NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **120**

DATA REQUIREMENTS FOR METROPOLITAN TRANSPORTATION PLANNING

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DATA REQUIREMENTS FOR METROPOLITAN TRANSPORTATION PLANNING

CREIGHTON, HAMBURG
PLANNING CONSULTANTS
DELMAR, NEW YORK

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION
OF STATE HIGHWAY OFFICIALS IN COOPERATION
WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST
TRAFFIC MEASUREMENTS
URBAN TRANSPORTATION ADMINISTRATION
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as· it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry, its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity, it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

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The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP Report 120

Project 8-7 FY '69
ISBN 0-309-01911-7
L C Catalog Card No 78-173643

Price $4.80

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the Federal Highway Administration Individual fiscal agreements are executed annually by the Academy-Research Council, the Federal Highway Administration, and participating state highway departments, members of the American Association of State Highway Officials

This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract It has been accepted by the Highway Research Board and published in the interest of effective dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Highway Research Board
National Academy of Sciences
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FOREWORD

By Staff
Highway Research Board

Urban transportation planning studies require extensive data on travel patterns, transportation facilities, and the various socioeconomic characteristics. This research reexamines the data requirements and collection techniques in light of the evolving nature of the transportation planning process. The findings will help those involved in urban transportation studies to formulate policy on data collection. Therefore, the report will be of special interest to transportation planning engineers, and analysts and administrators connected with urban transportation studies.

Techniques for obtaining necessary data to perform urban transportation planning studies are slow and costly. In view of the evolving nature of the transportation planning process, a reexamination of data requirements, and an evaluation of the accuracy, utility, and adequacy of the data and methods employed for their collection and assembly, has been needed.

The objective of this research project was to define data requirements for both basic and continuing urban transportation studies with regard to travel, transportation facility, land use, and socioeconomic data. Existing techniques were to be reviewed and evaluated, and improved techniques for obtaining necessary data—including evaluation of data from the Census and other secondary sources—were to be recommended.

The research was intended to answer such questions as: What data should be gathered in the future? What should be the policy on data collection? How can techniques for obtaining data be improved? What potential is there for multipurpose uses of the data?

The consulting firm of Creighton, Hamburg examined in detail five representative transportation studies to reveal the kinds of data needed, to determine the costs of data collection, and to check the degree of use of the collected data. Four related kinds of planning were examined to determine the relationships of their data requirements to those of the transportation planning process. The sensitivity of the transportation planning process to data errors was studied to determine the amount of data needed, of each type. Alternative data collection techniques were examined to see whether other techniques could obtain data more efficiently and at a lower cost. An examination of sampling reliability was undertaken.

The major focus of the research work was the strategic transportation planning process, defined as the process of determining long-range investments in urban transportation facilities. The research agency makes data collection policy recommendations for a continuing transportation planning study, although these recommendations are most applicable to urban areas over 250,000 population. Future research has been programmed by AASHO and should give attention to similar data needs for cities in the less-than-250,000 population range.

Transportation specialists will find this report of special value in helping to formulate policy for data requirements and collection techniques of urban transportation studies.

CONTENTS

ACKNOWLEDGMENTS

The study reported herein was conducted by Creighton, Hamburg, Planning Consultants, in connection with NCHRP Project 8-7. Roger L Creighton, President, acted as Principal Investigator

Sincere appreciation is expressed to the following persons and organizations who contributed generously of their time and data during the course of the project:

The Chicago Area Transportation Study (E. Wilson Campbell, Study Director), the Delaware State Highway Department (William A Elgie, Chief of Planning), the Southeastern Wisconsin Regional Planning Commission (Kurt W Bauer, Executive Director), the Tucson Area Transportation Planning Agency (William G Ealy, Manager), and the New York State Department of Transportation (John K. Mladinov, Assistant Commissioner) provided data and reviewed research findings in the investigation of data requirements of five representative transportation studies

The University Circle Research Center (Cleveland); the Battelle Memorial Institute; the Tri-State Transportation Commission; the Urban Development Division and the Public Transportation Branch of the Federal Highway Administration, Department of Transportation; and the Division of Systems Research and Development, Department of Housing and Urban Development, provided information and ideas on data needs for transit planning.

Meetings with four groups were held to discuss the research plan for the project and the entire field of data needs. Grateful thanks are extended to the following individuals who attended these meetings.

The Department of Transportation: Garland E. Marple, Kevin Heanue, Sidney Robertson, James MacDonald, and Steiner Silence

The Tri-State Transportation Commission. J Douglas Carroll, Jr., and William L Mertz

The Wisconsin Department of Transportation. Wesley Burmeister, Douglas Haist, Donald V Revello, George Gunderson, George Novenski, Bruce Wilson, John W. Fuller, and Kenneth Dueker.

Professor John Dyckman.

Michael Ferreri, of Simpson & Curtin, provided information on data requirements of studies of the Philadelphia-Lindenwold rapid transit line.

The following persons assisted in providing information on the Lincoln (Nebraska) TOPICS program: Richard A. Erixon, Bruce Gillan, Robert G. Holsinger, Marvin L Nuerenberger, and Robert D. Obering

The following persons assisted in providing information on the Woonsocket (Rhode Island) TOPICS program: Joseph Arruda, Francis H. Dutra, and David Rosenfield

The Connecticut and Vermont State Highway Departments provided copies of the Stamford and Rutland TOPICS reports prepared by Wilbur Smith and Associates.

The Tri-State Transportation Commission, through Paul C Watt and Stephen C. Carroll; the Southeastern Wisconsin Regional Planning Commission, through Kurt W Bauer, and the Northwestern Illinois Commission, through Matthew L Rockwell, provided information on data needs for metropolitan land use planning.

Grateful acknowledgment is made of the contributions of the following persons to the research work on this project and to the preparation of the progress and final reports

Louis E Keefer, Special Consultant to the project, did the majority of the research work for "Data Needs of the Strategic Planning Process" in Chapter Two, investigating data needs of three representative transportation studies. He wrote the Phase II-A progress report and contributed to and reviewed the study of TOPICS data needs. Mr. Keefer's wide experience and critical judgment were most helpful throughout the entire project

John M. Allderige did the bulk of the original research work on data needs for TOPICS planning, reported in "Transit Planning" in Chapter Two

The Rensselaer Research Corporation conducted a special study of data needs for the route location planning process, reported in "Highway Route Location (or Project) Planning" in Chapter Two. Professor Donald Mattzie was the principal investigator for this subcontract

Frederick F Frye was responsible for "Transit Planning" in Chapter Two (data needs for transit planning) and for the sensitivity studies of transit ridership estimates, reported in "Transit Ridership Estimates," in Chapter Two.

Most of the research work on alternative methods of data collection reported in "Alternative Methods of Data Collection" in Chapter Two was undertaken by Charles W. Manning

The technical studies of sensitivity and reliability were carried out by John R Hamburg, Robert S. Scott, and Geoffrey J. H. Brown, with the advice of Morton Schneider. Mr. Scott developed techniques for the analytic studies of sensitivity reported in "Analytic Study of the Sensitivity of the STPP to Selected Variables" in Chapter Two Messrs Hamburg and Brown handled the computer tests (Chapter Two), and Mr Hamburg carried out the reliability calculations

Messrs. Creighton and Hamburg were responsible for the over-all design of the research work and for the preparation of the final report and its conclusions.

DATA REQUIREMENTS FOR METROPOLITAN TRANSPORTATION PLANNING

SUMMARY

Urban transportation studies have collected substantial data on land use, travel, transportation facilities and socioeconomic characteristics. It has been alleged that the collection of these data is excessively costly and time-consuming In view of the evolving nature of the transportation planning process, a reexamination of data requirements and collection techniques has been needed. What data should be gathered in the future? What should be a transportation study's policy on data collection?

Accordingly, research was conducted through this Project 8-7 on the subject of data requirements and collection techniques for transportation planning. Five representative transportation studies were examined in detail to reveal the kinds of data needed, to determine the costs of data collection, and to check the degree of use of the collected data Four related kinds of planning were examined to determine the relationships of their data requirements to those of the transportation planning process. The sensitivity of the transportation planning process to data errors was studied to determine the amount of data needed, of each type. Alternative data collection techniques were examined to see whether other techniques could obtain data more efficiently and at a lower cost. An examination of sampling reliability was undertaken. The findings from these separate studies were then integrated and a suggested data collection policy was prepared.

The main focus of this work was the strategic transportation planning process (STPP). The STPP is defined as the process of determining a recommended long-range level of investment in transportation, the division of investment between major modes of travel, the location of corridors for expressways and rapid transit facilities and the general sequence of investment. The STPP is the core of the urban transportation planning process; it defines the systems of major facilities that will serve as the framework for lesser types of improvements and for more detailed, implementation planning.

Data Needs for the Strategic Transportation Planning Process

Examination of five representative transportation studies produced the following findings and recommendations regarding the STPP and related research work:

1. Transportation studies do in fact need extensive sets of primary and secondary data Typically, eight major primary surveys are taken, but some studies may take as many as 21. The eight surveys are:

- Home interview origin-destination survey.
- Truck-taxi origin-destination survey.
- Roadside (cordon line) origin-destination survey
- Arterial link inventory.
- Transit link inventory.
- Speed runs.
- Traffic counts.
- Land area measurements.

No record of secondary data collection practice was taken, but as many as 25 different kinds of secondary data were found to have been used. These, and typical sources for these data, are identified in this report.

2. In general, primary data files have been well used by each of the studies. Only a few "data items" are superfluous; these are identified in this report. A few entire data files—mainly collected experimentally—were not used at all. These also are identified.

3. Research work conducted by the five studies was found to have used only data obtained for STPP purposes. It is recommended that a definite program of financing "risk" data collection for research purposes should be adopted so that STPP agencies do not have to obtain such data as part of their regular programs. Such a policy would remove the limitations on research imposed by having to work only with what are now highly conventional sets of data.

4. The costs of data collection of the five studies averaged $0.52 per capita and 31 percent of total study costs. Total study costs averaged less than 1 percent of the capital costs of the recommended plans. Claims that costs are too high appear to be unfounded.

5. The times required to collect and process data, however, are excessive, averaging at least two years. Methods to speed up data collection, especially data processing, are badly needed.

6. A basic (or minimum) STPP was diagrammed (see Fig. 3) and its data needs are given in Table 9. These are the minimum data needs for strategic transportation planning.

7. Although the subject was not specifically part of this project, experience suggests that a great deal of time and money are spent by separate agencies re-collecting the same secondary data. Examples are vehicle operating costs; accident and travel time costs by different urban street types; transit operating and accident costs; and transit construction costs. It would be far more efficient to assign these subject areas to a university or government agency, requiring them to be a repository of data and a national expert in each field, answering questions and providing data as required.

Data Needs of Related Planning Process

Four related planning processes were examined. Three of these (TOPICS,* transit, and route location planning) are implementation planning operations. The fourth (metropolitan land use planning) is a strategic process.

TOPICS.—TOPICS planning is separated from the strategic transportation planning process by the spectrum of scale. Systems planning aims at the broad strategy of making metropolitan transportation investments, whereas TOPICS aims at the fine-grained tactics of making immediate and less expensive traffic engineering improvements.

The following specific recommendations can be made:

1. The STPP should not attempt to provide all of the detailed street inventory data required for TOPICS.

2. Where possible, the STPP should collect additional street intersection data (channelizations and heavy left-turning movements, for example) to make the calculation of "link" capacities more realistic than they have been in some transportation studies.

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* Traffic Operations Program to Increase Capacity and Safety

3. Further research should be undertaken to interrelate the capital improvement programming process, and its data needs for planning local and arterial streets, with both the STPP and TOPICS.

Transit Planning.—Strategic transit planning requires less detailed data than does implementation transit planning as practiced by transit operators or their consultants. This is largely because the latter concentrates on specific routes—much like highway route location planning—often after a preliminary decision has been made to build. Planning routes, schedules, or fare changes for transit falls outside the STPP as more of an operations than a planning problem; STPP data are clearly not sufficiently detailed for this purpose

With the addition of an on-board transit rider (person-miles of travel—PMT) survey, however, the STPP can make more significant contributions to implementation transit planning. This survey, still rare among transportation studies, not only provides data that the standard home interview survey does not, but also mitigates some of the problems of small sample sizes.

There are pressing needs to develop better statements of goals, or objectives, both for strategic and implementation transit planning. This seems particularly true in the smaller urban areas that face the basic question of whether to subsidize transit service or lose it altogether. In the larger urban areas, where transit service is more clearly needed, the basic question is how to test the effectiveness of possible new transit systems now under development. These questions will require continued research; they cannot be settled by using STPP data.

The following specific recommendations can be made:

1. The STPP should not attempt to provide all of the detailed data required for implementation transit planning.
2. The basic STPP should, however, incorporate a PMT survey as standard practice, particularly where existing transit service is minimal, for the dual purposes of (1) augmenting sparse home interview transit travel data, and (2) providing evidence on the advisability of maintaining marginal transit service.
3. Further research should be undertaken to design more rigorous STPP transit planning goals and objectives, and to develop the necessary evaluative tests to demonstrate how well the goals are met by alternative plans.

Highway Route Location (or Project) Planning.—The route location process is a process distinct and separate from that of the strategic transportation planning process. It employs different methods at a different level of detail.

Whereas the key factors of corridor termini and 20-year traffic forecasts used in route location planning are products of the systems planning process, most other data and estimates required for the route location planning process are prepared by route location planners. It would be inefficient to expect the STPP to collect the kind of data and make the kind of estimates—over an entire metropolitan area—that are required for highway route location planning.

Among the estimates prepared by highway route location planners are the critical peak-hour and directional estimates. These estimates can substantially expand or diminish requirements for lanes. Basic decisions as to number of lanes and interchange types ought to be made jointly by systems planners and route location planners.

Costly decisions about right-of-way, number of lanes, geometrics, and interchange design depend, in part, on traffic estimates. (These decisions also depend on other factors, such as basic decisions to build an expressway network of given spacing and configuration.) To compensate for the fact that traffic estimates will be in error, and to help close the gap between systems planning and route location planning, the following steps should be taken:

1. Research should be undertaken into methods for estimating the range of errors of traffic estimates.
2. The expected range of errors should be posted whenever estimates are made.
3 When estimates are made of traffic volumes that lie in critical volume ranges for lane decisions (or interchange design), additional right-of-way should be purchased to allow for widening
4. Research should be undertaken to measure the limits of trip density (generated by land use) that are allowable for planned spacings of roadways, to measure the costs of exceeding these limits, and to determine means of imposing land use density controls if resulting costs are excessive

Metropolitan Planning.—There is substantial joint use of the same data in metropolitan land use planning, land use modelling, and transportation planning. Seventeen major kinds of data are used in common by these three kinds of planning This substantial joint use of the same data is in sharp contrast with implementation planning, which largely has its own data requirements.

Because it is clear that economies can be obtained through joint collection and continuous maintenance of data, it is recommended that, wherever possible, transportation agencies and metropolitan planning agencies cooperate financially and administratively in the collection and maintenance of data that they can both use.

