, expertise and budget to operate the conventional models.

2. There have been developments in recent years in evolving inexpensive techniques for forecasting travel demands. It appears that researchers have been working on model simplification for at least a decade and have come up with several quick forecasting techniques. The use of traffic ground counts in these simplified models is promising, because generally these counts are routinely collected in such urban areas and are readily available.

3. As demonstrated through this research, there are at least four different inexpensive techniques that are suitable for small urban areas. These techniques make use of routinely collected traffic ground counts or have a potential for such use. The data requirement of these techniques is more or less similar.

4. The minimum data requirements for application of these methods are the following :

    a. Transportation network characteristics of the study area, including network configuration, link speeds, and operating rules.

    b. Representative traffic volumes derived from routinely collected ground counts, throughout the network.

    c. Volumes and patterns of trips with one or both ends outside the area under study (external trips).

d. Patterns and intensities of land use development in the base year as well as in the horizon year.

5. The simplified inexpensive travel demand techniques described in this report would prove most applicable in the following cases :

   a. Modeling small urban areas, especially rural free-standing cities, and possibly the extensions of larger metropolitan areas.

   b. Modeling small urban areas where qualified full-time transportation planners are not available on the planning staff.

   c. Modeling small urban areas where transportation systems management analysis is needed.

Recommendations

It is recommended that small urban areas (population of 50,000 or less) should:

1. Consider using one or more of the four inexpensive techniques described in this research report, for forecasting travel demand, using routinely collected ground counts. These four techniques are :

   a. Khisty-AlZahrani's Model

   b. Low's Model

   c. Neumann's Technique, and

   d. FHWA's Travel Simulation Procedure for Small Cities.

   Of these four techniques, (a) and (b) are preferred.

2. Consider systematically collecting and documenting a minimum set of data for running the techniques listed in (1). The data set should include :

   a. defining the transportation network characteristics, including network configuration, link speeds, and operating rules;

   b. maintaining and recording historical traffic ground count data and then coding them link-by-link on all arterials and major roads;

   c. recording volumes and patterns of trips with one or both ends outside the area under study : information about these external trips may be gathered from an interview survey conducted on the periphery of the study area;

   d. recording patterns and intensities of land use developments in the base year and in the horizon year : at the very least, this must include population or dwelling units and employment by zone.

It is also recommended that further research should be undertaken to refine the existing techniques.

1. INTRODUCTION

Much of the attention of transportation planners and policy makers in the past has concentrated on the problems of metropolitan areas. In recent years, however, there has been a greater awareness of the transportation problems in small urban areas. Small urban areas, generally those with populations under 50,000, have different transportation needs as compared to large metropolitan areas. These needs translate into requiring less sophisticated techniques for planning transportation facilities.

This report on "Inexpensive Travel Demand Techniques" has been prepared to address the needs of small urban areas with population under 50,000. Nationwide, these small urban areas with populations between 2,500 and 50,000 have been gaining in their population share as indicated in Table 1. These population changes suggest a need for a renewed focus on the transportation planning requirements of small urban areas.

Table 1
Population Share of Communities of Different Sizes

Size of Areas	% of Total Population			
	1950	1960	1970	1980
Large Urban Areas 50,000+	35.3	36.2	35.9	34.1
Small Urban Areas 2,500-50,000	28.7	33.7	37.7	39.6
Rural Areas Less than 2,500	36.0	30.1	26.4	26.3

Source : Bureau of Census, 1983

1.1 Purpose of the Study

A primary purpose of the transportation planning process is to generate information useful to decision makers on the consequences of alternative transportation actions (Meyer and Miller, 1984). The objective of this process is to provide information necessary for making decisions on when and where improvements should be made in the transportation system, thus satisfying travel demands and promoting land development patterns that are in keeping with community goals and objectives (USDOT, 1977).

Although sophisticated travel demand models exist, the need for simplified techniques for use by small urban areas was felt. All too frequently, the transportation problems encountered by the residents and businesses of small urban and rural areas were overlooked (USDOT, 1983). This report is an examination of inexpensive travel demand techniques using routinely-collected traffic ground counts.

1.2 Problem Statement

Conventional urban travel demand models, which are currently used to forecast horizon-year traffic volumes, have been the subject of much criticism because of their enormous costs, a significant portion of which is spent on the collection and analysis of large amounts of data by means of a home-interview survey, for example. These data-hungry models are also costly and time-consuming to operate.

Small urban areas in the State of Washington generally lack the financial resources necessary to run these sophisticated models. Also, these cities do not have the expertise needed to use these models. The need for simplification is justified.

In recent years, there have been developments in evolving inexpensive techniques for forecasting travel demands that needed to be investigated, and eventually used.

1.3 Objectives of the Study

The objectives of the study are as follows :

1. To study recent reports, articles, papers, and evaluations on inexpensive travel demand techniques, used across the country, using routinely collected traffic ground counts.
2. To contact selected MPOs, COGs, and cities on their experiences with inexpensive travel demand techniques.
3. To synthesize this information in a summary report.

1.4 Scope of the Study

This study synthesizes various techniques proposed by researchers and a few used by practitioners in recent years, which use routinely collected traffic ground counts. Thus, only those techniques are examined which make use of routinely collected ground counts, or those techniques which have a potential for such use. A few of these techniques are studied in detail and applied in a common setting. A set of qualitative evaluation criteria is used that addresses special characteristics of small urban areas.

The focus here is mainly on small urban areas (defined as those that have populations of 50,000 persons or less), although much of the discussion and recommendations could also be applicable to urban areas somewhat larger than 50,000. The techniques described in this report would be particularly useful to transportation planners at the regional and local levels concerned with the planning and operation of transportation facilities and services in small cities or urban areas, especially those that are free-standing in rural regions, and those that are extensions of large metropolitan areas.

2. BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

One of the most important pieces of information crucial for making decisions regarding transportation improvements is the horizon-year traffic volumes on the major links of a city's transportation network. It is the customary practice for most cities and counties across the country to collect traffic counts on their street system on a routine basis. This data base consisting of base year ground counts can be put to use in forecasting horizon year traffic flows. Some inexpensive techniques for forecasting travel demands have developed in recent years, using routinely collected ground counts, and socio-economic data.

This report describes and discusses inexpensive travel demand models using routinely collected ground counts. It also includes the results of a survey conducted across the State of Washington on the current practices of making travel demand forecasts in various cities and counties.

2.2 An Overview

Travel demand models using routinely collected ground counts is a comparatively recent endeavor. The development of a travel demand forecasting model based on base-year traffic ground counts was first initiated as recently as 1972 (Low, 1972). In these models, the link traffic volumes in the base year are used for calibration. The horizon year's socio-economic variables and the base-year calibrated model are then used to predict the traffic volumes in selected links of the network in the horizon year (Figure 1).