Metropolitan growth modelling and metropolitan planning operations have tended to use, and to be limited by, the data (such as data on land use, travel, and transportation facilities) traditionally gathered by transportation planners and city planners. It is recommended that new series of data, particularly on land values, building values, floor space, and the general economics of housing and non-residential building (both construction and maintenance), be obtained on a metropolitan-wide sampling basis, so that new measured understandings of urban growth and change can be obtained.

The techiques of metropolitan planning appear to be limited by the inability of planners to estimate, in an authentic manner, the consequences of their proposals or to evaluate those consequences rigorously. If planners are to be able to do this, greater measurement of urban phenomena is needed and more formal, and preferably more quantitative, evaluation techniques must be obtained.

Sensitivity Analyses

Studies of the basic STPP were conducted to ascertain how sensitive the STPP is to errors in data and thus to identify data that need to be gathered more accurately (mainly by higher sample rates) or more frequently. The following conclusions were reached:

1. Basically, strategic transportation plans are prepared on the basis of estimates, not data. Errors of estimates are likely, as a general rule, to be much larger than data errors. Gathering more data than are needed to establish the values of the estimating equations is apt to be unproductive.
2. The critical estimates used in the transportation planning process are the following:

- Trip destination density.
- Trip length.
- Comparative travel costs (expressway versus arterial).

- Network data (chiefly speeds and capacities).
- Variables affecting choice of mode, such as automobile ownership.
- Comparative transit-highway network speeds.
- The capital recovery factor.
- Capital costs of highways
- Capital costs of transit.

3. Forecast errors can have substantial impact on the plan, but this depends on many circumstances. The only way of knowing which errors are significant is to make calculations such as are described in this report under "Sensitivity" in Chapter Two

It must be concluded that there is little likelihood that a plan will be prepared without some errors in forecasts—either misjudgments or errors created by changes in the city that could not reasonably have been foreseen. The question then becomes what to do about these errors

There are at least two defenses that should be set up against expected errors.

The first of these defenses is a *regular monitoring activity* to be undertaken by the transportation study This monitoring activity should consist of biennial vehicle-miles of travel (VMT) and person-miles of travel (PMT) surveys, with the resulting data converted to daily travel costs by the use of carefully measured relationships between volumes and accident, time and operating costs, by street type. The daily travel costs should be employed to identify high travel cost areas and to determine whether changes in land use, trip generation, or trip length are having adverse effects on traffic flow If adverse effects are identified, then remedial actions can be taken.

The second defense should consist of *stressing studies,* in which errors of trip generation, trip length, mode or other critical variables are deliberately inflicted on the plan. This is analogous to imposing 100-year storm data on a water control system, or heavy "design" loads on a bridge. The ability of the plan to withstand wrong estimates—and the cost-consequences of such loads—would then be known.

In sum, the sensitivity studies have shown the critical nature of forecasts rather than data, and they suggest that defensive measures be created in the planning process to offset inevitable errors of estimates.

Alternative Data Collection Techniques

There are many different kinds of measurements that must be made to provide the primary data required by the strategic transportation plan. Consequently, research in this phase had to examine many alternative data collection techniques, with each technique providing data for only one or two sectors of data needs

A number of new data collection techniques have been advanced in the past ten years These include use of social security numbers, commercial "data banks," building and occupancy permits, assessors' records, census records (work trip, population, manufacturing, and business data), mail-back origin-destination surveys, on-board transit surveys, the Dual Independent Map Encoding (DIME) system, automatic vehicle monitoring and identification systems, aerial photography for vehicle counting and parking surveys, ground-based photography, and electronic counting of transit passengers

Although many of these techniques hold considerable potential, few of them—as yet—offer any marked improvement over established techniques of collecting the basic data needed for strategic transportation planning.

The following specific conclusions expand on the preceding statement:

1. In collecting primary population and related data, there is no available operational substitute for the decennial census and the household sample survey (mainly the home interview survey, but also telephone and mail-back surveys).

2. In collecting land use data there is no available operational substitute for a fairly large number of existing techniques by which the activities on parcels are identified and the parcels themselves are measured. For maintaining existing files, however, the use of building and/or occupancy permits appears to be a valuable technique.

3. In collecting origin-destination data, the decennial censuses and on-board transit surveys offer valuable new means of supplementing (but not replacing) existing origin-destination survey techniques. The mail-back survey is an economical technique, but inevitably it must be supplemented by telephone and/or home interviews. The home interview (or the telephone interview), the truck-taxi survey, and the roadside survey remain the best sources of origin-destination data.

4. In collecting transportation network data, the DIME system is compatible with existing network survey procedures, and offers the advantages of standardized data on all urban streets in all urban areas, and a means for relating network data to land use data. However, at present its primary use is as a tool for the geographic organization of data.

5. There are no new operational techniques for collecting speed and volume data. Aerial photography offers a new method for obtaining parking data, however, and its use in traffic volume counting should be improved.

From the research work done on alternative data collection techniques, it is possible to draw conclusions and make recommendations about the direction of future data collection.

1. The computer is becoming more and more of a factor in opening up, for planning and research uses, the capabilities of data files collected by government for taxation and administrative purposes. This trend will continue for many years.

2. Governmental administrative and tax programs create records that uniquely identify persons, businesses, and parcels of land. These include:

- Social security numbers.
- Employer identification numbers.
- Assessors' records.
- The DIME file.

3. Transportation planners should work to secure improvement and extension of the systems identified in item 2. From such records, data on population, employment, work trips, and land use can be extracted.

4. Research and experimentation should be encouraged in the use of aerial photography, on a sampling basis, for counting vehicle traffic on urban street systems.

5. Further research work should be undertaken in the area of special transit surveys, including on-board transit origin-destination surveys and electronic counting of transit passengers.

Data Reliability

Data reliability, assuming reasonably good workmanship in surveys, is only a problem in sample surveys, particularly the home interview survey. The reliability of home interview data was investigated by the use of statistical techniques and the examination of actual data from the Niagara Frontier Transportation Study. These studies have shown that because of intra-class correlation associated with the home interview sample, higher sample rates are required than have heretofore been thought to be needed.

However, these higher sample rates have to be balanced against lower requirements for data demonstrated under "Sensitivity" in Chapter Two. That section concludes that forecasts, rather than data, are the critical factors in defining the strategic transportation plan. Accordingly, the amount of travel data needed is reduced to the amount needed to establish the estimating equations. Substantially fewer data are, therefore, needed. The exact balance cannot be determined from simple tables or formulas. Instead, the planning process to be used in a particular metropolitan area must be defined, together with the kinds of models to be used. Then the amount of travel data needed can be fixed by statistical methods such as those employed in "Reliability" in Chapter Two.

Future Data Collection Policy

What should be the data collection policy of a continuing transportation planning study in the light of the foregoing findings?

To answer this question, one has to assume that it will be necessary to review present strategic transportation plans periodically to determine whether investment levels, mode-split of investment, and corridor locations are still valid in the light of the changing city. It is a safe assumption that this will require repetition of the basic STPP, featuring long-range estimates of trip production, by mode, and traffic assignments. Under these circumstances, the following recommendations can be made:

1. The transportation study should maintain land use and network data on a continuing basis. Both are essential to regular traffic assignments and to knowing the present distribution of population and trip ends. These data should be kept up-to-date annually using official files, including building inspector, assessor, and engineering records. The DIME file should serve as the coordinating file for land use data, although major streets data used for assignment purposes do not have to be in the form of the more complete DIME street network data.

2. Because trip densities and trip lengths may change over time, to the detriment of traffic quality, it is recommended that the transportation study should, biennially, measure the travel costs of the metropolitan area. This will require biennial VMT and PMT surveys. This is the monitoring activity, which should be a major function of the continuing urban transportation planning process. By regularly monitoring VMT and PMT, and calculating changes in travel costs, the transportation study will be in a position to determine whether the existing long-range plan needs revision or whether programmed improvements are producing sufficient gains so that the plan may still be considered valid. Regular measurements of travel costs will also aid in reaching conclusions on the benefits to be derived from imposing additional land density controls.

3. At least once a decade, and more often as determined by the monitoring activity, enough home interviews, roadside interviews, and truck-taxi interviews should be obtained so as to measure current levels of trip production (by mode) and trip length when related to present population and auto-ownership data by district and/or zone. For trip length, approximately 150 households should be sampled for any area (e.g., district for which trip length is desired to be known within ±10 percent at the 95-percent confidence limits level). For other variables, the number of trip samples is given in Table 29 in Chapter Two.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT AND OBJECTIVES

The research problem statement for Project 8-7 reads in part as follows

> Urban transportation planning studies require travel, transportation facility, land use, and various socioeconomic data Techniques for obtaining these data are slow and costly. The accuracy, utility and adequacy of the data and the methods employed for their collection and assembly need to be evaluated in the light of the evolving transportation planning process

The problem statement states three objectives of the research project.

> 1 Design data requirements for both basic and continuing transportation studies with regard to travel, transportation facility, land use, and socioeconomic data Utilize statistical analyses to establish desirable levels of precision for the travel component
> 2. Review and evaluate existing techniques and recommend improved techniques for obtaining necessary data, including evaluation of data from the Census and other secondary sources
> 3. Consider the potential for multiple-purpose use of data.

RESEARCH PLAN

To meet the needs just described it was decided to take a dual approach to the evaluation of data requirements and collection.

1. It was necessary to develop recommendations on data needs and collection techniques for a fairly standardized transportation planning process such as is required by the Bureau of Public Roads publication *PPM 50-9* (*63*), because such processes will continue to be used for some time. The first approach, therefore, was to develop recommendations based on studies of a representative sample of planning processes from cities of different sizes throughout the United States.

2 However, the evolutionary nature of planning requires that attention be paid to the data needs of (1) new kinds of transportation planning, and (2) other kinds of planning. Part of the research effort was therefore devoted to an examination of data needs of new and related kinds of planning.

Within this dual approach, the research plan was organized into five major parts. These five parts (some shown in more detail than others) are shown in their functional relationships to each other in Figure 1, and are described in the following.

Examination of Five Transportation Studies

The first phase of the project was based on the evidence gathered from completed transportation studies. Because it was necessary to make thorough and detailed investigations to obtain an accurate picture of data used in these processes, it was impractical to examine the practices of a large number of completed studies. Instead, five representative studies were selected and examined in depth

The planning process actually used by each study was carefully diagrammed and described. The sources for diagramming were the published reports of the studies, supplemented by details obtained from the staffs A formalized approach was used to ensure uniformity and consistency of transcription a macro-diagram described the major planning operations, and separate micro-diagrams described each of the minor operations For each individual step described in the micro-diagrams, the data required for its completion were identified. To draw conclusions concerning data needs for research purposes, data requirements for research projects were formally recorded also. The number of research projects to be examined was limited to 20.

This intensive review of the transportation study process and its data requirements was accomplished during visits to each study. At that time, data collection forms were assembled for the land use, travel, transportation facility, socioeconomic, and related major surveys; card or tape record formats were obtained; copies of all major study publications were obtained; and pertinent cost accounting records were transcribed When possible, the completed macro-diagrams and micro-diagrams were reviewed with key study personnel during the visits; the preliminary phase report was eventually reviewed by all five study directors

Subsequently, the macro-diagrams for all five studies were superimposed on each other, and the steps that were common to all, or to a majority of the processes, were noted. These, with some adjustments, composed a "minimum" or "basic" transportation planning process. This "process" became the reference for defining irreducible data requirements and for identifying those data items and estimates that have a substantial impact on the selection of the final transportation plan.

Examination of Related Planning Processes

Representatives from a state highway department, a transportation study, the academic world, and the Bureau of Public Roads (BPR) were interviewed during the first two months of the project. These representatives recommended that research should examine planning processes which, although closely related to transportation planning, have been traditionally isolated from it Several reasons were cited for this position.

First, transportation studies are taking on the responsibility of updating, and, in some cases, scheduling the implementation of transportation plans The planning process and data collection efforts must be responsive to these new responsibilities. Second, there are pressures for additional detail of planning output generally requested in the imple-

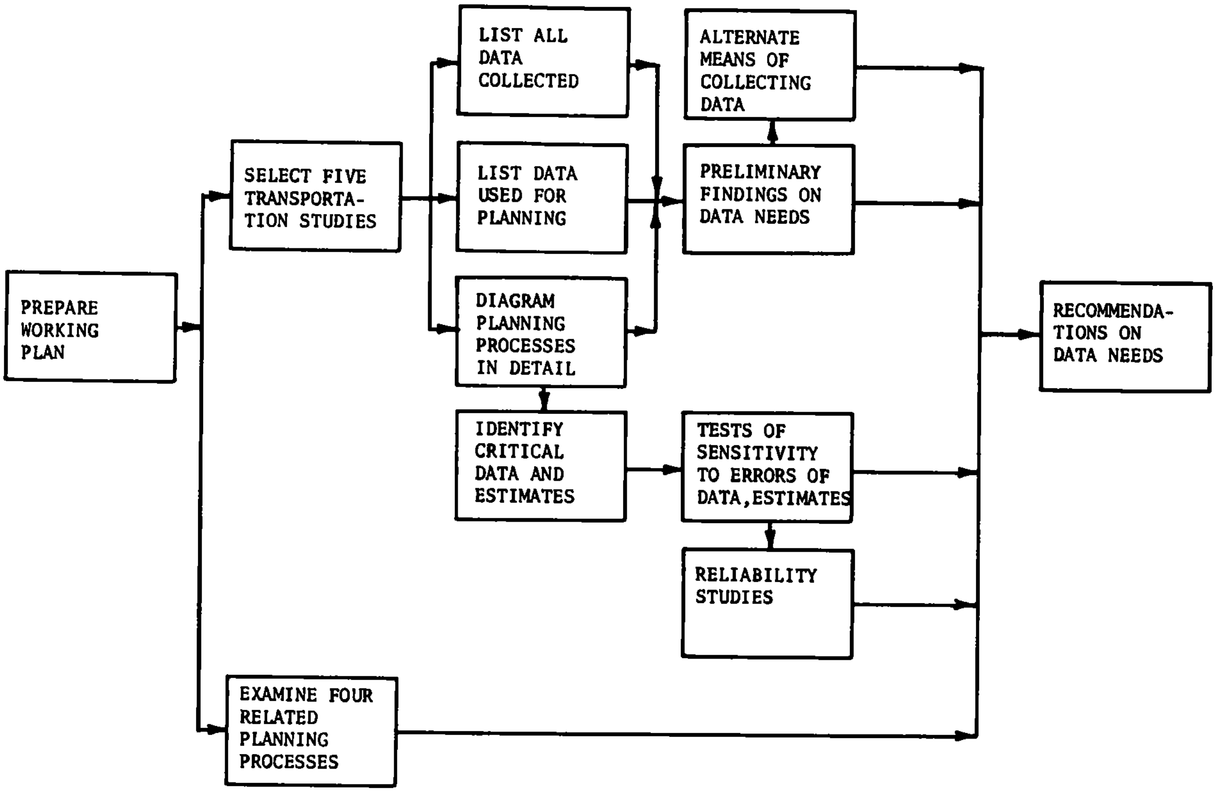

Figure 1. Project 8–7 research plan.

mentation stage of the strategic proposals. These requirements can be fulfilled by improving the basic transportation planning process, or by altering the strategic transportation planning process (STPP) to take into account the more specialized kinds of transportation planning. Third, there is a strongly felt need for closer collaboration between land use planning and transportation planning Finally, there is a need for coordinating data obtained for transportation planning with data obtained for related planning processes.

Four transportation-related planning processes were selected for study· (1) metropolitan land use, or comprehensive, planning, (2) highway route location studies, (3) transit planning, and (4) TOPICS (Traffic Operations Program to Increase Capacity and Safety).

A number of organizations actively engaged in these subject areas were contacted, and their planning processes were diagrammed, the extent of their data-gathering activity was determined, and data collected and data used were compared. From this evidence, the "actual" data needs for these planning efforts were specified.

Alternate Means of Data Collection

Once the data requirements for the STPP and for new kinds of transportation planning were determined, effort was devoted to determining whether there are alternative means for collecting the required data, means that would provide more accurate data, reduce the time for collecting and processing the data, and reduce the cost of data collection.

The newer techniques were examined in detail and evaluated within the limitations of the "hard" evidence available regarding cost, dependability, and accuracy

Sensitivity Tests

Sensitivity analysis is the process of examining variations in the output of a process or system resulting from a unit change in one of the system's input variables while all other system inputs are held constant. It is relevant to the evaluation of transportation data needs, providing a method for assessing the impact that data errors have on the transportation plan. the chief output of the transportation planning process.

If the planning process is insensitive to errors in certain data, or if errors tend to be self-cancelling, then it is clear that further expenditures to improve the accuracy of data, or for greater detail in data, are unlikely to produce benefits that justify the cost. If, however, a small error (for example, in estimated speed of travel) is found to have significant effect on forecasts and plans, it would be worthwhile to spend substantially more to improve the level of accuracy of the data.

The first phase of the sensitivity analysis was to examine the "basic" transportation planning process to see what data were influential in the operations of the process and how these data—or estimates replacing data—persisted through the process to affect the transportation plan.

The major part of this phase of the research work was then devoted to studying the sensitivity of the planning process to errors in the more critical data and/or estimates A variety of sensitivity tests was devised. Some of these tests required computer traffic assignments; others were accomplished analytically. In most cases, the impact of errors of several different magnitudes was estimated. The results will have general utility for transportation planners, and will provide new insight to persons active in the field of data collection.

Reliability Studies

Original plans called for a study of the reliability of data, independent of the sensitivity analysis tests. In practice, however, it was found that a great deal of overlapping occurred between the reliability and sensitivity phases of this work. Primarily for this reason, the reliability studies were reduced substantially. In addition, it was recognized that measures of any particular city's data sets could not be generalized beyond that city.

Statistical analysis of the problem of cluster sampling of the home interview was undertaken and this, together with the results of the sensitivity tests, enabled recommendations on home interview sample size to be made.

DEFINING THE FOCUS OF RESEARCH

At the outset of the research work on Project 8-7 it became clear that a definition of the kind of urban transportation planning for which data are to be gathered is a prerequisite to the examination of data requirements and collection techniques Such a definition must be sufficiently broad to allow for variations in emphasis resulting from local needs, population sizes, and other factors. Nevertheless, a clear idea of the nature of the planning process on which this project is focused must be obtained—otherwise it would be hard to set bounds on data needs. Furthermore, unless the kind of planning process is established for which the research work in this project is intended, there would be a danger of straying far afield with no single, unifying, and clearly defined focal point to which data requirements and collection techniques can be related.

Accordingly, one of the first tasks was to specify the kind of transportation planning to which research work on this project would be directed.

The Field of Urban Transportation Planning

The field of urban transportation planning has, over the past 25 years, become steadily more comprehensive. Starting with a focus that was directed primarily toward justifying urban highway improvements (and not necessarily in the context of entire networks or systems) the urban transportation planning process became more oriented toward systems of transportation facilities, and toward coordination of transportation plans with land use plans. Concern with terminal requirements for urban and interurban transportation has increased (parking facilities; and air, rail, and bus terminals), and greater attention is being paid to the movement of goods.

This broadening concern cannot be handled entirely by one kind of technical planning process. There are many types of planning which deal with problems of urban transportation. The Bureau of Public Roads, in its memorandum *PPM 50-9* (*63*), recognizes that urban transportation planning includes a range of types of planning.

In the words of *PPM 50-9*, the urban transportation planning process *"includes the operational procedures* and *working arrangements* by which *short-* and *long-range highway* and *transportation* plans are . . . developed." Further, transportation planning "is concerned with all facilities used for the movement of *persons* and *goods*, including *terminal facilities* and *traffic control systems."* In addition, transportation planning "includes not only the initial *preparation* and evaluation of transportation plan(s) . . . but also *periodic review and modification."* (Italics supplied.)

The foregoing language states that multiple "operational procedures and working arrangements" are needed to produce plans that deal with a wide variety of transportation problems. The multiple operational procedures produce highway plans, mass transportation plans, both short- and long-range plans, plans for both people and goods, and include both initial preparation and periodic review (or continuing planning).

It is possible to list a large number of kinds of planning that deal with transportation and related matters in urban areas For example, there is planning for the TOPICS program, transit planning, route location planning, planning for terminal facilities, planning for the movement of goods, and planning for intercity transportation by air, rail, and bus modes of travel. Metropolitan land use planning (or comprehensive metropolitan planning) is an activity closely related to certain kinds of transportation planning for urban areas, because it deals with the arrangement of land uses that must be linked by transportation facilities.

In addition, research work and public information are auxiliary activities needed to support the preparation, implementation, and periodic reviewing of transportation plans of all types.

The generalized relationships of these different kinds of transportation planning and related activities are shown in Figure 2. It is clear that there will be variations in the kinds of data required by the different technical procedures by which these different plans are prepared

Strategic Transportation Planning Defined

Among the kinds of transportation planning shown in Figure 2, there is a definite place and need for a process by which long-range plans can be prepared for major systems or networks of transportation facilities, covering entire urban areas, coordinating the several modes, and relating transportation plans to land use. This is, in fact, at the heart of *PPM 50-9*

To differentiate this long-range planning of major systems from other kinds of transportation planning, it is called in this report strategic transportation planning (STP). The process is called the strategic transportation planning process (STPP). Other names could have been used. This one has the virtue of distinguishing itself from the short-range and more implementation-oriented kinds of planning, such as TOPICS or route location planning. The STPP establishes a framework within which smaller-scale improvements can be planned.

Strategic transportation planning for urban areas is defined as the process of determining a recommended long-

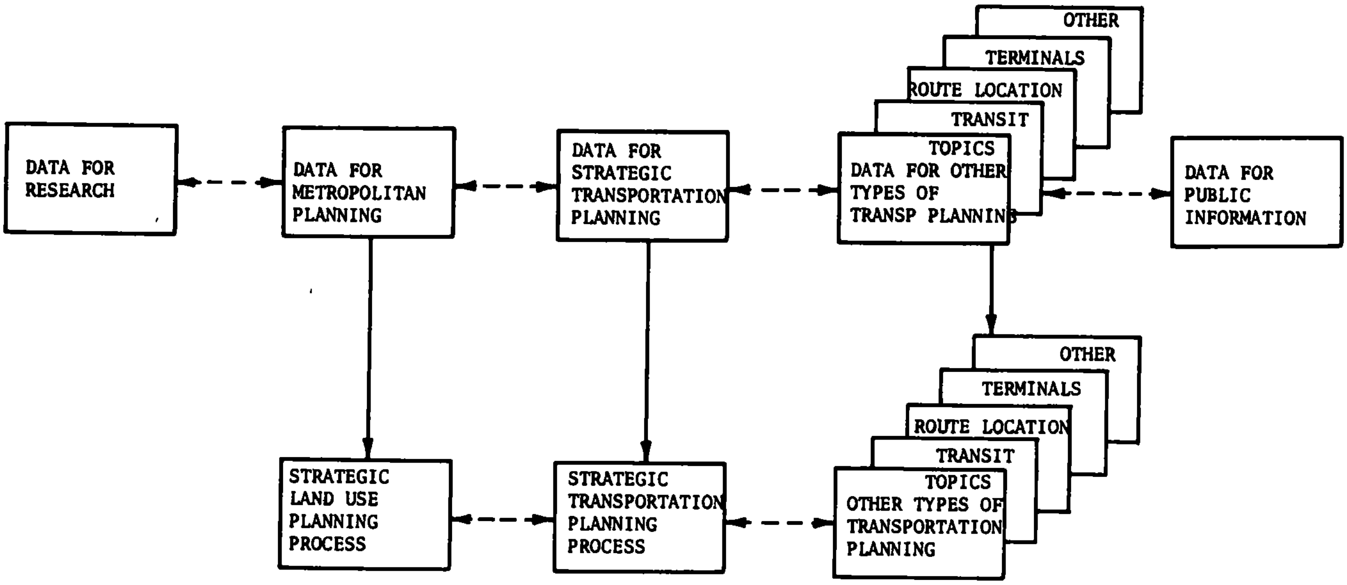

Figure 2 Relationships between different kinds of planning

range level of investment in transportation, the division of investment between major modes of travel (i.e., between expressways, arterials, and transit), the location of corridors for expressways and rail rapid transit facilities (or in smaller urban areas the locations of arterials), and the general timing and sequence of investments. The strategic plan establishes corridor locations for major facilities (as defined by the terminals of each corridor) that will carry approximately 40 percent of the total vehicle-miles of travel (VMT), together with the number and general location of expressway interchanges and rapid transit stations, and the width of the corridors within which route location studies should be made

The evidence obtained from the five metropolitan transportation studies examined during the course of this project showed that all five prepared strategic transportation plans, but that some of the studies went beyond this task in their work programs. Each of these studies prepared plans that show expressway systems carrying between 40 and 50 percent of the vehicle-miles of travel.

TRANSPORTATION STUDY	TARGET YEAR	VMT CARRIED ON EXPRESS-WAYS (%)
Chicago Area Transportation Study (CATS)	1980	45
Niagara Frontier Transportation Study	1985	40
Southeastern Wisconsin Regional Land Use Transportation Study	1990	41
Wilmington (New Castle County Program)	1985	47
Tucson Area Transportation Study	1980	45

The Chicago and Niagara Frontier studies did not prepare plans for specific arterial street improvements, but the other three studies did. The Tucson study, in particular, concentrated a great deal of work on planning arterial improvements.

Greater variety existed in transit planning. In Chicago, tests of rail rapid transit lines estimated that 27 percent of transit person-miles of travel (PMT) would be on rail facilities, although traffic assignments were made to all bus lines, no specific recommendations on new bus service were made In the Niagara Frontier, rail transit was tested extensively in the planning process, although no recommendations were made; buses were not dealt with in terms of specific routes. In Southeastern Wisconsin, rail rapid transit was investigated carefully during the plan design process, but was discarded after a comparative analysis of rail and bus cost and service characteristics. After more detailed examinations of the demand for transit were completed, special "busways" and freeway routes were proposed. In Wilmington, additional specific bus routes were recommended. Tucson did not include transit in its planning effort.

Thus, it can be seen that the studies were uniform in being long-range and in recommending the construction of expressways. However, in the larger cities, plans for specific arterial improvements and bus plans were generally given less attention In the smaller urban areas, arterials and bus lines become more important as carriers, and may in some cases be included in a long-range, strategic plan. In very small urban areas, however, transit may not be considered at all.

Southeastern Wisconsin is a prime example of an organization having not only a transportation planning function, but also a land use planning function. The Tri-State Transportation Commission has a similar mandate. Such joint planning of land use and transportation facilities at the metropolitan scale, as well as at the local level, is becoming more prevalent Unfortunately, it has been necessary to focus attention on one subject in this research project—transportation planning—and so the land use planning process has been dealt with only as a related kind of planning.

As a product of the research work described under "Data Needs of the Strategic Transportation Planning Process," which follows, it was possible to diagram the strategic transportation planning process in its most basic, or minimum, form This is shown in Figure 3.

This diagram was prepared by superimposing the macro-diagrams of the planning processes employed by the Chicago, Buffalo, Southeastern Wisconsin, Wilmington, and Tucson studies These processes were remarkably similar in their basic aspects. By comparing them and drawing off their common elements, a process was diagrammed that contains only the essential steps needed to produce the strategic plan as defined in the preceding section. (These basic steps are described in Appendix C)

This is the process, in essence, whose data needs and requirements were investigated in this research project

Related Kinds of Planning

The foregoing sections, for the purposes of this research project, separate strategic transportation planning from related kinds of planning work.

In this section, two categories of related kinds of planning are discussed.

Implementation Planning

Implementation planning has to do with improvements that are generally smaller in scale, lower in cost, more localized, and shorter in their planning time span than strategic transportation planning. Examples include·

1 Traffic engineering or TOPICS planning.*
2. Route location planning.*
3 Transit planning (individual routes or operations planning) *
4. Terminals planning (air, rail, intercity bus).
5. Planning for parking.