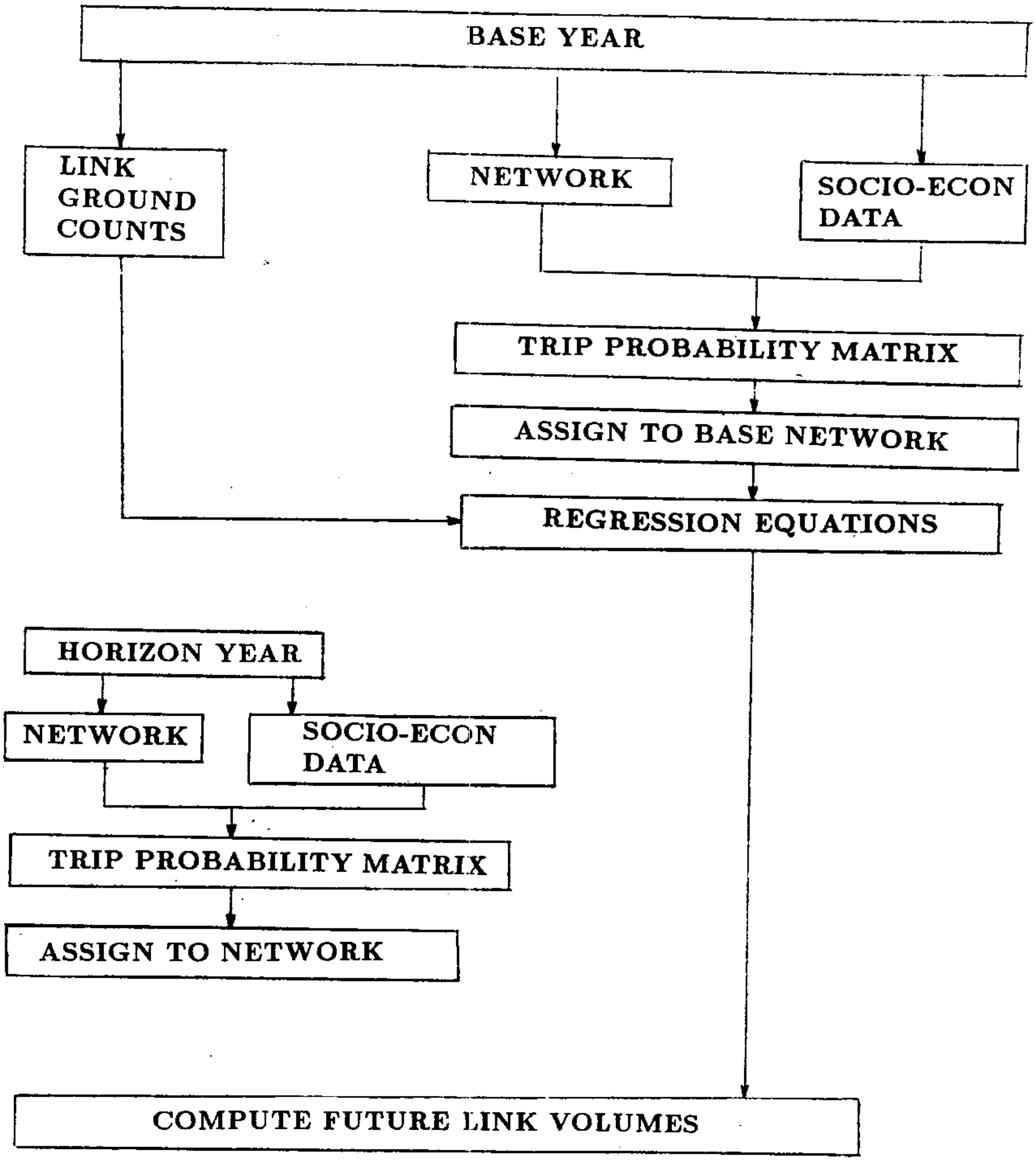

Figure 1. Flow Chart of a Demand Model Based on Traffic Ground Counts

These models are generally Internal Volume Forecasting (IVF) procedures that estimate all-purpose trips. Hogberg (1976), Smith and McFarlane (1978), Willumsen (1981), and Neumann et al. (1983) developed, refined, and applied Low's basic technique in various cities across the country with fairly good results. Willumsen has suggested that by resolving his model's theoretical limitations, it could be recommended for use in small- and medium-sized cities, because it offers three attractive features : a) simplicity of use, b) computational efficiency, and c) low cost.

Khisty (1984) applied a variation of Low's technique to the City of Spokane in Washington State with reasonably good results. Planners in European countries have also evolved demand models based on traffic counts. A few of these techniques are briefly described in a report of the Organization for Economic Cooperation and Development (OECD), Paris (1974). The Transportation Research Board has assembled and modified a number of quick-response techniques which have been developed over the years for use by the transportation planners, as viable alternatives to the more costly, data-intensive, computer models in two National Cooperative Highway Research Program (NCHRP) Reports, Nos. 186 and 187 (Sosslau et al., 1978a, 1978b). These reports include some models with the characteristics of inexpensiveness and use of minimum input requirements. In some cases, the use of routinely collected traffic ground counts as input data is also described. However, no synthesis of techniques has yet been done that aims at budgetary and time limitations for specifically small- and medium-sized communities, in addition to simplicity and operational efficiency in application. In fact, it is obvious that research is yet to be carried out to develop and operationalize techniques that will be widely acceptable for use by the small- and medium-sized communities in accordance with their needs and capabilities.

2.3 Literature Survey

The following is a brief review of thirteen techniques currently cited in the literature on travel demand forecasting. Comments are also made at the end of each technique critiqueing its applicability. The common criterion used in selecting a technique/model/procedure for review is that it makes use of routinely collected ground counts.

2.3.1 Low's New Approach to Transportation Systems Modeling

In this model, traffic volumes are determined one link at a time, primarily as a function of the relative probability that one link will be used in preference to another. Interzonal trip probabilities are assigned to the network, using traffic assignment procedures, to produce estimated trip probabilities on a link by link basis. Regression equations are then developed to relate the counted link volumes to assigned trip probabilities and other link characteristics. These equations are then used to estimate link volumes under other conditions, (such as for the horizon year), after determining and assigning new interzonal trip probabilities to reflect those conditions. This approach can be used to produce traffic volume forecasts when funds or the input data required for the traditional techniques are lacking. The procedure has been applied as a volume forecasting model for a metropolitan area in West Virginia. Hogberg (1976) as well as Smith and McFarlane (1978) evaluated the model by applying it to various small urban areas.

Some theoretical limitations have been pointed out in Low's model. In contrast to the conventional Urban Transportation Demand (UTD) models, it, in general, does not exhibit model stability over time because of incorrect specifications. One serious mis-specification is in representing trip productions and attractions by production and attraction *characteristics*. The result is that the changes in the trip-making propensity of the study area population over time are not included in the model. For example, the population of an urban area could remain stable over time, but the number of trips could increase dramatically because of increases in, say, auto ownership.

2.3.2 FHWA's Travel Simulation Procedure for Small Cities

The simulation procedure essentially has the same components as that of the conventional Transportation Planning Process, namely, trip generation, distribution and assignment. Modal choice is not considered since the role of mass transit is relatively minor in most small urban areas. The basis of the approach is the borrowing of information and experiences from other studies to develop trip generation and trip distribution models. By borrowing travel relationships, the home interview survey and much of the data editing and analyses are eliminated. This elimination results both in reduced costs and in great time savings. Small cities are defined as those having less than 100,000 population.

This procedure is significantly different from FHWA's later development of the Quick Response System (QRS) procedure. Unlike the QRS procedure, this procedure makes use of readily available traffic ground counts. The process begins by collecting standard socioeconomic and traffic count data. An internal O-D survey may be eliminated. A highway network and zones are selected and coded. Trip generation relationships (cross classification trip rates or equations) are selected from other studies in cities of similar size and similar characteristics. Productions and attractions for each trip purpose by zone are computed. These results are checked for reasonableness by the use of selected control zones, comparison of estimated Vehicle-Miles of Travel (VMT) with counted VMT, and comparison of trip rates per Dwelling Unit (DU) and per capita to other similar studies. The productions and attractions are distributed by purpose using the gravity model and friction factors derived from other transportation studies. The resulting trip length frequencies for each trip purpose are checked for reasonableness by comparison to the frequency curves from similar urban areas. The trip assignment is then made to the existing network. Gross checks and fine tuning are done and the model is adjusted accordingly.

Several small urban areas have successfully used the approach achieving satisfactory reproduction of travel patterns. With reasonable care being taken in the selection of information developed by other studies and with appropriate validity checks and adjustments, the procedure should produce results which are valid enough to be used in making decisions regarding future transportation plans and for evaluation of the current system adequacy. Experienced transportation planning personnel and data analysts are needed to apply the method. Standard socioeconomic data, traffic counts (standard cordon, Central Business District cordon, screenline crossings, etc.), highway network details as well as a comprehensive knowledge of models, procedures and results of similar transportation studies, and the use of FHWA Urban Transportation Planning (UTP) computer program are needed.

The merits of the procedure lie in the large saving in cost, time, and effort, and in the fact that the internal survey is eliminated and data editing and analysis is minimal.

The limitations, however, include dependence on other transportation studies of similar dimensions, which may be difficult to come by. Inaccuracies from other relationships may be carried over. On the face of what has been stated here, this procedure is not as simple and efficient as it sounds. The saving in time and money lies in transferring rates from other studies.

2.3.3 Grecco et al.'s Transportation Planning for Small Urban Areas

The methodology deals with the estimation of travel demand in urban areas with a population 50,000 or less. Simplified transportation planning techniques are used that make use of synthetic or borrowed data to analyze small area networks, transit demand, corridor and localized traffic impacts. Techniques are customized to suit local needs. The network simulation procedure is used in applying simplifications to portions of the conventional Urban Transportation Planning (UTP) process. Basically, synthetic and borrowed household category models are utilized. For trip generation, production and attraction, rates are developed from a small home interview survey for home-based work, home-based other and nonhome-based purposes. Trip distribution consists of applying the gravity model with synthetic friction factor curves. Modal split is also conducted. Corridor analysis is based on a growth factor technique and analyzes internal and external traffic separately. Both the capacity of the available thoroughfares and future traffic volumes are required in order to determine system deficiencies. For localized traffic impacts, alternative factors are applied to trips generated from different land uses – these factors represent the decay of trips as a function of distance from the special generator. After distributing trips, manual trip assignments are made to determine additional traffic loading. By incorporating directional splits, intersection turning movements can also be estimated.

The planning techniques have been applied and then evaluated for a limited sample of cities (varying in population from 11,000 to 55,000). Generally, the results were less accurate than the conventional methods, but actual applications were quite cost-effective. The corridor technique provided estimates of the external traffic with errors usually within 2,000 vehicles per day. The application of the techniques and interpretation of the results are heavily dependent upon an experienced transportation planner's knowledge of the urban area and the exercising of professional judgement in an adhoc or opportunistic fashion. Most of the techniques can be applied manually. The network simulation technique, however, may require some simple computer analysis. The techniques are simple, quick and cost-effective, but require extensive knowledge of the study area and transportation engineering experience. Due to simplfication of the procedures, accuracies in the final results are compromised.

2.3.4 DeLeuw-Cather's Simplified Procedure for Urban Transportation Planning

It consists essentially of working within a closed system and apportioning the important elements of travel within that system in accordance with information, experience and judgement developed from previous transportation studies. Nomographs are used for trip generation, trip distribution and modal split. Traffic assignment is made by inspection of selected checkpoints in the transportation network. A continuing planning process is used. The procedure makes use of information collected from travel data of different cities in order to reduce the requirements for collection, manipulation and interpretation quantity of new travel data. Computerized analysis is almost eliminated. The analysis is conducted manually, and it emphasizes correctness, rather than precision. The procedure begins with the organization of a multidisciplinary team appropriate to the particular study area and to the purpose of the study. Maps and listings of the area are made that describe the parts of the area in three classifications : major employment areas, residential communities, and major activity centers. Next, important permanent features of the city and long-range future possibilities for land use development and transportation routes are identified. A framework design of major transportation corridors and other permanent land uses is then established. From assessment of the economic potential for development sites, alternative 20-year tentative future arrangements of land development and compatible future transportation networks are prepared and represented on maps. One alternative is selected and a forecast of future travel is made according to trip-end generation, trip distribution and travel assignment. Only maps and nomographs based on data from previous surveys are mostly used. Other alternatives are similarly explored.