Related Strategic Planning

Related strategic planning involves planning operations concerned with large areas, long time spans, and major questions of public policy, investment or regulation, but which, for various reasons, only partially coincide with the activities of strategic transportation planning. Examples include:

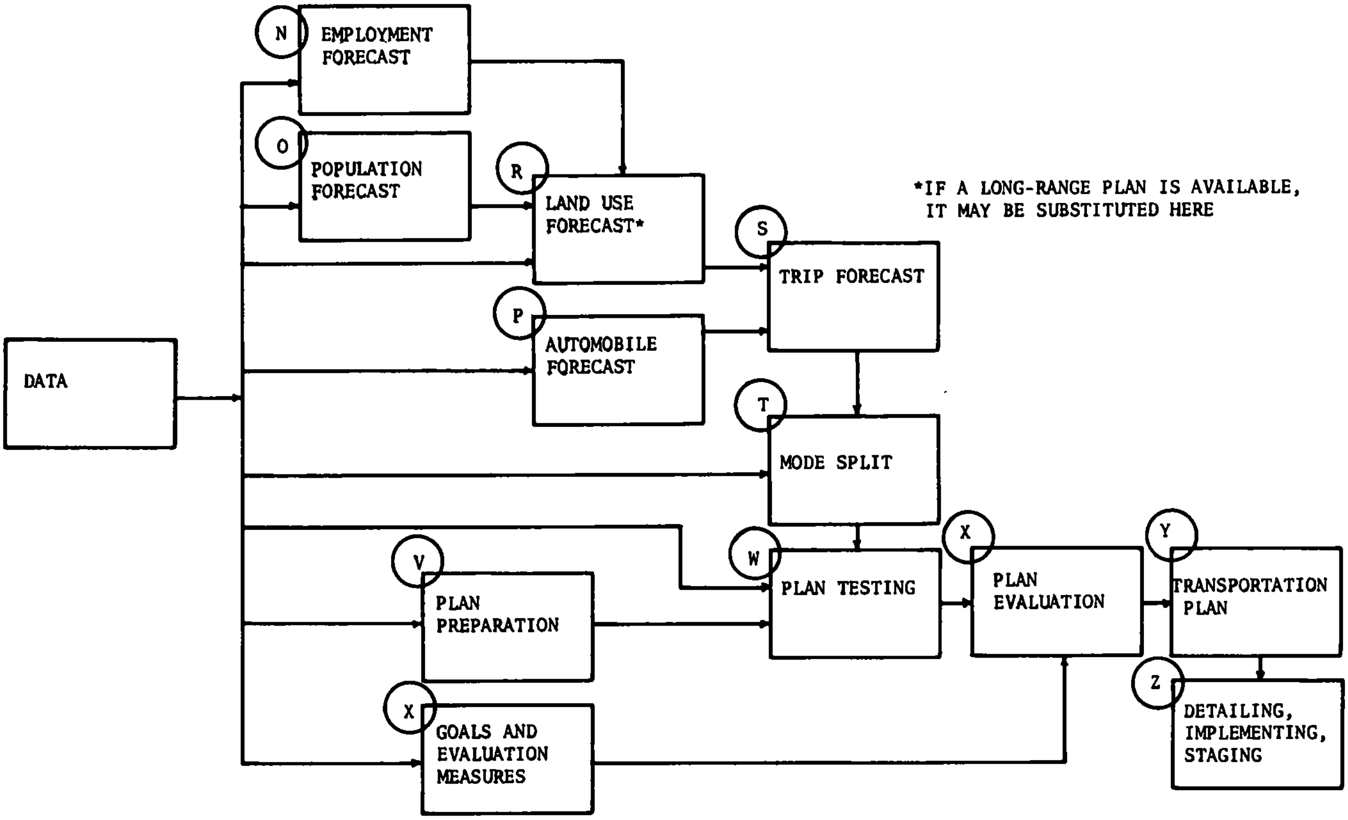

Figure 3. Generalized work flow diagram of minimum transportation planning process (Letters refer to detailed process description in Appendix B).

1 Metropolitan land use planning.*
2 Goods movement planning.
3. Regional land development planning
4. Statewide transportation planning.
5 Planning for cities of less than 50,000 population

Because there are urgent needs to improve coordination of data collection for planning, four of these related kinds of planning, marked with an asterisk in the preceding lists, were examined in this project.

CHAPTER TWO

FINDINGS

DATA NEEDS OF THE STRATEGIC TRANSPORTATION PLANNING PROCESS

This section reports on the needs of strategic transportation planning processes for data as determined by an examination of five completed transportation studies Through a careful review of a representative number of real-life planning processes it was possible to answer questions on the kinds of data collected, the amount of collected data that was used, and data collection costs.

Research Method

Five transportation studies were selected for detailed examination These were considered to be reasonably representative of all studies, and the research results are felt to have general application Twelve criteria were established to aid in the selection These included the following: study area population and geographic location, study completion date, administrative organization, availability of data and original staff members, type of traffic models used, accuracy checks used, research published, relationship to land use planning, innovative quality, availability of data collection cost data, and whether the study was a "second-round" repeat study

The five studies selected were: (1) the Chicago Area Transportation Study (CATS), (2) the Niagara Frontier Transportation Study (Buffalo and Niagara Falls, N.Y), (2) the Southeastern Wisconsin Regional Land Use Transportation Study, (4) the New Castle County Program (Wilmington, Del.), and (5) the Tucson Area Transportation Study For simplicity, they are called the Chicago, Buffalo, Milwaukee, Wilmington, and Tucson studies, respectively.

Following the selection of the five studies, the planning process actually used by each was carefully diagrammed and described. The sources for diagramming were the published reports of the studies, augmented by details obtained from the staffs. A formalized approach was used to ensure uniformity and consistency of transcription, a macro-diagram described the major planning operations, and separate micro-diagrams described each of the minor operations.

For each individual step described in the micro-diagrams, the data required for its completion were identified by tape or punch card numbers and by fields or columns on a special form developed for the purpose From this strict accounting, various summary forms were completed that provided a complete picture of which data had not been used. In this report only the macro-diagrams and certain summary forms are reproduced, although all original diagrams and forms have been retained. To draw conclusions on data needs for research purposes, data requirements for research projects were similarly recorded A limit of 20 research projects per study was set.

This intensive review of the transportation study process and its data requirements was accomplished during visits to each study At that time, data collection forms were assembled for the land use, travel, transportation facility, socioeconomic, and related major surveys; card or tape record formats, and copies of all major study publications were obtained, and pertinent cost accounting records were transcribed. In most cases, there was an opportunity before departing to review the completed macro- and micro-diagrams with key study personnel; the preliminary phase report was eventually reviewed by all five study directors

Subsequently, the macro-diagrams for all five studies were superimposed on each other, and the steps that were common to all or a majority of the processes were noted. These, with some adjustments, composed a "minimum" or "basic" transportation planning process. This process then became the reference for defining irreducible data requirements and for identifying those data items and estimates that influence the transportation plan substantially.

The studies selected are representative of those in the recent past designed to prepare urban transportation plans. They include studies of small and large urban areas in different parts of the United States; they have used different models and study techniques, and their research emphases have varied These and other differences provide valuable variety to the analyses of their data needs and data collection experiences.

Several different study "schools" are represented. For example, the Chicago and Buffalo studies prepared land use forecasts; the Milwaukee and Wilmington studies prepared land use plans; the Tucson study prepared a land use forecast within the context of a land use plan. This distinction alone indicates a diversity of study philosophy, and other distinctions stem from it. Although the several studies do not purport to be a valid statistical sample, the selection should be adequate for the analytical purpose intended.

Primary and Secondary Data Defined

For convenience, the kinds of data needed for transportation planning are divided into two groups—"primary" and "secondary" data

"Primary" data are data that are collected by the staff of a transportation study either through direct surveys (as in the home interview or roadside interview) or through the extensive measurement or specialized manipulation of records that may have been assembled previously by other agencies Examples of this latter type of "primary" survey work are the land use survey, which may involve measurement of assessors' maps, and the arterial link inventory, which involves measurement of engineering maps

By contrast, "secondary" data are defined for the purposes of this project as data that have been previously published more or less in the form required by a transportation study staff.

Most of the attention of this report is concentrated on primary data.

Major, Primary Surveys Taken

Table 1 gives the major primary data surveys undertaken by five transportation studies

Among these surveys, eight were undertaken by all five studies. These were:

1. Home interview origin-destination survey.*
2. Truck-taxi origin-destination survey.*
3. Roadside (cordon-line) origin-destination survey *
4. Arterial link inventory.
5. Transit link inventory.
6. Speed runs.
7. Traffic counts.
8. Land area measurements.*

The data items obtained in the surveys marked by an asterisk are given in Tables 2 through 6.

Other major surveys were taken to fulfill special needs in one or more of the metropolitan areas being studied For example, railroad passenger surveys were taken in Chicago and Wilmington, but not in the other survey areas. Mil-

TABLE 1

MAJOR PRIMARY DATA SURVEYS CONDUCTED BY EACH OF THE FIVE SELECTED STUDIES

	INDICATION OF SURVEY TAKEN, BY STUDY				
MAJOR SURVEY	CHICAGO	BUFFALO	MILWAUKEE	WILMINGTON	TUCSON
Travel·					
Home interview	√	√	√	√	√
Truck-taxi interview	√	√	√	√	√
Roadside interview	√	√	√	√	√
Railroad passenger questionnaire	√[a]			√[a]	
Transportation facilities.					
Arterial link inventory	√	√	√	√	√
Transit link inventory	√	√	√	√	
Intersection capacity studies					√[a]
Speed runs	√	√	√	√	√
Traffic count program	√	√	√	√	√
Parking studies					√[a]
Air-bus-rail terminal studies		√[a]			
Goods movement studies		√[a]			
Person-miles of travel		√			
Land use:					
Land area measurements	√	√	√	√	√
Floor space measurements	√[a]	√[a]			
Public utilities			√		
Soils and surface water			√		
Parks and open space studies			√		
Socioeconomic:					
Personal opinion questionnaire			√[a]	√[a]	
Household history questionnaire			√[a]		
Industrial management survey			√[a]		

[a] The survey is not essential to the STPP, or has not more than marginal utility

waukee obtained more data in the area of land use because its program called for the joint planning of transportation and land use

Use of Primary Data

From the detailed examination of data collected in each survey it is also possible to show specifically which individual data items were used or not used. Summaries have been prepared for the travel and land use surveys, and are presented herein. In a discussion of these summaries, it is important to note that only data items (the smallest meaningful unit of primary input information which could potentially be used in the STPP) are included. Both processed data (data that have been derived through computations applied to other data) and collectional data (data that are used to identify a unit being surveyed, geographically or otherwise, and which are used for management purposes or for control of records in coding, factoring, checking and for data processing) have been eliminated to facilitate. (1) study of original primary data inputs, and (2) comparison of data collected and data used within and among studies Only data that were keypunched for tabulation were considered to be real data.

Travel Survey Data

Of all the primary data collected in the STPP, the travel surveys (origin-destination) are generally the most expensive and the most detailed. They provide a good starting point for an examination of relative data use. The following discussion groups travel survey data as to person and household attributes, trip characteristics, and those special travel-related data items generally found to be unique to particular transportation studies.

Person and Household Attributes.—In the home interview survey, household attributes include the definition of the sample addresses selected for interview as single-unit homes, duplexes, apartments, etc. (structure type), as categories of dwelling units or non-dwelling units per Bureau of Census definitions (type of living quarters); as to location of the sample address, the number of persons residing or visiting there, the number of passenger cars owned there; and sometimes various information about the previous address of the occupants and their recent history of residential moves. At the same time, certain information about each occupant is obtained; namely, sex, race, age, driver licensing, occupation-industry, employed-unemployed, etc.

In the roadside interview and truck-taxi surveys, such data are necessarily limited or of a different nature Roadside interviews generally record only the garaging address of the vehicle whose driver is interviewed—a method for eliminating the duplication of trips by study area residents, and, incidentally, the basis for the cordon line accuracy check In effect, no person or household attributes are recorded Truck-taxi surveys, however, do generally record the business-industry of the vehicle owner, the number of vehicles he owns or operates, and where the vehicles are garaged overnight. Such surveys also note the type of truck and/or its weight class, and its license number. These types of data more or less equate to "household" and "person" attributes. They are used primarily in the development of trip generation rates, and in the analysis of truck terminal location/activity patterns.

Person and household attributes have two principal applications in the planning process. (1) as reference points in the projection of population, employment and auto ownership, and subsequently as spatially distributed elements in the land use forecast or plan, and (2) as prime determinants of present and future trip generation and modal choice

Total study area household data were used sparingly. (See Table 2) No study used expanded sample address data to derive study area totals involving sex, age, driver licensing, or occupation-industry, and only one study used race Only three items were used by all five studies: sample address location, total persons, and total cars. The general explanation is that most STPP analyses are more concerned with the household and personal attributes of persons making trips than with all persons.

Note that "non-used" data might indeed have been tabulated, analyzed to some greater or lesser extent, and even to have been reported in preliminary or final study publications. For example, most studies still prepare tables that summarize total study area household data. The conclusion reached in the preceding paragraph is simply that such data apparently are more for reference than for substantive planning use In this report, non-use means non-application in the mainstream of the STPP.

Trip Characteristics.—There is more consistent application of trip data among the five studies from the home interview surveys. (See Table 3.) All used trip origin and destination, trip purpose to (two studies did not use trip purpose from), destination land use (three studies did not use origin land use), start and arrival time, and travel mode Use of remaining trip data, however, was not so consistent. Only two studies used sex and race of tripmaker, or blocks walked at origin and destination, only one study used age, occupation, industry, (family) income of the tripmaker, or auto availability Kind of parking data were not used by any study (Note that all of the foregoing items, except income, were collected by each study, and note also that all studies did keypunch and therefore have available for analysis all data collected, data collected but not keypunched is not a problem so far as basic travel surveys are concerned.)

Non-use was fairly common among those data items of a more unique and experimental nature; as, for example, Chicago's "Principal Route of Travel," Buffalo's "X-way Entrance or Exit," and Tucson's "Park and Shop" data The first two were analyzed but found no direct utility in the STPP; the third, for various reasons, was never analyzed. The Buffalo "X-way Entrance or Exit" data subsequently found valuable use in a study of toll-road use. (The conclusion that new or unique questions should be avoided would be erroneous, although some have, in the past, proved nonessential, others have led to significant improvements in the STPP.)

Roadside interview trip data are somewhat less extensive than home interview trip data, but somewhat more uniformly used. (See Table 4.) All studies used trip origin and destination (or station location as an alternative to one

TABLE 2

HOME INTERVIEW—HOUSEHOLD RECORD

DESCRIPTION OF DATA	DATA COLLECTION AND USE, BY STUDY [a]				
	CHICAGO	BUFFALO	MILWAUKEE [b]	WILMINGTON	TUCSON
Structure type	X	X	X ✓	X ✓	X ✓
Type of living quarters	X	X ✓	X	X ✓	
Interview address	X ✓	X ✓	X ✓	X ✓	X ✓
Number of passengers [c]	X ✓	X ✓	X ✓	X ✓	X ✓
Number of persons	X ✓	X ✓	X ✓	X ✓	X ✓
Persons age 5 and up	X	X	X	X	X ✓
Overnight visitors	X	X	X	X ✓	
Time at present address	X			X ✓	X ✓
Previous address	X			X	
Time at previous address	X				
Sex	X	X	X		
Race	X	X	X	X ✓	X
Age 5 and up making trips [d]	X	X	X	X	X
Age 5 and up not making trips	X	X	X	X	X
Total trips made	X	X	X ✓	X	X ✓
Persons age 16 and up	X		X	X	
Driver status (age 16 and up)	X	X	X	X	
Number of walking trips	X				
Income		X ✓	X ✓	X	
Occupation	[e]	X	X		
Industry	[e]	X	X		
Age		X	X		
Worked on travel day		X			
Year around resident					X ✓
Part-time resident, months lived at address					X ✓
Persons employed					X ✓
Auto driver trips					X ✓

[a] X means that data were collected, ✓ means that data were used

[b] Milwaukee home interview and postal home interview combined The latter did not collect all the data of the former

[c] Milwaukee collected data for private and company cars and total cars

[d] Milwaukee persons making/not making trips not limited to age 5 and up

[e] Data collected for trip makers only See Table 3

or the other), vehicle type, trip purpose to, destination land use, and vehicle garaging location. Inconsistently used were hour period beginning, number of persons in vehicle, trip purpose from, and origin land use. Least frequently used (and not uniformly collected) was the various information connected with "through" trips, such as route of entry or exit, and intermediate-stop trip purpose and location

Truck-taxi trip data are the least consistently used of the three basic travel surveys. (See Table 5.) Perhaps this reflects the differing importance of truck travel in particular urban areas, sometimes as requiring distinct, as opposed to mixed-vehicular-mode, analyses of travel patterns. In any event, all studies considered vehicle type, trip origin and destination, and destination land use, three studies used start and arrival times, two studies used trip purpose to (one study used trip purpose from); and no more than one study used any of a variety of other trip data Significantly, none of the studies effectively used "commodity-carried" data, whether collected in the truck-taxi or roadside interview surveys

Travel-Related Data Items.—Auxiliary travel data, whether from fairly standard surveys such as Chicago's or Wilmington's railroad commuter surveys, or from special surveys such as Milwaukee's postal questionnaire for travelers residing inside the study area but outside the designated home interview sample areas, had mixed use Such special surveys tend to pick up only a fractional percentage of the total person travel in urban areas, resulting in a need for special analyses that do not carry throughout the STPP, or do not particularly affect areawide systems planning procedures

Milwaukee's and Wilmington's attitudinal, or personal opinion, surveys were at least partly travel-related In both instances, a subsample of home interview respondents were asked to complete questionnaires relative to their attitudes about travel and housing preferences. Wilmington's data were extensively analyzed; Milwaukee's were not Both surveys did, however, provide some inputs to land use planning decisions.