The procedure has been developed through comprehensive research of travel data from more than 60 cities and is capable of producing results that are more appropriate to the real purpose of transportation planning – that of deciding the locations, and types of designs of urban transportation improvements. Information required for its application is the existing population, employment and land use charateristics. More emphasis is given to other charateristics of qualitative nature. Good quality maps of the study area and a multidisciplinary staff team are required. Simple graphical procedures and hand-held calculators eliminate the use of the computer.

The method, although simple, can be used either for detailed studies or for quick preliminary reviews. It does not require extensive O-D surveys or complex techniques and computers for analysis, although computers can be used to reduce the amount of work. It produces results at each step of the planning process which are useful and easily understood. It can be sufficiently accurate in small cities with a population of less than 50,000. The limitations of the procedure lie in the fact that it requires experienced, multidisciplinary staff and is not accurate enough for a large complicated comprehensive transportation network analysis. It has been recommended that it should not be applied independently, but only as a preliminary phase to the conventional transportation study if comprehensive planning is being undertaken. This point is debatable.

2.3.5 Schneider's Direct Traffic Estimation Method

This method is based on the premise that the traffic volume at a point on a network is dependent upon the trip generating potential of the surrounding area and the access of the point in question. Trip distribution and assignment are handled as a single process, and no records are kept of zone to zone flows. Traffic estimates can be made for a single link at a time, for a group of links, or for an entire network. The models depend heavily on symmetry, and so is limited to treatment of two-way links and balanced (two-way) flows. The model is comparable to the traditional methods, but significant saving in time and cost is obtainable for small areas. Experienced transportation planners and computer analysts, coded network, travel cost, time, distance, trip ends by grids, and a definition of a region on a grid basis are needed for its operation. It uses trip end density instead of the O-D matrix.

2.3.6 Schneider-Scott's Direct Assignment Splitter

It is a macro, direct assignment network model. Typical input data include regional area, total vehicles-miles of travel (VMT), number of twenty-four hour vehicular trips, miles, lanes, speed limits by facility type, and interchange spacing. The method uses volume formulas to compute VMT by facility type as a function of trip end densities, trip lengths and spacings. It needs transportation planners, and about 1/2 to 1 day for data preparation and runs. It differs from the conventional traffic assignment models in that its approach is less cumbersome.

The model assumes a multiple grid road system superimposed on an unlimited square area with uniformly distributed trip ends. There are three types of facilities : freeways, surface arterials, and locals. These form a system of interconnecting grids where locals connect with surface arterials at every intersections in the system, and surface arterials connect with freeways where the two cross, but there are no connections between locals and freeways. It is further assumed that the daily volume of traffic is same for every link of a particular functional class and that the rate of change of the number of trips of a given trip length to trip length is a negative exponential function. Also, it is assumed that there are probabilities associated with turning at connections between street systems, and that local street volume is independent of expressway spacing. Based on these assumptions, the model calculates turn probabilities between lower and higher type facilities. Using these and facility volume equations, the daily volume of traffic on links are determined for the three systems. These predicted volumes are used to find the implied speed by speed-v/c (volume/capacity) functions. If this speed is not the same as the speeds used to find the volumes, the new speeds are used to find the new volumes. This process is repeated until speeds and volumes are brought into equilibrium.

The method is fast, no network coding is needed, and policies can be analyzed with minimal input. It has been extensively tested with results within ±3% of observed splits. But, the assumptions made do not reflect reality in the model. It yields good results only for dense areas.

2.3.7 Schneider's Direct Assignment Approach

The method is the forerunner of Schneider's other two methods (described above) and was developed as a short-cut method which could be applied in estimating volumes on a street system. This is a direct assignment manual method. It determines volume by facility types using volume formulas and tables. Given input data, results are obtained instantaneously. No computer is needed. Trip end density, average trip length, and facility spacings are input data. Several assumptions are made in the development of the formulas based upon the relationship between traffic volumes on the various levels of facility. The basic assumption is that the region for which trip estimates are made is very large, and the rate of trip origins per day per square mile is the same everywhere in this region. Also, the local, arterial and expressway networks each forms a uniform grid : expressways connect with arterials (but not with locals) at every intersection of the two, and arterials connect with locals at every intersection. Additionally, all trips originate and terminate on the local system and that the daily volume of traffic is the same on every link of a particular network.

The method is easy to understand, and its application has a rapid turn around time. It is an extremely useful tool which may be used as an aid in the development of alternative systems and in the pre-evaluation of alternative density patterns. But, the results are not vary accurate, and not applicable for detailed work. Its inaccuracies arise from several weaknesses and problems in the analytic framework.

2.3.8 MacKinder's Simple Transportation Planning Package

This is a single computer program to carry out the network building, trip distribution, modal split and assignment phases of a transportation model. The function of transportation models in forecasting travel demand is described with particular reference to the two main inputs : planning variables and transport vehicle descriptions, and the structure is illustrated by means of a block diagram. The model is for two types of travel : car and public transport, and two types of persons : car owners and non-car owners.

It is basically a few standard models chained together to handle small networks (98 zones, 200 nodes, 600 links, 6 trip purposes, etc.). Data requirement is the same as for standard Urban Transport Planning models. It requires simple programs to get speedy low-cost runs.

The most likely applications of this model would be in small town studies, in structure plans, initial shifting of broad strategies, and as a training tool. There are some limitations, however, to maximum number of zones, nodes and links.

2.3.9 Overgaard's Simplified Traffic Model

The method starts with determination of external traffic by roadside interviews on streets entering the city. Then, the car density in each zone is determined from total number of inhabitants and cars in the city, and borrowed information from other cities regarding the number of cars per 1,000 inhabitants. The total traffic generation for each zone is estimated from an equation involving the number of work places, the number of inhabitants, and the percentage of one-family houses as independent variables. Travel laws with different exponential powers are used to determine the interzonal traffic. The external traffic matrix is then added to the internal traffic matrix for the city. The best travel law is thus selected for use. The total travel matrices (external traffic included) is then assigned to the streets according to the all-or-nothing method.

This method was applied to the City of Silkeborg, Denmark. It takes care of the variability in generation coefficients from zone to zone. It was found that for traffic volumes from 10,000 to 20,000 cars per day, the method gives about the same errors (10% to 20%) as does Low's method. For volumes below 10,000, however, it seems to give better results than Low's.

2.3.10 Jensen-Nielsen's Gravity model

This model calculates the traffic in a region. All the traffic coming from the surrounding regions are included in the calculation. The travel law involving traffic and travel distance is used with different values of the exponent in the gravity function, and finally the best exponent value is chosen. The traffic between two zones is anticipated to be proportional to population in the two zones and the distance between them. A traffic matrix is thus determined, and the speed on each street, based on counted traffic is calculated. The matrix is assigned to the streets using the all-or-nothing principle. The estimated values are then compared with the counted values. The steps are repeated until the sum of the square of the distances between them is minimized.

The method was applied to the county of Aarhus in Denmark. This method seems to give better results than Low's model for traffic volumes below 10,000. A comparison with a method based on home interviews revealed that the model gives errors up to 50 percent on some streets with traffic from 10,000 to 20,000 cars per day.

2.3.11 Neumann et al.'s Estimation of Trip Rates

The model directly estimates area-wide, all-purpose trip production rates. The methodology distributes and assigns zonal socioeconomic variables (autos, dwelling units and population) directly to the study area network. Ground counts must be reduced by internal-external and external-internal trips. The residuals, reduced ground counts are entered into a linear regression model as the dependent variables and the assigned socioeconomic variables are entered as the independent variables. The resulting regression coefficients are the estimates of the area-wide all-purpose trip production rates.

The method is sensitive to the friction factor curves used in the trip distribution step. The methodology was tested in Lynchburg, VA (1970 SMSA population 146,000) and Lexington, KY (1970 SMSA population 295,000). Estimated production rates obtained were within 96% of true rates. It produces accurate results and can be used in verifying borrowed production rates in the synthetic procedures. Since the method is sensitive to the accuracy of the friction factors utilized, a large proportion of the count stations should be located outside the Central Business Districts (CBD). In addition, data must be available on external-external and external-internal trip volumes for the city. This suggests that the methodology might find application in cities where the resources are sufficient to conduct external surveys. If a network is already available, the effort required for an analysis would involve one or two man-days, and the cost of data collection would be negligible. If a small number of housholds could be surveyed, then the method would assist in verifying the trip rates produced from the survey.