Land Use Data

Land use and related surveys constitute another major data collection item in the STPP. A variety of techniques have been used; Chicago's survey was based largely upon transcription from fire insurance atlases (Sanborn maps) with supplemental field work. Buffalo's survey was taken predominantly in the field. Milwaukee's and Wilmington's surveys were based partly on aerial photography, and partly on completed field work by the planning staffs of the major cities within those study areas. Tucson's work consisted

TABLE 3

HOME INTERVIEW—PERSON TRIP RECORD

DESCRIPTION OF DATA	DATA COLLECTION AND USE, BY STUDY [a]				
	CHICAGO	BUFFALO	MILWAUKEE	WILMINGTON	TUCSON
Sex	X ✓	X	X ✓	X	X
Race	X ✓		X ✓		X
Age	X	X	X ✓	X	
Occupation	X	X	X	X ✓	X
Industry	X	X	X ✓	X	X
Origin location	X ✓	X ✓	X ✓	X	X
Destination location	X ✓	X ✓	X ✓	X ✓	X ✓
Purpose "from"	X ✓	X	X ✓	X ✓	X
Purpose "to"	X ✓	X ✓	X ✓	X ✓	X ✓
Land use at origin	X ✓	X	X	X ✓	X
Land use at destination	X ✓	X ✓	X ✓	X ✓	X ✓
Starting time of trip	X	X ✓	X ✓	X ✓	X ✓
Arrival time of trip	X ✓	X ✓	X ✓	X ✓	X ✓
Mode of travel [b]	X ✓	X ✓	X ✓	X ✓	X ✓
Blocks walked at origin	X	X	X ✓	X	X ✓
Blocks walked at destination	X	X	X ✓	X	X ✓
Number of persons in car	X	X	X ✓	X	X
Kind of parking	X	X	X	X	X
Screen line control points [c]	X ✓				X ✓
Expressway used	X	X			
Principal route of travel	X				X
First work trip	X				X ✓
Expressway entrance		X			
Expressway exit		X			
Automobile available			X ✓	X	
Income		X	X ✓	X	
Structure			X		
Density			X		
Car pool					X
Park and shop					X

[a] X means that data were collected, ✓ means that data were used

[b] In Chicago, a "priority mode" was defined data on other trips where two or more modes were used

[c] Screen line data were used in factoring

TABLE 4

ROADSIDE INTERVIEW

DESCRIPTION OF DATA	DATA COLLECTION AND USE, BY STUDY [a]				
	CHICAGO	BUFFALO	MILWAUKEE	WILMINGTON	TUCSON
Sample location (station)	X	X	X ✓	X ✓	X ✓
Hour period beginning	X	X	X ✓	X ✓	X ✓
Direction (in or out)	X ✓	X ✓	X ✓	X ✓	X ✓
Vehicle type	X ✓	X	X ✓	X ✓	X ✓
Number in vehicle	X	X ✓	X ✓	X ✓	X ✓
Trip origin location	X ✓	X ✓	X	X	X ✓
Trip destination location	X ✓	X ✓	X ✓	X ✓	X ✓
Trip purpose	X ✓	X	X ✓	X ✓	X ✓
Land use at destination	X ✓	X ✓	X ✓	X ✓	X ✓
Where is vehicle garaged (registered)	X	X ✓		X ✓	X ✓
Route of exit and/or entrance (through trips)	X	X	X	X ✓	X
Screen line crossed (control points) [b]	X ✓				X ✓
Canadian registration		X			
Truck load		X		X	
Entrance or exit points to thruway		X			
Land use at origin			X	X	X
Number of stops			X		
Commodity			X		
CBD origin			X ✓		
CBD destination			X ✓		
Through trip			X ✓		
New Jersey Route used for Station 01				X	
Trip purpose, through trips [c]					X
Land use at destination, through trips [c]					

[a] X means that data were collected, ✓ means that data were used

[b] Screen line data used in factoring

[c] Other studies collected these data, but had no special field for it

TABLE 5

TRUCK-TAXI TRIP RECORD

DESCRIPTION OF DATA	DATA COLLECTION AND USE, BY STUDY [a] CHICAGO	BUFFALO	MILWAUKEE	WILMINGTON	TUCSON
Sample location	X ✓	X	X	X	
Vehicle type	X ✓	X	X ✓	X ✓	X ✓
Garage address	X	X	X		
Business—industry	X	X	X ✓		X ✓
Number of trucks owned or rented	X	X			
Total trips reported	X	X	X ✓		X ✓
Trip origin location	X ✓	X ✓	X ✓	X	X ✓
Trip destination location	X ✓	X ✓	X ✓	X ✓	X ✓
Trip purpose origin	X	X	X ✓	X	X
Trip purpose destination	X	X	X ✓	X ✓	X
Land use at origin	X ✓	X	X	X	X
Land use at destination	X ✓	X ✓	X ✓	X ✓	X ✓
Starting time of trip	X	X	X ✓	X ✓	X ✓
Arrival time of trip	X	X	X ✓	X ✓	X ✓
Principal route of travel	X				X
Truck or taxi loading		X		X	
Expressway used		X			
Expressway entrance		X			
Expressway exit		X			
Number of stops reported		X		X	
Commodity carried			X		X
CBD origin			X		
CBD destination			X		
Year of manufacture					X
Unladen weight					X
Use of pick-up					X
Control points					X ✓

[a] X means that data were collected, ✓ means that data were used

mainly of updating surveys taken by city and county planning agencies.

Depending upon the technique used, there was considerable variation in the types of data collected, in the units of areas for which the smallest measurements were recorded, in the number and rural-urban orientation of land use categories used, and in other particulars. (See Table 6.) In the various analyses there was also variation in the degree of detailed processing to which such data were subjected. Most studies ran numerous tabulations of present land use

An item-by-item comparison of which land use data were or were not used by different studies is difficult. In some cases, particularly where data were furnished by local planning agencies and were originally collected for their own use, it must be assumed that all the data elements had planning utility—if not for the STPP, then for other planning purposes. Common for all purposes, however, was the identification and aerial measurement by land use category; this was required by all studies, and used by all.

Little may be gained from examining the merits of many versus few land use categories, within normal limits, neither the difference in cost nor the "accuracy" of the resulting data can be readily measured. Unlike with travel data, the problem is not the number and variety of individual types of data collected, but the finer breakdown of a single type of data—land use. Note, however, that no study carried the full range of data collection categories through all subsequent analyses and forecasts; the common experience was to combine categories first for the review of existing land use pattern and trip generation relationships, and then to simplify them further by combining the categories once more for the forecasting or planning phases.

In Chicago and Buffalo, floor space data were collected as adjunct surveys. Such data were expected to yield more detailed assessments of trip generation in central business districts (CBD) and other high-rise activity centers, in turn providing greater confidence with respect to modal split analyses and rapid transit planning. Although the floor area data provided extremely useful insights into the structure of the city and of the CBD, they were only marginally useful in the STPP. Unless an improved STPP is developed in which floor area data are required, it is doubtful whether such floor area surveys will be repeated.

With regard to land use-related data, the experience of the Milwaukee study is virtually without parallel. Because it was mandated to prepare a regional land use plan, and thus by definition emphasize those elements with which regional planning is most concerned (e.g., water supply, public open space, and wildlife habitats), the Milwaukee study undertook numerous special land use surveys. In effect, nearly all of these data were used in preparing the alternative land use plans, either directly in a quantitative

TABLE 6

LAND USE INVENTORY

DESCRIPTION OF DATA	DATA COLLECTION AND USE, BY STUDY [a] CHICAGO	BUFFALO	MILWAUKEE	WILMINGTON	TUCSON
Address—location	X ✓	X ✓	X ✓	X ✓	X ✓
Type of land use	X ✓	X ✓	X ✓	X ✓	X ✓
Vacant unusable	X ✓				
Vacant zoned by type	X ✓	X ✓			X ✓
Secondary land use code				X ✓	
Secondary land use of parcels in 100's acres				X ✓	
Number owner-occupied dwelling units				X ✓	
Number renter-occupied dwelling units				X ✓	
Number non-white occupied dwelling units				X ✓	
Non-conforming land use code				X ✓	
Number persons dwelling on parcel				X ✓	
Number of uses				X ✓	
Number of secondary uses				X ✓	
Watershed			X ✓		
Dwellings		X ✓			

[a] X means that data were collected, ✓ means that data were used

way, or indirectly under the "general learning" theory of data collection.

Where the STPP is construed as being limited to land use forecasting, such surveys as Milwaukee's are probably not essential, although they might improve the reliability of the forecasts. All conventional land use forecasts contain many "planning" elements. Forecasting and planning are not mutually exclusive; forecasting may, as in the Tucson study, be done entirely within the context of a land use plan, and thus primarily reflect the rate at which a plan may be fulfilled. To this extent, at least, the Milwaukee-type special land use-related surveys might serve to increase the acceptability of land use forecasting

Transportation Facilities Data

A third basic set of STPP data derives from the transportation facilities inventories that provide information about highway, bus, and rail networks, and terminal facilities.

The highway inventories were similar in all studies, differing only in the detail deemed necessary to compute highway study section, or link, capacities and traffic assignment travel times. First, arterial systems were designated (with greater or lesser attention to detailed functional classification breakdown) and link-node maps were prepared. Inventories were concerned only with the more important routes in the study areas (although in Chicago and Buffalo, traffic counts were taken on small samples of local streets for the purpose of deriving estimates of total study area vehicle-miles of travel). Various inventory data were then assembled for each link, various capacity and speed calculations were performed, and various capacity-use measures were tabulated. Rarely was extensive field work required, various highway agency records provided the bulk of the physical inventory, field work usually related only to vehicle use (i.e., traffic counts and speed runs).

Some specific observations can be drawn about the highway network inventories with respect to physical features and use measures. All of the studies assumed that link capacities were dictated by intersection approach capacities. Therefore, physical features of prime concern were generally those at intersections: approach widths, approach grades, and presence of left-turn storage lanes. Signalization and parking conditions generally were assumed, as were traffic use measures such as percentage of turns and percentage of commercial vehicles. Field work by study staffs was limited to the examination of a limited number of intersections where approach widths or major design details were not already available from various highway agency records Little, if any, attention was paid to mid-link geometrics as reflected in percentage of safe passing sight distance, shoulder widths, and marginal or medial obstructions In effect, highway network inventories in transportation studies are for a specialized purpose, and are far less detailed than those taken for some other purpose (e.g., for a statewide highway needs study or a TOPICS study).

The Tucson study represented some slight departures from the common experience. Fully detailed capacity studies, following standard *Highway Capacity Manual* (*28*) procedures, were undertaken at key intersections, and in addition surface and right-of-way widths, surface types, and "ridability" were recorded for the full length of all links. This reflected Tucson's greater concern for present highway network deficiencies, and the need for short-range improvements In such newer urban areas, where basic highway networks are not yet fully developed (in contrast to older urban areas in the East, for example), there is sometimes as much interest in the present network as in a long-range freeway plan

With regard to network use variables, there were marked differences among the studies Chicago and Milwaukee invested relatively little effort in taking traffic counts (but instead relied on updating existing traffic flow maps by a sampling technique), whereas Wilmington invested considerable effort. Buffalo, Wilmington, and Tucson made both turning movement counts and speed-delay runs—Tucson doing so more to measure present street performance than as an STPP input. Chicago's speed-volume study was done mainly for related research purposes, whereas Milwaukee undertook only limited studies in order to have a "feel" for network speeds.

Bus and rail network inventories were taken by all studies. Route, schedule, fare, and equipment data were obtained from company records. Although no field work was required for the physical inventory, the network mapping and summarization of scheduled services represented lengthy analytical tasks. In addition to quantifications of bus and rail use as reported in their travel surveys, Buffalo and Wilmington found it desirable to measure passenger-miles of travel (PMT) by direct surveys on buses. For example, Wilmington study staff recorded on-off passenger counts at every stop on all bus routes. Such data were used not only for transit travel accuracy checks, but also for subsequent detailed planning of alternative bus systems.

TABLE 7

SECONDARY DATA REQUIRED BY THE STRATEGIC TRANSPORTATION PLANNING PROCESS, WITH TYPICAL SOURCES OF SUCH DATA

DATA NEEDED	TYPICAL SOURCES
Population data	U.S. Bureau of the Census
Birth and death rates	City or County Clerk
Number of dwellings and other structures affected	Census, Sanborn, or local directories, special surveys
Employment data	State Department of Labor
Plans for land uses, by type	City or county planning board
Zoning maps and regulations	City, county, or town planning board
Topographic, floodplain data	U.S. Geological Survey
Historical buildings	Special survey may be required
Barriers map	Local planning boards
Automobile registration data	State Department of Motor Vehicles
Transit fares	Local transit company
Parking costs	Special survey may be required
Travel cost data for road types	Published sources (e.g., HRB)
Transit travel cost	Local transit company [a]
Accident cost data, by road type	Miscellaneous published sources [a]
Accident cost data, by transit type	Local transit company [a]
Road construction costs	State Highway Department
Transit construction costs	Miscellaneous published sources [a]
Arterial widths and pavement conditions	City, County Engineering Departments
Truck registration data	State Department of Motor Vehicles
Transportation plans	Highway Engineering Department
Value of person and vehicle time	Miscellaneous published sources [a]
Transit revenue passengers	Local transit company
Detailed maps, air photos	Highway Engineering Department
Other social value data	Special survey may be required

[a] Improvement in the quality and quantity of these data is needed

Terminal facility inventories were widely diverse. Excluding limited analyses of "kind of parking" as recorded in home interview surveys, Chicago and Wilmington simply ignored terminal facility problems (the latter demonstrating that a prior study of Wilmington's downtown parking problem met BPR requirements). Milwaukee and Buffalo assembled and analyzed CBD parking-space inventories available from city engineering departments. Tucson, however, took a special field survey of CBD parking, and performed detailed analyses of parking supply and demand—again, largely the result of the Tucson emphasis on short-term needs, not particularly related to long-range planning.