2.3.12 Khisty-AlZahrani's Inexpensive Travel Demand Model

This is an Internal Volume Forecasting (IVF) model based on Low's model. The model incorporates improvements suggested by Smith and McFarlane (1978). To eliminate the errors in Low's model, they recommended replacement of the zonal production and attraction characteristics by direct estimates of trip productions and attractions, and inclusion of origin zone accessibility in the denominator of the probability factor. The production and attraction variables and the friction factors are modified in this model as follows :

1. The production zone variable (P_i) is replaced by the number of employees residing in zone i (ER_i).
2. The attraction zone variable (A_j) is replaced by the number of employees working in zone j (EW_j).
3. The friction factor values, $F(C_{ij})$, are calculated in a manner similar to that used in trip distribution models. $F(C_{ij})$ is an indirect indicator of the cost of travel (t_{ij}) between zones i and j : $F(C_{ij}) = exp(-0.10t_{ij})$

The second theoretical limitation is avoided simply by dividing the attraction term EW_j at the destination by the total attractions ($\sum_j EW_j$) of the study area.

The model was applied to the City of Spokane, WA (1980 population 171,300). The 1970 data were used to calibrate the model. The calibrated model was used to forecast the traffic volume for the horizon year 1980. It was assumed that the major street network would not change significantly between the base year and the horizon year. The only data that are necessary for the application of the model are the two variables ER_i and EW_j for 1980 that were obtained exogeneously. These values as well as the friction factor matrix were used to obtain the horizon year trip interchange indices matrix. External-external and external-internal volumes on the links were obtained from suggestions provided in NCHRP 187.

A comparison of the model with Low's original model indicated that the model output gives somewhat better results. Also, a comparison of the observed and the estimated horizon year link volumes were made. Although the actual to estimated volumes for the horizon year ranged from 0.93 to 1.27, most volume groups were within 10% of the actual volumes.

Because network configuration and census data are generally available, the effort required to work the model for a small- or medium-sized city might involve 10-15 man-days. The model combines several conventional submodels into one process and the output in terms of traffic volumes can be statistically described and tested. The model is quick, reliable, and transparent for forecasting travel in small urban areas.

2.3.13 Bates' Derivation of Internal Trips

The procedure estimates internal trip movements for a network without interview surveys. A generalized trip generation model is based on analysis of generation characteristics of several cities (ranging from 15,000 to 85,000 in population). The method, in fact, determines gravity model travel time factors based on maximum trip length over the traffic assignment network.

The synthetic procedures were applied in several cities. Internal trip tables derived by synthetic procedures were added to external trip tables from the roadside cordon interviews, and the resulting total trip table was assigned to the network. The assigned link volumes were compared to observed volumes. The procedures appear to adequately reproduce observed conditions and after adjustment indicate system error no worse than those for traditional survey techniques. The procedure provides a quick, inexpensive method, 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. The procedures provide significant increases in staff capabilities and do not require significantly greater effort than the external-oriented bypass studies that exclude internal movements.

The model was recommended as a planning methodology in urban and suburban areas of 25,000 to 50,000 population.

Summary of the Techniques

In order to obtain comparable information regarding the techniques described in the preceeding section, the pertinent features of the techniques are summarized in Table 2.

Table 2 ,
Summary of the Techniques

Model	Year Developed	Manually Possible?	Size of Client City	Max. # of Zones	Max. # of Links	Other Inputs	Time for Execution	Technical Expertise	Where Applied
Low	1972	Yes	Variable	Variable	Variable	Socioecon., Netwk detail	Variable	Transport. Planner	Metropolitan Area in WV
FHWA	1973	Yes	Less Than 100,000	Variable	Variable	Socioecon., Network Details	Variable	Transport. Planner, Data Analyst	Several Small Urban Areas
Grecco	1975	Yes	50,000 or Less	Variable	Variable	Sample O-D Survey, LU, Socioecon.	Few Days	Transport. Planner	Not Available
DeLeuw-Cather	1969	Yes	Less Than 50,000	Variable	Variable	Socioecon. Land Use	Variable	Multidiscip. Team	Not Available
Schneider Estimation	1966	No	Variable	Variable	Variable	Netwk, Trav. Cost, Trip-Ends	Variable	Transport. Planner, Analysts	Not Available
Schneider Scott	1971	No	Variable	Variable	Variable	VMT, Trips Lanes, Etc.	1/2 to 1 Day	Transport. Planner	Not Available
Schneider Assignment	1963	Yes	Region or County Level	Variable	Variable	Trip-Ends, Lane Spacing	Variable	Transport. Planner	Not Available
Mackinder	1973	No	Small Towns	96	600	Socioecon., Traffic, LU	Variable	Planner, Comp. Anal.	Not Available
Overgarrd	1972	Yes	50,000 or Less	Variable	Variable	Population, Cars, LU	Variable	Transport. Planner	Silkeborg, Denmark
Jensen-Nielsen	1973	Yes	Region or County	Variable	Variable	Population By Zones	Variable	Transport. Planner	Aarhus, Denmark
Neumann	1983	Yes	295,000 or Less	Variable	Variable	Socioecon. DU, O-D	1 or 2 Man-days	Transport. Planner	Lexington, KY Lynchburg, VA
Khisty-AlZahrani	1984	Yes	200,000 or Less	Variable	Variable	Socioecon. Netwk, LU	1 or 2 Mandays	Transport. Planner	Spokane, WA
Bates	1974	Yes	25,000 to 50,000	Variable	Variable	Trip Length Netwk Detail	Variable	Transport. Planner	Several Cities In USA

2.4 Survey Results

Letters were written to twenty nine County and Regional Planning Councils, Conferences and Commissions in the State of Washington, as suggested by Mr. John Doyle of WSDOT, representing small- and medium-sized urban areas (population 5,000-250,000). A sample letter is placed in Appendix A. It requested response to questions based on the use of traffic ground counts in forecasting travel demand in the cities by simplified methods/techniques. The results were disappointing. Only 33% responses were received. Seventy percent of the respondents indicated that they were not using any kind of formal procedure for forecasting travel demand. The few that responded positively indicated that

1. it was only in obtaining county-wide forecasts in urbanized areas of population over 50,000 that the sophisticated demand forecasting models are used. In most cases, the mainframe computer of WSDOT is accessed for data base and traffic modeling programs (e.g., UTPS). At the same time, some other simplified techniques such as MINUTP, QRS, IMPAX, TMODEL are used in small-scale projects and for site-specific purposes. Small cities (population less than 50,000) depend on the respective county/regional planning council to get their forecasts as and when needed.

2. traffic ground counts are recorded in most urbanized areas or accessed from WSDOT. While they are not used directly as input in a travel demand model, they are invariably used to check and validate forecasts performed by conventional procedures or with the help of traffic growth factors.

3. most of the planning councils while using the conventional methods feel that simplified, easy-to-understand and inexpensive travel demand techniques would be useful, if available. They mention that the lack of staff, expertise and budget often prevents them from making site-specific forecasts.

4. communities with a population of under 5,000 are satisfied with heuristic methods that they are currently utilizing.

2.5 Summary and Conclusions

Thirteen travel demand techniques are described in this chapter, which make use of routinely collected ground counts and a variety of socioeconomic data to forecast horizon year link volumes.

There are several commonalities among these methods, but the individual differences are unique. It appears that researchers have been working on model simplification for at least a decade to be able to come up with a quick forecasting technique. Contacts with selected MPOs, COGs, Planning Commissions across the State of Washington reveal that such techniques will be useful, when available, to small- and medium-sized cities considering their staff, expertise and budget limitation. Currently, these cities have to depend on WSDOT county-wide forecasts obtained through conventional sophisticated methods or the use of unproven heuristic methods.

3. SELECTION AND APPLICATION OF TECHNIQUES

3.1 Selection of Specific Techniques for Application

All of the thirteen techniques reviewed in the preceeding section are legitimate contenders for possible application to a small city. On the surface, some of the techniques show remarkable similarities, although on deeper scrutiny one discovers subtle differences. Also, the possibility exists for amalgamating the stronger elements in each model and evolving one or two models for general use. With this objective in mind it was considered profitable to apply a set of general criteria to aid in the selection process. These are as follows :

1. Data required
2. Transparency of method (no black-box effects)
3. Simplicity in application
4. Ease of updating
5. Use of ground counts
6. Use of large memory computers
7. Use of hand-held calculators/personal computers
8. Cost of running the model
9. Time required
10. Expertise needed.

Each of the techniques is matched against these criteria and 'scores' are given for each criterion (See Table 3). Most of the scores assigned to the techniques were derived from a review of the appropriate literature. Also, where possible, planners acquainted with a particular technique were called upon to provide necessary input. Since the top scorers are to be selected for application in a common setting the data base available in a typical small urban areas will have to be critically considered. The thirteen techniques described before are as follows :

1. Low's Model

2. FHWA's Travel Simulation Procedure
3. Grecco's Technique
4. DeLeuw-Cather Procedure
5. Schneider's Method
6. Schneider-Scott Model
7. Schneider's Assignment Approach
8. Mackinder's Method
9. Overgaard's Model
10. Jensen-Nielsen Model
11. Neumann's Technique
12. Khisty-AlZahrani Model
13. Bate's Technique.