Buffalo was the only study to make special field surveys at bus, rail, and air terminals. These data were analyzed by the Office of Transportation, a sister agency in New York State government, and the results were used in the STPP only for increasing general knowledge. A related Buffalo study analyzed and reported the movement of goods by rail freight, but did not use the results in the STPP. Chicago, Buffalo, and Milwaukee considered truck terminal problems through truck-garaging or truck trip-end data, both from truck-taxi survey information.

Socioeconomic Data

The fourth, and last, major category of primary data is socioeconomic data. Apart from the household information stemming from home interview surveys, and apart from the assembly of various information from secondary sources considered in the following, only Milwaukee reported significant socioeconomic data collection surveys (the household history and the industrial management surveys), and neither had extensive use in the STPP. Otherwise, there were no separate socioeconomic surveys, as such.

Secondary Data

More secondary data are required in the STPP than is commonly supposed. Table 7 gives the numerous types of secondary data needed and the variety of individual sources. Use varies from less essential "general learning" to more essential "mainstream STPP" applications. Population, housing, business, and manufacturing census data clearly were essential for forecasting and planning, highway and transit unit costs for construction and operations were essential for benefit-cost analyses, and so forth down the list. The various uses of secondary data in the basic STPP appear in Appendix B.

As most planners will appreciate, secondary data were seldom completely and conveniently available in the form desired. Thus, there was generally some reported difficulty in searching through various, often conflicting, source materials to find the most applicable data. Although it will continue to be a problem to obtain those secondary data that are specific for each metropolitan area, it can—in the opinion of the researchers—be made easier to obtain some secondary data that represent national experience of one kind or another. For example, vehicle operating, accident, and travel time costs by different urban street types; transit operating and accident costs, and transit construction costs are data that are constantly being sought by different transportation studies. Search for such data continues to plow old ground. It should be possible to assign each of these subject areas to a state agency, or possibly a university, that would then be expected to be the national expert in that field, answering questions and providing data as required.

Data for Research

The amount of research in a transportation study appears to be mainly a function of study size and organization Only the very largest studies have had the requisite budget and personnel to undertake significant research, and they tend to be ad hoc studies rather than consultant or highway-department-directed studies. Study objectives also play an important role in determining the amount and kind of research to be attempted. The first studies to make transit assignments, for example, necessarily had to undertake applied research to do so. Among the most prolonged research projects (because so difficult to accomplish) have been those related to simulation-modeling of urban growth Where these have been included as prime study objectives, extensive work has been required. At the other end of the scale, some studies (Wilmington, for example) have expressed the intention to do as little research as possible, indicating instead a preference for doing a "production job" using methodology and models already at hand.

Among the studies examined here, Chicago is recognized for its research work in several areas. traffic and transit computer-assignments to complete networks; least-cost travel solutions involving the efficient spacing concept, etc Buffalo contributed a multi-mode, or simultaneous, traffic-transit assignment package and an improved land use forecasting program. Milwaukee adapted existing techniques for most of the preceding steps, but is noted for contributing its own modal split, land use, and economic models By contrast, neither Wilmington nor Tucson provided documented research on major topics (Tucson's modified version of the opportunity model, developed by the BPR in the Washington, D.C , office, is described in its final report, however).

As noted in the introduction to this report, the use of data for research was recorded on special forms. From these forms, it is possible to generalize that most of the major research projects have been done with the basic data gathered for the STPP. A minimum of special data obtained solely for research purposes was obtained. Special data were, however, required for the Milwaukee study's development of a regional economic simulation model and a land use, or urban growth, model. The requisite household history and industrial management data were relatively expensive and difficult to collect The experience highlights an often perplexing problem: should the STPP include that type of research, such as economic model development, having great interest for related planning purposes, but only tenuous connection with transportation?

Two conflicting policies on collecting data for research can be posed· one policy is to collect only those data that are known to be required by a fairly well-defined planning process. The second policy is to collect more data than are needed, so that the data can be used for research work, either to prove hypotheses that have already been advanced or to make measurements for the purpose of assisting in the development of new hypotheses and theories.

This report concentrates on studies of fairly well-defined planning processes. However, it is recognized that there is a need for data for research purposes, and it is recommended that "risk capital" funds be expended to fill this need Although it might be preferable to have these "risk capital" funds acknowledged as such, this may not always be possible. The administrative necessities of the data collection phase of a major transportation or land use planning process may require the speculative collection of additional data for research purposes without a guarantee of the ultimate utility of the additional data obtained.

Costs and Times

One of the alleged faults of past data collection efforts has been the apparent high cost. A review of the five-study experience tends to refute this. Total primary data collection cost has been taken to include coding, editing, correcting, keypunching, verifying, factoring, and tabulating data for checking purposes. In this review, costs are included only for those data considered to be essential to the basic transportation planning process (more than 95 percent of all data costs). However, this does not hold true for the Southeastern Wisconsin Regional Planning Commission program, which had a much broader program than just transportation, and collected data on other resources at substantial additional costs. These costs are excluded here because this study is concerned with transportation planning

Because the cost accounting practices of transportation studies vary, costs were obtained on individual data collection activities (such as for origin-destination surveys), then added for each study to give total data collection costs. Although the costs for individual surveys may be off, the total costs are of the right order of magnitude.

The total cost of primary data collection averaged only $0 52 per capita (Table 8) For the five studies, such rates range from $0 22 to $0.86 per capita, all of which are well within the range commonly accepted for budgeting purposes.

Another criticism has been that data collection and processing costs far outweigh data analysis and planning costs Evidence, however, suggests that primary data collection costs run only about one-third of total study costs—a level that certainly allows adequate funds for thinking and planning. The total cost of primary data collection averaged 31 percent of the total study budgets, ranging from 25 percent to 38 percent (see Table 8)

Secondary data (costs for which are not given in Table 8) are not acquired cost-free Such data usually require some transposition, some updating, some intermingling of content, or some sorting out of conflicting numbers. Costs tend to be unpredictable. It is suggestive, however, that various staff members confided that: "We wish we had run our *own* survey of that." Apparently, costs of using secondary data are significant

The total cost of the transportation studies was but a small fraction of the capital costs of the transportation plans recommended. The latter, for example, range from

TABLE 8

COMPARATIVE COSTS OF COLLECTING "BASIC" PRIMARY DATA IN FIVE TRANSPORTATION STUDIES

STUDY	DATA COLLECTION COSTS ($)[a]	PER CAPITA COST OF DATA COLLECTION ($)	TOTAL STUDY COST FOR DATA COLLECTION (%)
Buffalo	584,000[b]	0.43	36
Chicago	1,160,000[c]	0.22	28
Milwaukee	603,000[d]	0.36	30
Tucson	209,000[e]	0.86	38
Wilmington	236,000	0.73	25
Average (unweighted)		0.52	31

[a] These costs, based on data provided by the studies, have been interpreted and adjusted to place costs on a more nearly uniform basis

[b] Does not include $25,000 for railroad network and goods movement surveys

[c] Does not include cost of statewide motor vehicle use and accident cost studies made late in the study's 6-year planning period

[d] Does not include $256,300 for attitudinal, economic, demographic, natural resource, financial resource, and planning legislation surveys, the large bulk of which were required for the Southeastern Wisconsin Regional Planning Commission's land planning mandate

[e] Does not include $13,000 for accident and CBD parking surveys

$281 million to $2 billion. The total study costs, therefore, average less than 1 percent of the capital costs of the recommended plans

A real problem with past data collection has been the length of time required to plan for, collect, and process the required primary data. It is difficult to generalize on this subject, because the collection of data includes several distinct types of surveys, some of which are completed quickly and others, more slowly.

From experience, however, it appears that 2 years has been the average time required to collect and process the major land use, travel, and network files. This length of time has been a major problem in past planning programs, increasing frictions between transportation studies and both sponsoring agencies and the public. One of the advantages of a continuing transportation planning program is that data collection will not stop other operations, but will be part of an on-going program.

The "Basic" STPP

To provide a basis for making generalizations about data needs, it was decided to diagram a "basic" strategic transportation planning process. The idea was to lay out a process that would produce a strategic transportation plan (as defined in "Strategic Transportation Planning Defined") as simply as possible, including only work elements that were considered essential.

The "basic" STPP was developed by superimposing the macro-diagrams of the five transportation studies' planning processes, and drawing off the common elements. Judgment had to be used at this stage. The resulting diagram is shown in Figure 3.

The data needs (both primary and secondary) of the "basic" STPP were then defined. This lengthy list is included in Appendix B. A short form of the Appendix B data is given in Table 9. This is considered to be the minimum amount of data required to prepare a strategic transportation plan. Variations in data are specified to allow for the use of different models, such as the gravity model or the opportunity model.

DATA NEEDS OF RELATED PLANNING PROCESSES

As noted under "Defining the Focus of Research," transportation planning is a term that embraces a fairly large family of different technical planning processes. Besides the strategic planning process, data needs for which are described previously, there are a number of related planning processes that include both implementation and strategic types.

At the outset of this research project, interviews with transportation officials disclosed their desire for the investigation of the data needs of related kinds of planning. The purposes for so doing were three First, knowing that transportation planning is an evolving and expanding family of processes, it was considered desirable to find out more about some of the kinds of planning that may have new and increasingly close relationships with the well-established strategic planning process. Second, it was deemed important to determine the data needs of these processes The third purpose was to see if there were potential economies from coordinating data collection of these related processes with the data collection of the strategic planning process

Of the many possible kinds of related planning processes, four were selected for detailed examination. These were·

1 TOPICS planning.
2 Transit planning.
3. Route location planning.
4. Metropolitan planning.

The first three of these types of planning are implementation planning processes. This reflects the concern of transportation officials with improving implementation planning and for closing the gaps between the strategic planning process and all kinds of implementation planning

Research into data needs for metropolitan planning reflects the trend toward more joint land use and transportation planning at the strategic level Here also the possibility for joint use of data seemed good.

The research method for each of these four kinds of related planning was basically the same, although circumstances tended to require some modifications. Organizations that had done recognized work in these study areas were contacted, their planning processes were diagrammed, and their data files were examined. Data needs were determined on the basis of this evidence. Also, literature searches were conducted and leaders in each type of planning were interviewed.

TOPICS Planning

There are two main purposes for considering the relationships between strategic transportation planning and TOPICS:

1. To determine how several cities have approached the relatively new TOPICS program in terms of the planning

process used, and to look for ways that the process is still evolving

2 To compare that process with the strategic transportation planning process from the standpoints of:

a Data needs (improving STPP data collection surveys, if possible, to better serve TOPICS data needs).

b The impact of TOPICS improvements on the extensiveness of planned major systems of transportation improvements and the comparative timing of such improvements.

c. The possible need for a more rigorous TOPICS planning process.

A "traffic operations program for increasing capacity and safety" of selected arterial streets in urban areas (TOPICS) was announced by the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, early in 1967. Essentially, the program provides the first opportunity for extending Federal-aid, through state highway departments, toward traffic engineering improvements.

Street improvements eligible for TOPICS funds include· channelization of intersections, providing more traffic lanes at signalized intersection approaches; construction of pedestrian grade separations or highway grade separations, installation of a variety of traffic control systems; addition and upgrading of highway lighting, traffic control signs, pavement markings, and other control devices; improvements to truck and transit terminal and loading facilities; and the establishment of traffic surveillance systems

There are strong links between systems planning and TOPICS. Both processes deal directly with improving transportation in urban areas, but at opposite ends of the planning spectrum: systems planning aims at the broad strategy of making major transportation facility investments, whereas TOPICS aims at the fine-grained tactics of making more immediate and less expensive investments Usually each process affects the other, as is shown later.

The TOPICS planning process is deliberately flexible. Because overly restrictive requirements at the outset might have delayed the development of the program, Bureau of Public Roads' instructional memoranda described only general procedures, including (1) a functional street classification study leading to the designation of a new Type II Federal-aid primary system (which, along with existing Federal-aid systems, would be eligible for TOPICS funding), and (2) an inventory, for all streets on all Federal-aid systems, describing physical features, traffic flow and capacity, accident experience, public transportation routes, and terminal facilities (*1*).

The memoranda did not specify the types and content of the subsequent analyses, or establish any fixed "planning process." This suggests general recognition that (1) standard traffic engineering analyses were acceptable, and that (2) individual problems in individual urban areas would require flexibility of analytical approach. Defining a TOPICS planning process more specifically would have amounted to defining the whole range of traffic engineering studies—unnecessary, because they are fully described in such basic references as the *Traffic Engineering Handbook* (*2*) and the *Manual of Traffic Engineering Studies* (*3*)

TABLE 9

PRIMARY AND SECONDARY DATA REQUIRED FOR THE BASIC (OR STRATEGIC) PLANNING PROCESS

PRIMARY DATA	SECONDARY DATA
Primary population data	Census population
Dwelling places	Birth and death rates
Employment by land use	Number of dwellings and other structures affected
Land use by type	Employment
Person trip destination by mode	Plans for land uses, by type
Person trip destinations, by purpose	Zoning maps and regulations
Person trip destinations, by land use	Topography and floodplains
Person trip origins and destinations	Historical buildings
Truck trip destinations, by land use	Barriers map
Taxi-trip destinations	Automobile registrations
External vehicle trip destinations, by type, purpose, land use	Transit fares
Person trips by mode by time of day related to auto use	Parking costs
Automobiles available	Travel costs, by road types
Road network	Transit travel cost
Transit network	Acident costs, by road type
Vehicle-miles of travel	Accident costs, by transit type
Person-miles of transit	Road construction costs
Speed-volume data	Transit Construction Costs
Screen line volumes	Arterial widths and pavement conditions
Link speeds	Truck registrations
	Transportation plans
	Value of person and vehicle time
	Transit revenue passengers, by type
	Detailed maps and air photos
	Other social values

The general TOPICS planning process is reviewed first to illustrate how several cities have approached the program, and, particularly, to describe the relationships of data needs as between TOPICS and the STPP. Thus the next sections summarize the TOPICS experience in Woonsocket, R.I , Lincoln, Neb , Rutland, Vt.; and Stamford, Conn. Subsequent sections consider present versus future TOPICS data requirements as they relate to the timing and extensiveness of STPP plans. Various findings are summarized in a concluding section

TOPICS in Woonsocket and Lincoln

As part of this project, personal visits were arranged with various highway officials both in Woonsocket (*4*) and Lincoln (*5*) Such visits provided the researchers with first-hand descriptions of the TOPICS work completed and of the problems involved.

The Woonsocket Experience.—Woonsocket was the first TOPICS pilot study completed Essentially, it was conducted by the Rhode Island Statewide Comprehensive

Transportation and Land Use Planning Program (RISPP) as part of its continuing transportation planning function. Technical assistance was provided by the Rhode Island Department of Public Works and the City of Woonsocket The study began in October 1967 and a final report was delivered in April 1968 That report, *Woonsocket Topics* (*6*), described the study as "one of several being conducted throughout the country for the purpose of testing the organizational, administrative, and technical feasibility of TOPICS."