Table 3
Applicability Scores of the Methods

Range : 0 (bad) → 5 (good)

	Criteria									
	Data Required	Transparency	Simplicity	Ease of Updating	Use of Counts	Computer Required	Calculators/PC	Cost of Running	Time Required	Expertise Needed	
Model	1	2	3	4	5	6	7	8	9	10	Total
Low	4	1	3	0	5	4	4	5	5	4	39
FHWA	4	4	4	4	2	3	2	3	4	3	33
Grecco	3	3	3	2	2	2	2	3	3	1	24
DeLeuw-Cather	4	2	3	2	3	5	4	3	3	2	31
Schneider Estimation	3	2	2	2	3	1	0	3	4	1	21
Schneider-Scott	4	3	3	3	3	5	5	3	2	0	31
Schneider Assignment	4	2	3	2	2	5	5	4	3	2	32
Mackinder	2	2	4	3	1	2	2	3	3	2	24
Overgaard	2	2	3	3	3	3	3	3	2	2	26
Jensen-Nielsen	2	3	3	3	3	3	3	3	2	1	26
Neumann	4	4	2	3	4	3	3	4	4	3	34
Khisty-AlZahrani	4	4	3	4	5	4	4	5	4	3	40
Bates	3	2	3	3	4	4	4	3	2	2	30

An important conclusion that surfaces from this preliminary evaluation is that a few of the techniques appear worthy of further investigation. Four of the techniques selected from this qualitative evaluation for application in a common setting are :

1. Low's Model
2. FHWA's Travel Simulation Procedure
3. Neumann's Technique, and
4. Khisty-AlZahrani Model.

3.2 Application of Selected Techniques in a Common Setting

Four of the thirteen methods examined in the previous section emerged as the most promising techniques for use in small urban areas. They are now applied in a common setting in order to demonstrate their application procedures, and also to determine their relative merits and ease of application. A demonstration city (with a hypothetical network) is used as the common setting for this purpose. This exercise provides details on how the techniques work, not how well they work. The minimum data available to the city engineer for use in the travel demand estimation models are assumed. For the base year the following data are available :

1. Transportation network showing the zones of origin and destination of trips along with travel times on the links.
2. Traffic counts on the links.
3. Population of each of the zones.
4. Employment data at each of the zones.

The O-D travel times are estimated from the link travel times by using the all-or-nothing traffic assignment based on the shortest path of travel between each of the O-D pairs. Also, the information regarding which O-D pairs are using each of the network links is developed from the traffic assignment. In the case of small networks with, say 50 links or less, it would be most convenient to work out the shortest paths manually. However, for larger networks one could use any standard software that calculates minimum time paths for a transportation network, on a personal computer.

It is assumed that only a fraction of the link counts are available for use, although the link volumes on all the links may need to be forecasted for the horizon year. The extent of external-external and external-internal trips should be assessed by means of a roadside interview as indicated in NCHRP Report 187 (Sosslau et al., 1978b).

For application of the methods, a set of horizon year traffic and socioeconomic data for the city is also developed. Figure 2 and Tables 4 through 9 show the network data and traffic and socioeconomic data for the city, respectively.

Table 4
Base Year Zonal Population and Employment

Zone	Population	Employment
1	20,200	10,000
2	3,700	500
3	18100	4000
4	9900	2500
5	17300	6500
	$\sum = 69200$	$\sum = 23500$

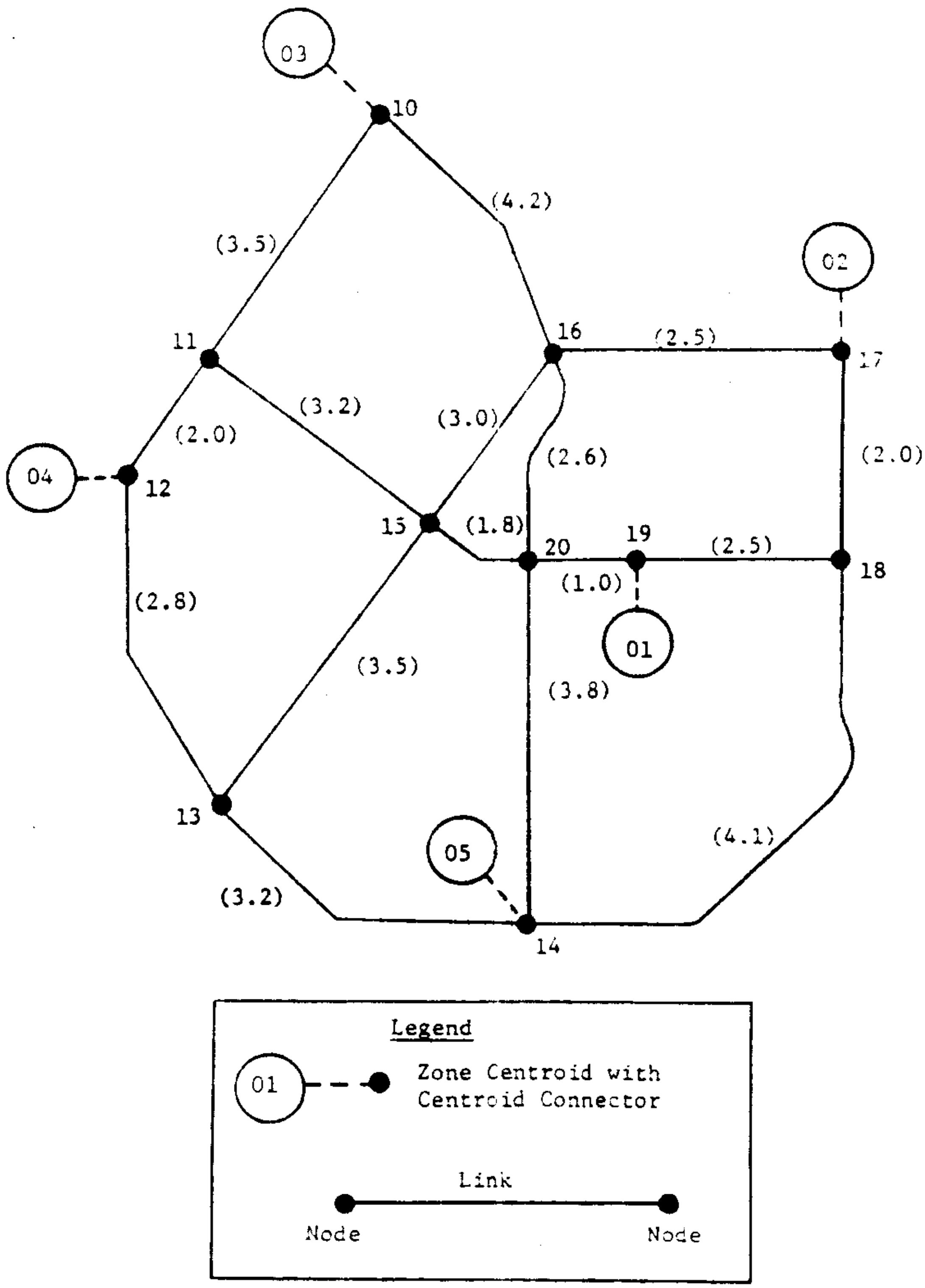

Figure 2. Transportation Network Data of a Demonstration City

Table 5
Horizon Year Zonal Population and Employment

Zone	Population	Employment
1	20000	9000
2	5000	800
3	17300	4000
4	12200	3500
5	20400	8700
	$\sum = 74900$	$\sum = 26000$

Table 6
O-D Travel Times in Minutes

O D	1	2	3	4	5
1	1	5	8	8	5
2	5	1	7	11	6
3	8	7	1	6	11
4	8	11	6	1	6
5	5	6	11	6	1

Table 7
Base Year Volumes and O-Ds on the Links

Link(Node-Node)	Travel Time	Volume	O-D Pairs
1(10-11)	3.5 min.	2190	3-4,4-3
2(10-16)	4.2	4730	1-3,3-1,2-3, 3-2,3-5,5-3
3(11-12)	2.0	3300	1-4,4-1,2-4, 4-2,3-4,4-3
4(11-15)	3.2	1910	1-4,4-1,2-4,4-2
5(12-13)	2.8	1500	4-5,5-4
6(13-15)	3.5	0	-
7(13-14)	3.2	1500	4-5,5-4
8(14-18)	4.1	500	2-5,5-2
9(14-20)	3.8	9500	1-5,5-1,3-5,5-3
10(15-16)	3.0	110	2-4,4-2
11(15-20)	1.8	1800	1-4,4-1
12(16-17)	2.5	380	2-3,3-2,2-4,4-2
13(16-20)	2.6	4460	1-3,3-1,3-5,5-3
14(17-18)	2.0	1260	1-2,2-1,2-5,5-2
15(18-19)	2.5	760	1-2,2-1
16(19-20)	1.0	12160	1-3,3-1,1-4,4-1,1-5, 5-1

3.2.1 Khisty-AlZahrani Model

A step-by-step procedure is shown below (see flow chart in Appendix B):

1. Number of workers residing (labor force) in and number of employment available at each zone are calculated :

Assuming that the labor force participation rate or the number of persons depending on one worker approximates to 3 for the entire region, the number of workers living in each zone is roughly calculated from the zonal population data. The following table shows the result of these calculations alongwith the zonal employment data :

Table 8
Zonal Workers (Labor Force) and Employment Data, Base Yr.

Zone	Workers Living	Employment
1	7000	10000
2	1200	500
3	6000	4000
4	3300	2500
5	6000	6500
	$\sum = 23500$	$\sum = 23500$

Similarly, these data for the horizon year are also calculated from horizon year population data and shown below :

Table 9
Zonal Workers (Labor Force) and Employment Data, Horizon Yr.

Zone	Workers Living	Employment
1	6000	9000
2	2000	800
3	5500	4000
4	4500	3500
5	8000	8700
	$\sum = 26000$	$\sum = 26000$

2. Trip Interchange Index I_{ij} calculation :

$$I_{ij} = ER_i \frac{EW_j}{\sum EW_j} F(C_{ij})$$

where,

ER_i = No. of workers residing in zone i

EW_j = No. of employment available at zone j

$F(C_{ij}) = e^{-0.1t_{ij}}$ = Friction factor between zones i and j

t_{ij} = Travel time between zones i and j

I_{ij}'s are calculated for all the interchanges for both the base year and the horizon year and are shown below :

$$\frac{\left(\frac{EW_j}{\sum EW_j}\right)\text{horiz.}}{\frac{j}{\left(\frac{EW_j}{\sum EW_j}\right)\text{base}}}$$

	O \ D	.426 1 .346	.021 2 .030	.170 3 .154	.106 4 .135	.277 5 .335
	6000 1 7000		109.8 .61 89.67	415.8 .45 535.5	364.5 .45 333.9	1226.1 .61 1182.79
	2000 2 1200	422.12 .61 309.64		154.0 .50 102.0	89.1 .33 41.98	368.5 .55 182.82
(ER_i)horiz. i (ER_i)base	5500 3 6000	856.35 .45 1142.1	82.5 .50 63.0	I_{ij}horiz. $F(C_{ij})$ I_{ij} base	408.38 .55 349.8	608.03 .33 548.46
	4500 4 3300	700.65 .45 628.16	44.35 .33 22.87	381.15 .55 308.55		829.13 .55 502.76
	8000 5 6000	1688.48 .61 1548.18	132.0 .55 69.3	406.56 .33 336.6	594.0 .55 349.8	

3. Assignment of the I_{ij}'s :

The all-or-nothing assignment is used to calculate the sum of the $P_{ij}^{kl} I_{ij}$'s for each link. These values and the link counts available for the 7 links are tabulated below. It is assumed that traffic counts for only these links are available for use in the model. P_{ij}^{kl} values are equal to either 1 (if the trip interchange is found on link k), or zero (if it is not).

Link	$\sum\sum P_{ij}^{kl} I_{ij}$	Link Counts
1	658.35	2190
2	2727.66	4730
3	1685.26	3300
4	1026.91	1910
9	3616.03	9500
13	2562.66	4460
16	5370.63	12160

4. Regression Analysis :

Using link counts as dependent variable and $\sum\sum P_{ij}^{kl} I_{ij}$ as independent variable in the regression, the following equation is developed for use in the horizon year :

$$V^{kl} = -376.79 + 2.3169 \sum\sum P_{ij}^{kl} I_{ij}$$

$$(R^2 = 0.9329 \qquad t_0 = 8.34 > t_{.005} = 4.032)$$

5. Horizon year $\sum\sum P_{ij}^{kl} I_{ij}$ and forecasts for link volumes :

The horizon year I_{ij}'s are assigned to the network and the values of the terms $\sum\sum P_{ij}^{kl} I_{ij}$ are calculated for all the links in the horizon year. These values are used in the regression equation developed from the base year data to calculate the horizon year link volumes. The results are shown in the following table :

Link	$\sum I_{ij}$	Link Volume
1	789.53	2116
2	2523.24	5269
3	1988.33	4297
4	1198.8	2860
5	1423.13	3269
6	-	-
7	1423.13	3269
8	500.5	1590
9	3929.17	7827
10	133.65	923
11	1065.15	2617
12	370.15	1353
13	2286.74	4839
14	1032.42	2558
15	531.3	1646
16	5251.88	10233

3.2.2 Low's Model

A step-by-step procedure is shown below (see flow chart in Appendix B):

1. Estimating trip productions and attractions for the zones :

   For work trips,

   Zonal productions, P_i = No. of workers living in zone i

   Zonal attractions A_j = No. of employments located at zone j.

2. f_{ij} (friction factors between zones i and j) calculations :

$$f_{ij} = P_i A_j t_{ij}^{-2}$$

where t_{ij} is the travel time between zones i and j. For O-D pair (1-2), base year,

$$f_{ij} = 7,000 \times 500 \times 5^{-2} = 140 \times 10^3$$

Results of these calculations are shown in the following table for both base year and the horizon year :

(A_j)horiz.
j
(A_j)base

	O\D	9000 1 10000	800 2 500	4000 3 4000	3500 4 2500	8700 5 6500
	6000 1 7000		.04 192 140	.016 384 448	.016 336 280	.04 2088 1820
	2000 2 1200	.04 720 480		.02 160 96	.008 56 24	.028 487 218
(P_i)horiz. i (P_i)base	5500 3 6000	.016 792 960	.02 88 60	t_{ij}^{-2} (f_{ij})horiz $(f_{ij}$base	.028 539 420	.008 383 312
	4500 4 3300	.016 648 528	.008 29 13	.028 504 370		.028 1096 601
	8000 5 6000	.04 2880 2400	.028 179 84	.008 256 192	.028 784 420	

3. Assignment of the f_{ij}'s to the network by all-or-nothing technique :

The assigned f_{ij} values are shown for both the base year and the horizon year as follows :

Link	$\sum\sum P_{ij}^{kl} f_{ij}$ base yr.	$\sum\sum P_{ij}^{kl} f_{ij}$ horiz. yr
1	790	1043
2	2068	2063
3	1635	2112
4	845	1069
5		1880
6		
7		1880
8		666
9	4724	5607
10		85
11		984
12		333
13	1912	1815
14		1578
15		912
16	6436	7128

4. Regression analysis :

Using the 7 available link counts the equation is developed as follows :

$$V^{kl} = 680.478 + 1.8189 \sum\sum P_{ij}^{kl} f_{ij}$$

$$(R^2 = 0.994 \qquad t_0 = 29.96 > t_{.005} = 4.032)$$

5. Estimation of the horizon year link volumes :

The regression equation developed and the assigned horizon year f_{ij} values are used to estimate horizon year link volumes. These are as follows :

Link	Volume
1	2578
2	4433
3	4522
4	2625
5	4100
6	0
7	4100
8	1891
9	10879
10	835
11	2470
12	1286
13	3982
14	3550
15	2339
16	13646

3.2.3 Neumann's Technique

A step-by-step procedure is shown below (see flow chart in Appendix B):

1. Assignment of socioeconomic variables directly to the network :

   The socioeconomic variable available for application here is zonal population. The Gravity model is used to distribute the variable. The zonal population and employment (as attraction) for base year are used for this purpose. The friction factors for the model are borrowed from NCHRP 187 and are listed as follows :

O-D travel time	Friction factor
1	30
5	8
6	7
7	5
8	3
11	2

Using the travel time matrix the Gravity model is applied to distribute the socioeconomic variable. The distribution is shown as follows :

O\D	1	2	3	4	5
1	16138	215	646	403	2797
2	1794	336	448	112	1020
3	2828	236	11313	1650	1226
4	1655	55	1544	4136	2509
5	4553	199	455	996	11097

Assignment of this table gives the link totals for the socioeconomic variable (population). The available 7 link counts are used as dependent variable while the corresponding link totals for population are used as independent variable for regression analysis. The data as well as the regression equation are shown as follows :

Link	Link Counts	Link Totals
1	2190	3194
2	4730	5837
3	3300	5419
4	1910	2225
9	9500	9029
13	4460	5153
16	12160	12882

$$V^{kl} = -1085.6 + 1.05 \sum \sum P^{kl} X_p^{kl}$$

$$(R^2 = 0.961 \qquad t_0 = 11.07 > t_{.005} = 4.032)$$

where X_p^{kl} is the contribution of socioeconomic variable p to link $(k-l)$, and P^{kl} is either 1 (if link is contributed by p) or 0 (otherwise). Therefore, the areawide trip rate = 1.05 trips per person.

2. Socioeconomic variable for the horizon year :

Similarly, the horizon year zonal population and employment are used to distribute the socioeconomic variable in the horizon year. The same set of friction factors are used in the Gravity model. The results are shown below :

O\D	1	2	3	4	5
1	1453	347	650	570	3777
2	1958	653	545	190	1655
3	2422	359	10761	2198	1560
4	1480	87	1534	5758	3340
5	3958	309	441	1346	14349

When the socioeconomic variable is assigned to the network it gives the link totals for the horizon year. These totals are used in the regression equation developed from the base year data to estimate the horizon year link volumes. The results are shown in the following table where the link volumes are the forecasted link counts :

Link	Link Total	Link Volume
1	3732	2833
2	5977	5190
3	6059	5276
4	2327	1358
5	4686	3835
6	-	-
7	4686	3837
8	1964	977
9	9736	9137
10	277	0
11	2050	1067
12	1181	156
13	5073	4241
14	4269	3397
15	2305	1335
16	12857	12414

3.2.4 FHWA's Travel Simulation Procedure

A step-by-step procedure is shown below (see flow chart in Appendix B):

1. Borrowing trip rates for zonal production and attraction from other studies :

   Since we are considering only the work trips and estimating the horizon year traffic volume on the links the zonal production and attractions are assumed to be equal to the number of workers living in the zone and the number of employment available at the zone, respectively. Table 5 on page 31, is available for use here. In the AM hours, zonal productions are equal to the number of zonal workers while zonal attractions are equal to the number of zonal employments. In the PM hours, zonal productions are equal to the number of zonal employments while zonal attractions are equal to the number of zonal workers.