Woonsocket is a typical old New England mill town, separated from the main portion of the Providence-Pawtucket-Warwick Standard Metropolitan Statistical Area (SMSA) by rural development, and consequently somewhat self-contained With a population of around 50,000 and significant further growth not expected, city streets were termed "adequate but particular sections of them are not geared to the exacting requirements of the modern-day motor age " There has never been a city traffic engineer, although some traffic engineering services have been provided occasionally by the Rhode Island Department of Public Works

The Woonsocket TOPICS planning process is shown in Figure 4. The total six-month TOPICS study period can be reduced to separate time stages only with difficulty. Often the stages overlapped, as reflected in the parallel lines of the diagram. Some of the feedback loops and interactive steps in the process reflect the near-continuous review of Woonsocket officials (particularly important in selecting the streets with critical safety and congestion problems) rather than an analytical stage.

The general strategy was, apparently, to establish the critical trouble spots quickly—those intersection and mid-block locations with special traffic problems (Steps B, C, D and E) Although analysis of longer routes, per se, was not an immediate objective, those intersections finally selected as most critical were situated largely along half a dozen principal routes, so that route improvement was a final result

At the same time, considerable background data were assembled, largely from Rhode Island Statewide Planning Program (RISPP) sources, in order to "document and to understand the existing situation." This included inventorying socioeconomic factors, charting traffic regulations, detailing traffic flows, and functionally classifying streets (Steps K, L, M and N)—all apparently secondary to identifying critical troublespots

Two basic criteria for determining "criticalness" were established as the study progressed. (1) locations with five accidents per year, or more, and (2) locations with peak period intersection delays of more than two signal cycles Once selected, and following review with Woonsocket officials (Step F), in-depth analyses of the critical trouble spots (Steps G, H, and I) were aimed at improvement specifications (Step J).

The final report called for the redesign of 19 intersections

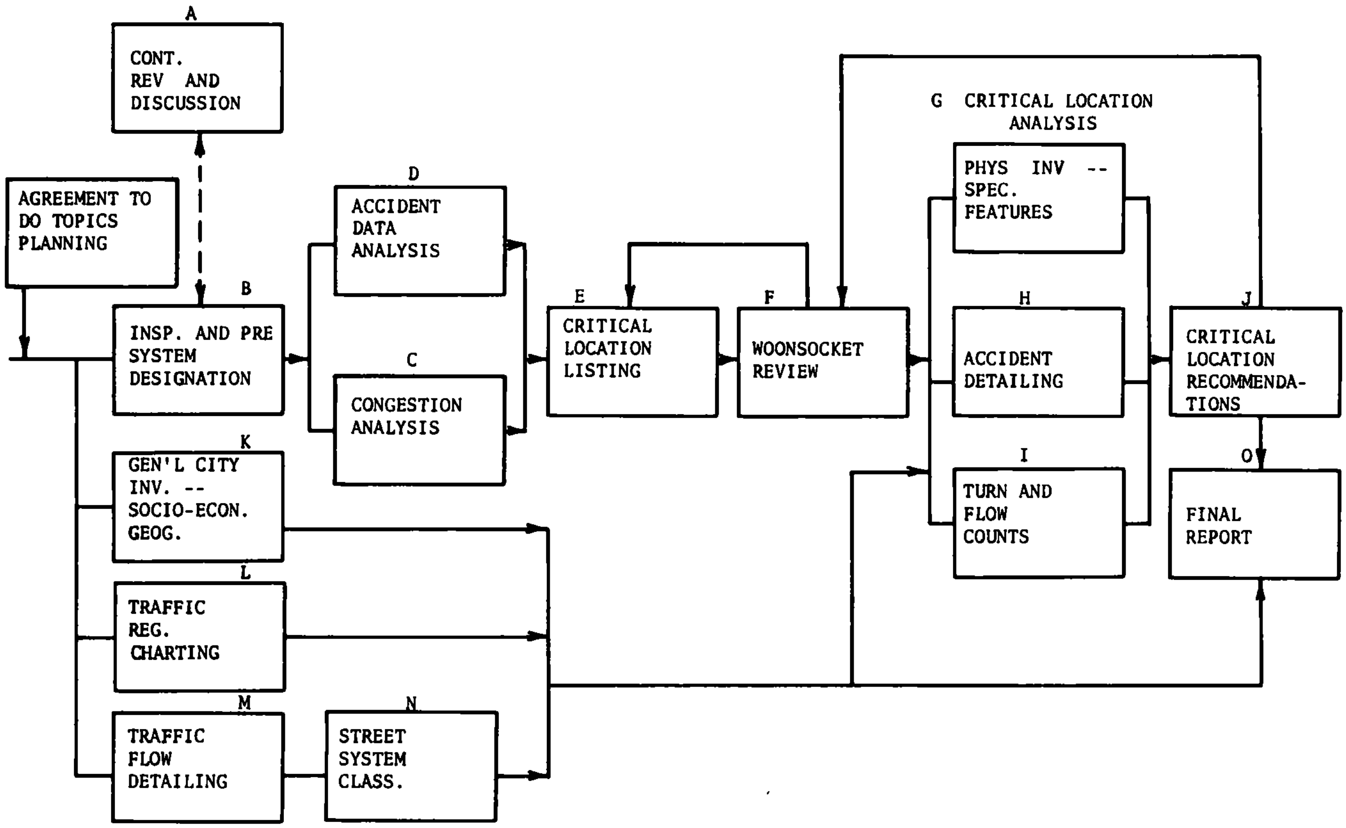

Figure 4 TOPICS planning process—Woonsocket, R I

"which currently experience high traffic congestion or which are demonstrably unsafe", for design modifications at 20 additional intersections "to improve traffic flow and safety", and for seven midblock areas "in need of improvement" Current situation diagrams and specific recommendations for each location were described in the report

Because such changes would not fully meet Woonsocket's transportation needs, the report also specified that a "traffic relief route for the downtown section of Main Street be constructed in the immediate future." This recommendation, the subject of a separate report, *Downtown Traffic Relief Route* (*7*) by the RISPP illustrated how TOPICS improvements could be derived within the context of major systems planning and route construction.

Other TOPICS-related recommendations separately called for route market and truck route signing improvements, for creation of a traffic engineering department (or equivalent consultant services), for modification of existing Federal-aid systems, and for adoption of the necessary Type II Federal-aid primary system The estimated cost of operational improvements, fundable through TOPICS, was $270,000.

The Lincoln Experience—In Lincoln, TOPICS was essentially a modification and refinement of existing street improvement plans This is stated clearly in the report, *TOPICS Program for Lincoln, Nebraska* (*8*)·

> The development of the program is based on a previously well-planned improvement program outlined in the "Lincoln Metropolitan Area Transportation Study, 1966," and each individual improvement is an integral part of that program

TOPICS, in fact, if not by name, already existed—the city having had a professional traffic engineer for at least 5 years. Thus, the city traffic engineering department, in conducting the 18-month study (June 1967 to December 1968), found special surveys unnecessary. Requisite data were available either from its own files or those of prior studies, principally the Lincoln Metropolitan Area Transportation Study (1966) and a major city engineering department study (1964) immediately preceding it.

Lincoln's growth prospects are excellent. The study area population is about 163,000 and is projected to reach about 256,000 by 1985. Lincoln's industrial base is expanding rapidly, and, as the state capital and site of the University of Nebraska, it has an active retail and wholesale trade. As a result, urban area vehicular travel is projected to increase about 79 percent between 1963 and 1985.

Lincoln's TOPICS program recommendations call for major redesign of 15 intersections at a cost of $2.4 million, upgrading of the downtown traffic control system to cost $0.7 million, and provision of improved arterial street lighting to cost $0 8 million—a total of $3.9 million. In the process of arriving at these recommendations, the planning problem was one of designating priorities within existing programs and their associated costs. The foregoing recommendations, relatively generalized in the final report, primarily reflect an allocation of limited funds to a preferred list of previously identified projects.

The TOPICS planning process in Lincoln was the means of making that allocation through the reexamination of priorities, design details and costs. The process was generally quite direct, with but one consequential feedback loop required to finalize the critical location listing (see Fig 5). In effect, TOPICS funds would simply speed up the implementation of established programs on a modified priority basis.

TOPICS in Rutland and Stamford

Stamford is a city of about 125,000, centered in a metropolitan area of about 200,000 (*9*) A pilot TOPICS study, *Stamford Traffic Engineering Program* (*10*), was completed in March 1968 by Wilbur Smith and Associates, with participation by the Connecticut State Highway Department and local officials The city has employed traffic engineering consultant services in the past, but has not had an organized city traffic engineering department.

The TOPICS planning process used a "systems approach" in which careful consideration was given to the functional interrelationships among all arterial streets, and to long-range plans and urban renewal activities. Six planning steps were involved: (1) existing traffic data were assembled, (2) both air and ground reconnaissance investigations were made, (3) detailed field studies of peak and off-peak traffic volumes, levels of service, parking conditions, and traffic controls and devices were made, (4) an arterial street system was delineated, (5) service deficiencies and problem locations on this system were identified, and (6) recommendations and priorities for improvements were made

Although many pertinent planning data were available, the researchers conducted several field inventories, including traffic volume and turning movement counts at 160 locations, speed and delay runs, and various reviews of traffic control devices and actual traffic operations. These inventories were deemed essential for the analytical phases of the study and for the development of recommendations. They also served as a "bench mark" for evaluating benefits of proposed TOPICS improvements: for example, through expected reductions of congestion and accidents—based on the bench-mark measures—the improvements were estimated to save motorists more than $1 million annually.

Recommendations totaled $4 3 million, of which $2.6 million were related to "electrical and utilities" costs and $1.7 million were related to "engineering and construction" costs. Priorities were established on area and route bases, generally proceeding outward from the CBD, where present congestion was most critical, to peripheral areas. It was stressed, however, that all parts of the city would benefit from the resulting TOPICS improvements.

Rutland is one of the smaller cities—population 18,000—to have completed its TOPICS study (*11*). *Rutland TOPICS* (*12*), the final report, was transmitted in May 1968. The work was done by Wilbur Smith and Associates, with participation by the Vermont Department of Highways and local officials. There has never been a traffic engineering department That function has been handled by the police department, and, from time to time, by the Vermont Department of Highways.

The TOPICS planning process espoused a systems approach that gave "full recognition to areawide traffic interaction." This consisted of five sequential steps: (1) ex-

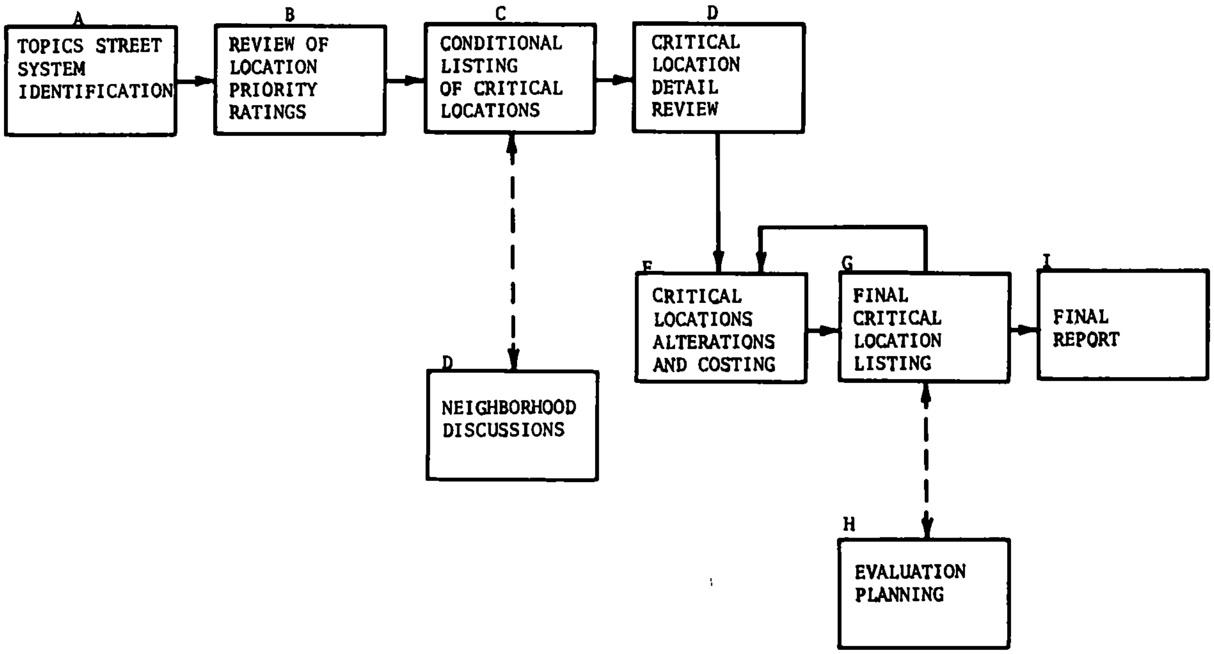

Figure 5 TOPICS planning process—Lincoln, Neb

tensive field reconnaissance of existing traffic operations, (2) detailed field studies, (3) designation of an arterial street network, (4) identification of deficiencies, and (5) recommendations and priorities developed on a system basis (see Fig. 6).

Although various background information was available from several previous traffic and planning studies, the researchers performed the following field surveys: (1) turning movement, manual classification, and machine traffic counts, (2) speed and delay runs, (3) special counts and license plate survey at a downtown shopping center, (4) parking regulations survey for the study, and actual parking supply and demand survey in the downtown area, (5) sign and signal survey, and (6) a street and sidewalk width and condition survey. These surveys were not restricted to "TOPICS system" streets, and, in fact, generally preceded designation of the final arterial street network.

Recommended improvements were estimated to cost $435,000, including $147,000 for selective widening, resurfacing, channelization and other physical improvements on a route basis, $193,000 for the traffic signal system, $10,000 for signs and markings; and $85,000 for a new municipal parking lot (to be financed entirely by the city). About three-fourths of the non-city costs were for improvements on Type II Federal-aid primary streets, and one-fourth was for improvements on existing Federal-aid system streets

TOPICS Nationally

TOPICS studies now have been undertaken throughout the United States. As of August 1969, 85 areas were formally engaged in the TOPICS program, and preliminary negotiations were underway in an additional 85 areas (*13*). At that time, about $2.0 million in Federal-aid funds had been authorized or programmed to finance TOPICS projects estimated to cost about $3 9 million. Of the Federal share of the total cost, about $1.6 million were specifically TOPICS funds, and about $0.4 million were ABC funds

Like most new programs, TOPICS started slowly. But BPR officials, interviewed late in 1969 by the researcher, expect the TOPICS program to become steadily more active. Congress has appropriated $200 million for it both for fiscal years 1970 and 1971, and there is good prospect that this level of funding will be maintained. The still-newer Federal programs for CBD fringe parking facilities (*14*), and urban travel corridor improvements (*15*), both of which can be undertaken in conjunction with TOPICS, seem likely to enhance its interest to all concerned.