2. The Gravity model is applied to distribute the zonal productions and attractions :

   The friction factors are borrowed from NCHRP 187 (see page 39) as in the Neumann's technique. The following trip table is consequently developed :

O\D	1	2	3	4	5
1	9982	600	707	590	3117
2	975	501	328	112	886
3	1069	280	6165	1223	762
4	797	88	1102	4003	2011
5	2764	475	451	1324	11688

3. Distributed trips are assigned to the network :

   All-or-nothing traffic assignment is used and transit availability is ignored for the small city. The assigned link volumes are calculated and shown in the following table. These are the forecasted link volumes for the horizon year.

Link	Volume
1	2325
2	3597
3	3912
4	1587
5	3335
6	0
7	3335
8	1361
9	7094
10	200
11	1387
12	808
13	2989
14	2936
15	1575
16	9044

Base Year and Horizon Year Forecasted Link Volumes

The horizon year link volumes forecasted by each of the four methods, along with the base year link volumes used to apply the methods are shown in Table 10.

Table 10
Base Year and Horizon Year Forecasted Link Volumes

Link No. (time,min.)	Base Yr. Vol. Observed	Khisty Forecasted	Low Forecasted	Neumann Forecasted	FHWA Forecasted
1 (3.5)	2190	2116	2578	2833	2325
2 (4.2)	4730	5269	4433	5190	3597
3 (2.0)	3300	4297	4522	5276	3912
4 (3.2)	1910	2860	2625	1358	1587
5 (2.8)	1500	3269	4100	3835	3335
6 (3.5)	0	0	0	0	0
7 (3.2)	1500	3269	4100	3835	3335
8 (4.1)	500	1590	1891	977	1361
9 (3.8)	9500	7827	10879	9137	7094
10(3.0)	110	923	835	0	200
11(1.8)	1800	2617	2470	1037	1387
12(2.5)	380	1353	1286	156	808
13(2.6)	4460	4839	3982	4241	2989
14(2.0)	1260	2558	3550	3397	2936
15(2.5)	760	1646	2339	1335	1575
16(1.0)	12160	10233	13646	12414	9044

3.4 Summary and Conclusions

A qualitative evaluation of each of the thirteen travel demand forecasting techniques described in Chapter 2 is made here. Four techniques are selected as the most promising for application to small- and medium-sized cities. These techniques are applied in a common setting to determine how the techniques work and their comparative advantages in application. Step-by-step procedures are shown for each of these techniques using a demonstration city road network with socioeconomic and traffic data.

The conclusions drawn from this exercise indicate that the following techniques are worthy of consideration, based on the ease of application, input requirements, use of available traffic ground counts, and resource and expertise requirements :

1. Khisty-AlZahrani's Model
2. Low's Model
3. Neumann's Technique, and
4. FHWA's Travel Simulation Procedure for Small Cities.

4. APPLICATIONS, BENEFITS AND FURTHER RESEARCH NEEDS

4.1 Application

The four techniques applied in a common setting can be easily applied to small urban areas with much advantage. In particular, the techniques would prove most applicable in the following cases :

1. Modeling small urban areas, especially those that are free-standing in rural regions, and possibly those that are extensions (population less than 50,000) of larger metropolitan areas,
2. Modeling small urban areas where qualified full-time transportation planners are not available on the planning staff, and
3. Modeling small urban areas where transportation system management analysis is needed.

4.2 Data Requirement and Implementation

To apply the techniques described in this report to a city network, the following minimum data are required :

1. Transportation network characteristics, including network configuration, link speed and operating rules : From this information, the travel times on each link on the network are to be determined. If any change in travel speed on the links is predicted for the horizon year, a separate list of travel times on the links is to be prepared to use in forecasting horizon-year link volumes.
2. Representative base-year traffic volumes from ground counts throughout the net-

work : A base-year traffic flow map depicting actual volumes (from ground counts) throughout the network can serve as the source of this information. Volumes on each major link in the network is to be calculated.

3. Volumes and patterns of trips with one or both ends outside the area under study : Information about these external trips may be gathered from an interview survey conducted on the periphery of the study area. A trip table for the external trips across the study area cordon line may be developed.

4. Patterns and intensities of land use development, in the base year as well as in the horizon year : At the very least, this must include population or dwelling units and employment by zone. Additional breakdowns, for example, population by income or automobile ownership level, or employment by industrial, commercial, or other categories, may also be recorded, if possible. The most recent census data can be used to obtain this information for the base year. For the horizon year, economic analysis and social studies conducted for the city can be used. If such studies have not been done, simple trend analysis figures could be used.

4.3 Benefits

The benefits derived from this research are as follows :

1. It provides a synthesis of techniques available to the transportation planner regarding the various techniques available and their characteristics.

2. It provides details regarding four promising techniques selected from thirteen that can be applied to small urban areas.

3. Other details regarding base-year data, time needed, etc. are provided.

In general, the use of these techniques will result in considerable savings in time, money, and man-power, besides enabling decision-makers to examine a variety of alternative plans reflecting broad policy.

4.4 Recommendations

The following recommendations are made for the application of inexpensive travel demand techniques to small urban areas :

1. Every city and urban area with population over 5,000 should define its transportation network characteristics, including network configuration, link speeds, and operating rules.

2. Every city and urban area with population over 5,000 should maintain and record historical traffic ground counts and then code them link-by-link on all arterials and major roads.

3. Cities should maintain and record volumes and patterns of external trips. These trips have one or both ends outside the urban area under study, and are important particularly for small areas since they comprise a sizable proportion of total area travel.

4. Cities should maintain and record patterns and intensities of land use development in the base year as well as in the horizon year. At the very least, this must include population or dwelling units and employment by zone. Base-year information can be obtained from recent census data. For the horizon-year information, economic analysis and social studies are necessary.

4.5 Further Research Needs

Further research should be undertaken with a view to refining the travel demand forecasting models so that simpler, quicker and more inexpensive methods are developed and more reliable results are obtainable. Research studies should aim at finding ways to derive more information from traffic counts. The results may lead to less costly models, better monitoring of travel patterns and rates of change in travel behavior, and more accurate projections.

It is also suggested that the four procedures recommended in this report be tested with actual data sets from several small communities, for obtaining an accurate comparative evaluation of the techniques.

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Appendix A

Sample Letter Sent to Selected Planning Organizations

Mr./Ms. ————————————
————Planning Council/Commission
————————————————
————————————————
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Dear

We are conducting a study sponsored by the Washington State Department of Transportation on forecasting travel demand in small- and medium- sized cities (population 5,000-250,000) with the help of inexpensive travel demand techniques using routinely collected traffic ground counts.

As a part of our research effort we are contacting some selected MPOs, COGs, and cities to collect information on their experiences with inexpensive travel demand techniques. We would appreciate it very much if you would respond to the following questions at your earliest convenience :

1. What are the current practices in the small- and medium-sized cities under your jurisdiction on predicting future travel demand on the streets of transportation network ? Do you use any simplified method/technique in order to minimize cost and time requirements in transportation planning ?

2. Do you use traffic ground counts as one of the inputs in making forecasts on travel demand ? If so, how ?

3. What is your opinion regarding current methods used in traffic planning ? Would you suggest any modifications to improve current practice ?

Thank you very much for your cooperation. We would appreciate your response by August 21, 1986. Please feel free to contact us at (509)335-6638 if you have any question.

Sincerely,

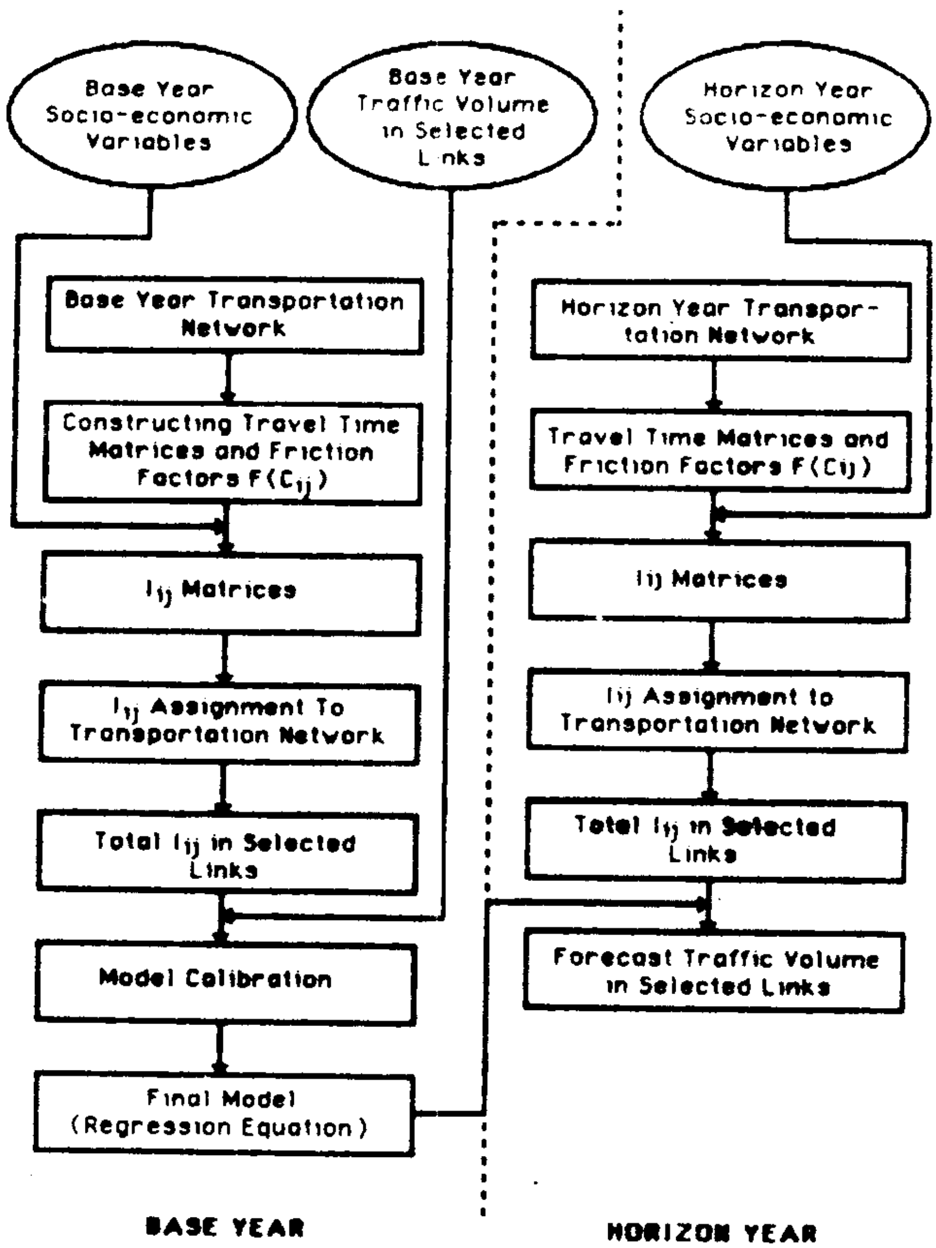
C. J. Khisty, PhD, PE
Associate Professor, Transportation

Appendix B

Flow Charts of Four Travel Forecasting Techniques

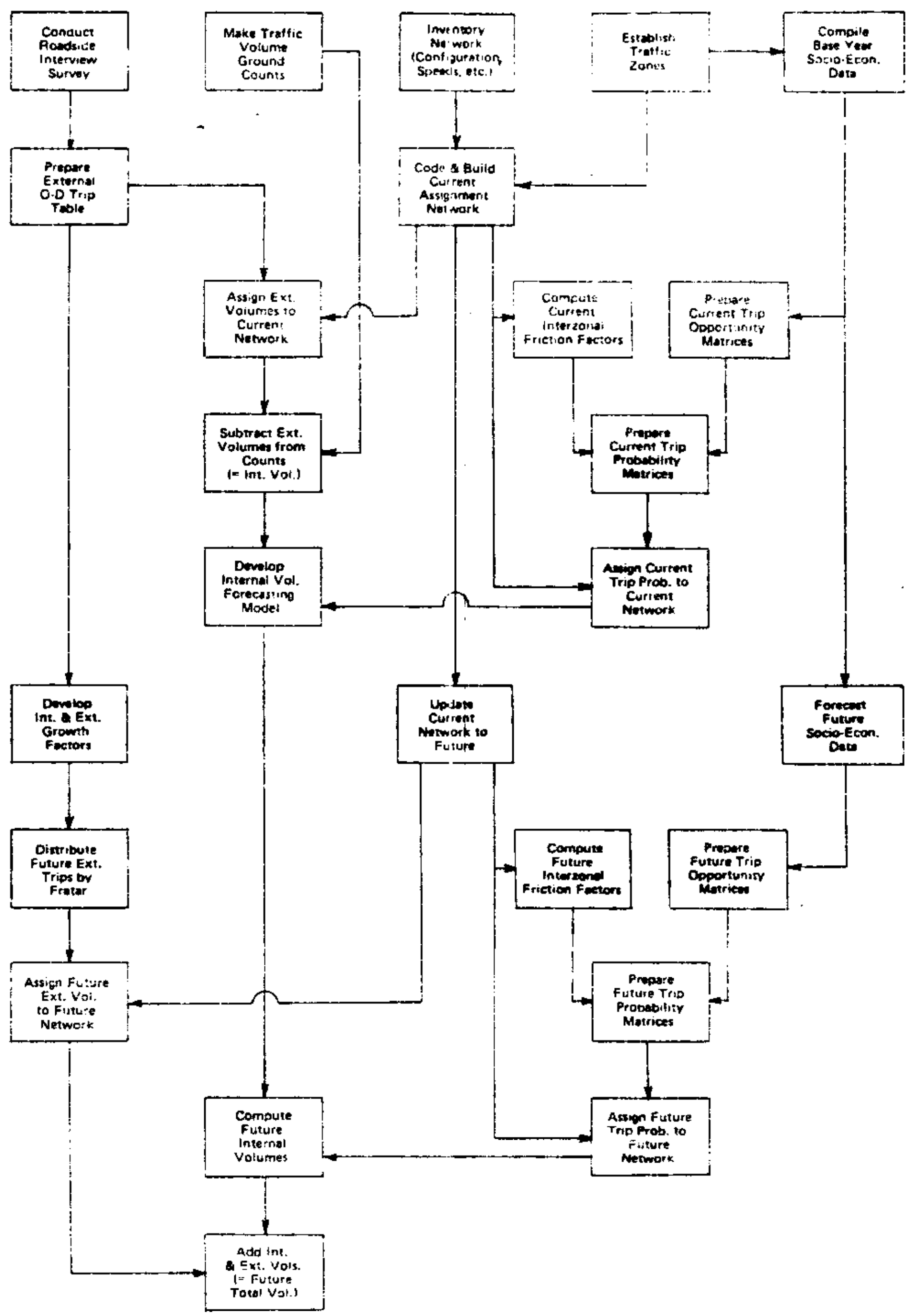
Khisty-AlZahrani Model

The following is the flow chart showing the sequence of Khisty-AlZahrani's model application (source : Khisty and AlZahrani, 1984) :



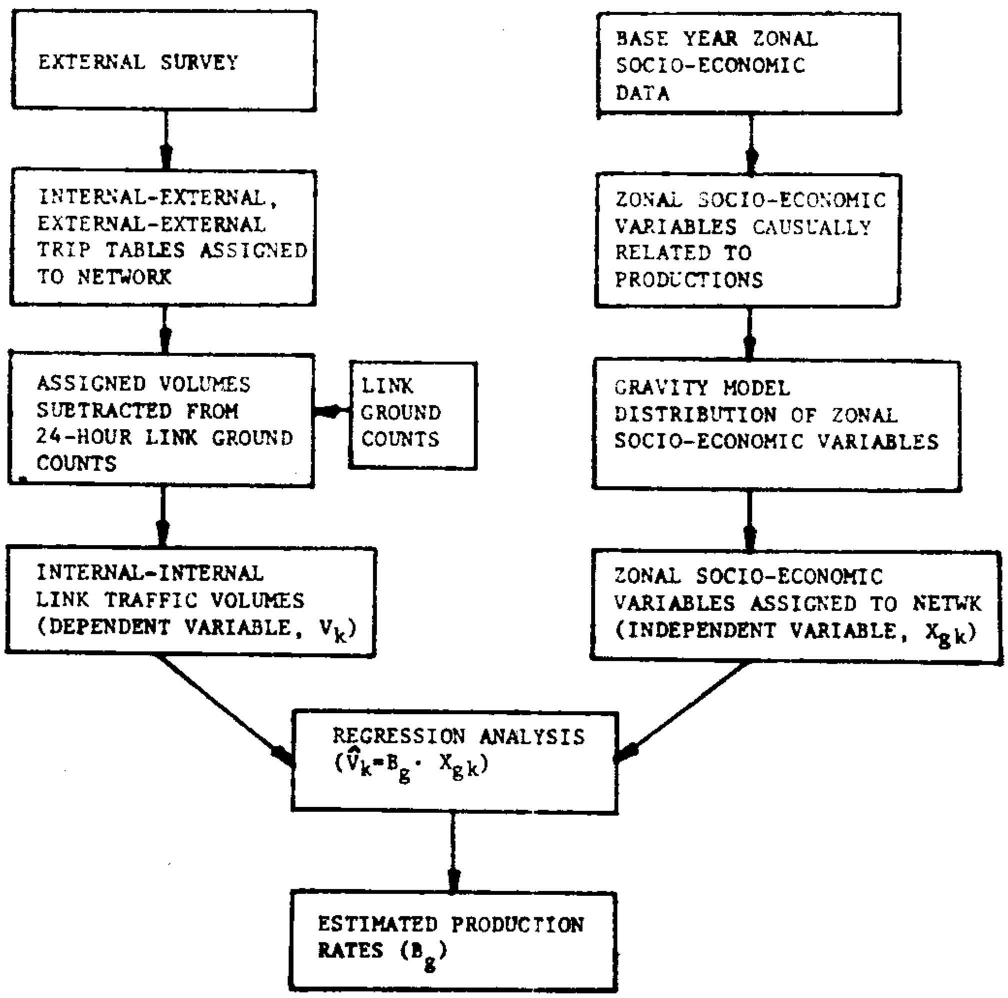
Low's Model

The following is the flow chart showing the sequence of Low's model application (source : Low, 1972) :



Neumann's Technique

The following is the flow chart showing the sequence of Neumann's technique application (source : Neumann et al., 1983) :



FHWA's Travel Simulation Procedure for Small Cities

The following is the flow chart showing the sequence of FHWA's Travel Simulation Procedure application (source : drawn as described in Sosslau et al., 1978) :