TOPICS seems destined to have increasing importance. As more major facilities—freeways and rapid transit—are built, the prime systems of movement will approach completion. Emphasis must necessarily shift toward the supporting arterial street systems. It follows that coordination of TOPICS and STPP data requirements will have increasing significance. The following section discusses the degree to which typical STPP data meet these needs

TOPICS Data Requirements, Present and Future

Considerations of Timing.—Fundamentally, TOPICS is a short-range program dealing with street improvements needed now. To this extent, TOPICS data requirements concentrate on existing rather than forecasted conditions. As an action program in which recommended improvements will come within five to six years, the 20-year forecasts that the transportation planning process prepares are not needed as direct or immediate parts of the planning process. However, such long-term forecasts are necessary background factors that must be considered.

The basic street inventory and traffic data for TOPICS, where not already available as part of the on-going activities of an established city (or traffic) engineering department, are directly accessible by field inventories. By contrast to the STPP, these are relatively simple and straightforward, and do not require complicated sampling techniques. Such inventories do, however, stress detail, because detail is essential to making immediate recommendations

Where recommendations involve permanent rather than temporary changes, such as the reconstruction of an intersection versus the retiming and upgrading of signalization equipment, TOPICS must look farther ahead than the span of a single capital improvement program. Intersection redesign requires a long-range traffic forecast This information should derive from the STPP, where it has been developed in the context of an areawide plan

A single TOPICS study does not, obviously, specify for all time the operational improvements needed in a given city. With continuing urban growth, mounting traffic will require both additions to, and changes in, the various systems of traffic control devices. TOPICS might best be seen as a continuous series of short-range planning studies within the broader framework of long-range transportation studies

TOPICS would thus seem to require intermediate-year traffic forecasts (not just a 20-year look ahead) as well as continuous basic inventory data, for making immediate recommendations. In establishing TOPICS priorities, for example, it might be more economical to improve an intersection which, although not presently critical, would become much more critical in ten years than others, presently critical, would become. This approach, possibly beyond the explicit current concept of TOPICS, will surely be reflected in the thinking of many TOPICS planners.

In between TOPICS and freeway systems planning lies the area of local and arterial street planning. city streets or county and state highways within or at the edge of urban areas. Not only do these require periodic redesign and reconstruction, but, through the years, new streets and roads must be added to serve developing areas. In larger urban areas, considerable planning is required to decide where and when these new streets and roads will be built. Often such projects represent the major item in local capital improvement programs, and, for this reason, local officials have sometimes sought planning help through the STPP. Generally speaking, however, the STPP has not been helpful, because of its technical limitations at this level of detail—nor will TOPICS necessarily fill this gap.

In effect, arterial street planning is another of the implementation planning processes not considered in this report. Clearly, the process is highly dependent on analytical methods of selecting priorities; the literature on the subject refers frequently to sufficiency ratings and other approaches to ranking projects by need. Because this is a continuing process, with capital improvement programs reassessed at least every few years, this report recommends that there should be stronger link with the continuing STPP. Any "special" data required for arterial street planning, however, are viewed as implementation data, and not to be included as part of the basic STPP outlined earlier.

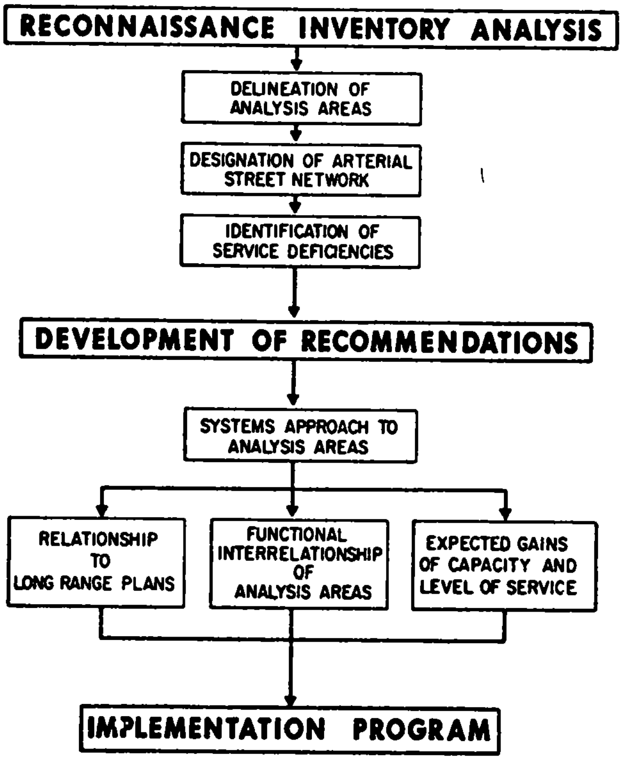

Figure 6 TOPICS planning process—Rutland, Vt. Source Wilbur Smith and Associates (12, *Fig 2*).

Considerations of Network Extensiveness.—TOPICS funds may be spent only on existing Federal-aid systems and the newly created Type II Federal-aid primary system —potentially 20 to 30 percent of total urban street mileage. However, a TOPICS "study" need not limit itself to studying and making recommendations for Federal-aid routes only; indeed, for TOPICS improvements to be effective, improvements on non-TOPICS streets—both arterial and local—may often prove mandatory. In effect, the systems approach described in both the Rutland and Stamford reports illustrates why TOPICS needs can no more logically be separated from other existing street needs than total existing street needs can be separated from future transportation system needs for the whole urban area. Only in the funding sense is TOPICS limited to Federal-aid systems improvements.

Ideally, then, TOPICS inventories should cover all arterial streets in any urban area (though they are required only for Federal-aid routes) The inventory items specified by the Bureau of Public Roads include, "to the extent necessary," those items given in the first column of Table 10 (*16*).

A literal interpretation of the BPR requirements is not intended An inventory of all traffic control devices, for example, literally would call for recording the location, type, size, legend, and condition of every traffic sign and pavement marking along every potential TOPICS route. Obviously, many signs and markings would have no significant effect on safety or capacity, and could be ignored

To the extent that traffic problems vary from city to city,

TABLE 10

REQUISITE INVENTORY ITEMS IN TYPICAL TOPICS STUDIES

ITEMS TO BE INVENTORIED IN A TOPICS STUDY, AS SPECIFIED IN BUREAU OF PUBLIC ROADS' *PPM 21–18* (*16*)	ITEMS INVENTORIED BY FOUR CITIES REVIEWED IN THIS PROJECT			
	WOONSOCKET	LINCOLN	STAMFORD	RUTLAND
1. Right-of-way width, pavement width, roadway type and conditions, and traffic control devices	✓[a]	✓[a]	✓	✓
2. Public transportation routes, stops, headways, layout of bus stops, and type and location of passenger facilities	✓[a]	✓[a]	✓	NA
3. Existing traffic laws and ordinances and regulations relevant to realizing the full potential of a street network	✓	✓	✓	✓
4. All traffic operations practices, authorized and unauthorized, that influence street capacity and safety	✓	✓	✓	✓
5 Traffic capacities for major segments of the street system based on level of service C (or D)	✓[a]	✓[a]	✓	✓
6 Classification of traffic by motor-vehicle types where needed for capacity or other studies	✓[a]	✓[a]	✓	✓
7. ADT, peak hour, peak-hour factors, and off-peak-hour flows	✓[a]	✓[a]	✓	✓
8. Peak-hour and off-peak-hour travel speeds and points of delay along major segments.	✓[a]	✓[a]	✓	✓
9 Accidents, accident rates, and other related accident information for major segments	✓	✓[a]	✓	✓
10. Highway access to commercial airports, considered in context of complete transportation system	✓	✓[a]	NA	NA

[a] Data needs at least partially met by STPP
NA = not applicable for lack of transit system or major commercial airport

greater or lesser emphasis could, and should, be placed on particular items within the required inventory. This is so indicated by BPR memorandum *PPM 21-18* (*16*):

> The data required for study will vary depending on local conditions, but should be adequate for conducting all necessary traffic engineering analysis . . Generalized data will normally be adequate for overall evaluation of operations on the existing Federal-aid systems and the proposed Type II system, with more detailed data required for those locations found to be problem areas.

Such flexibility was clearly evident in the four cities where TOPICS plans were reviewed: as Table 10 indicates, the requisite inventories were taken in each case; the scope and detail of the comparable inventories, however, tended to vary widely. Emphases varied as a result of different underlying anticipations of what might be accomplished: for example, Lincoln saw its TOPICS improvements as going well beyond an already routine traffic engineering program, where Woonsocket was just taking the first step in that direction.

It is significant that STPP street and transit facility inventory data only partially fulfilled TOPICS data needs at best (indicated in Table 10). A fairly large share of TOPICS data needs in Lincoln were so provided (the remainder coming from other previous inventories by the city engineering department), perhaps not more than a third in Woonsocket; and none in Stamford (though Stamford falls within the Tri-State Transportation Commission Study Area). Rutland had never had a full-scale strategic transportation planning study because of its small size—only 18,000 population.

Evolving TOPICS Methodology —It is too soon to speculate about future TOPICS data requirements. Much will depend on the evolution of the TOPICS planning process itself. Nevertheless, some trends are already evident For example, the systems approach probably will gain greater acceptance. Instead of studying critical locations or critical areas, and sometimes setting improvement priorities for them as though unrelated, the evolving planning process will begin to treat whole routes and systems. If TOPICS had its genesis in the BPR *Wisconsin Avenue Study* (*17*), then the route approach has been intended all along. The problem so far may have been determining the relative cost effectiveness of improving one route as against another.

More rigorous methods of assessing benefit-cost relationships will emerge. Completed TOPICS studies have often begged the question of cost effectiveness—possibly because traffic engineering improvements have been so badly needed that, even at extremely elemental levels, almost any of the improvements that are made at the outset are highly rewarding. When all the more obvious improvements have been made, however, continued TOPICS planning will require greater concentration on benefits versus costs.

The problem is that any changes in street systems, whether through capital improvements or minor traffic engineering improvements, create repercussions that extend throughout the system, to a greater or lesser degree. Many of these consequences cannot be foreseen without extensive study through simulation. Hence, it appears desirable to establish an approach for traffic simulation that would determine the cost effectiveness of proposed changes prior to installation of improvements.

This approach—possible through the process of microassignment (*18*)—would greatly expand present TOPICS planning options. Moreover, current research toward "Optimizing Flow on Existing Street Networks" (*19*) may produce better measures of the efficacy of individual traffic engineering remedies. The objectives of this two-year, $1 million project, as specified in the Project Statement, are to "develop a practical method of measuring the degree of change in network traffic flow resulting from various system modifications and to evaluate the degree of change resulting from practicable modifications."

In short, future TOPICS data requirements are apt to relate to a planning process not unlike the STPP itself, only at a much finer level of detail. All the ingredients are present. TOPICS deals with a street system, and with measurable benefits and costs.

TOPICS and the Strategic Transportation Planning Process

The review of five completed tarnsportation studies discussed previously shows that the designated "arterial street networks" normally included all streets potentially to be programmed for TOPICS improvements. Exceptions are possible. for example, the networks might omit some downtown streets potentially eligible for TOPICS. Moreover, as noted before, non-arterial streets sometimes must be considered in order to make TOPICS improvements effective But the extensiveness of STPP networks would generally be no problem to TOPICS data collection or planning.

The associated STPP inventories for those networks would not, however, meet TOPICS data requirements Although the study inventories differed slightly, almost no data were collected for STPP purposes on traffic control devices, parking regulations and practices, loading zones, or accident rates. Relatively few data were available on right-of-way widths (as distinct from pavement widths) or roadway type and conditions. "Link" capacities were calculated largely by generalizing about intersection characteristics, rather than by relying on precise field studies. Although all studies assembled reasonably complete traffic count, travel speed, and public transportation system information, only Tucson collected much of the foregoing types, largely because of its greater interest in immediate street improvements.

Moreover, the STPP inventories typically concentrated on intersection conditions, assuming these to control capacities and speeds for whole links regardless of link length or conditions between intersections. This automatically excluded much information necessary in TOPICS planning Again, there can be exceptions. the inventory conducted for the Lincoln Metropolitan Area Transportation Study was essentially the kind taken in statewide "highway needs" studies; it included more data, generally, and more "mid-link" data, specifically, than typical STPP inventories (*20*). This was possibly the major reason that the Lincoln TOPICS study needed no new data collection.

Still, STPP inventory data, after summarization and analysis, can fulfill one very important part of the TOPICS planning process: the rapid convergence on critical problem areas and problem routes. For example, volume/capacity ratios, plotted by link, or aggregated by traffic zones or districts, can quickly and systematically reveal the general nature and location of existing deficiencies. Such an approach was used in Woonsocket, using RISPP processed data, with some success. STPP generalizations regarding "link" capacities did not seem to pose any difficult problems.

Once TOPICS locations are fixed, however, typical STPP inventory data prove inadequate for determining the precise problems or for designing remedial traffic engineering treatments. Logically, the requisite detail data should be collected only at this stage. Until the problem locations or routes are fixed, it would seem inefficient to gather detailed data on a whole arterial street network basis through the STPP. It would be extremely costly and time-consuming—and of no particular value for systems planning purpose.

It is recommended that the street and transit facilities inventories, specified earlier for the basic STPP, not be significantly expanded or enlarged in detail to meet TOPICS data requirements

Transit Planning

There are three main purposes for examining the relationships between strategic transportation planning and transit planning:

1 To define different kinds of transit planning—some of which are more closely associated with the STPP than others—and to examine the similarities and differences of their planning processes.

2. To determine comparative data needs in order to disclose whether STPP data can or should meet data requirements of transit planning outside the STPP.

3. To determine from closer inspection than in the preceding section whether STPP data for strategic transit planning warrant expansion for STPP purposes alone.

Transit planning dates back at least 100 years Several phases can be identified: (1) establishing horsecar, cable-car, and then electric streetcar systems, (2) establishing commuter railroad systems, (3) building rail rapid transit systems, (4) substituting buses for streetcars and inaugurating express bus service on freeways, and (5) planning and building modern rail rapid transit systems.

Different planning objectives have emerged through the years From 1830 to 1910, transit planning was undertaken by private firms intent on maximizing profits. From 1910 to 1955, there was a period of consolidation and integration of separate lines into single urban area systems, but almost no new fixed-right-of-way facilities were being built. Transit operators simply adjusted bus and trolley service to observed changes in travel demand, this was more operational planning than planning of new facilities. Such is still largely the case: the literature seldom describes the "planning" of local bus systems. Even since 1955, long-range transit planning has been concerned mostly with new rapid transit or commuter railroad lines.

Actually, it is possible to talk about four types of transit planning. First, there is strategic transit planning, concerned with making decisions on whether new transit facilities should be built (especially new rail transit lines), where, and of what type. Second, there is transit planning that is concerned with the more precise definition of new rail lines—station locations, coordination with bus systems, and similar details. Third, there is planning for transit operations—scheduling, routing, fares, coordination of services, and similar work somewhat analogous to traffic engineering of existing street systems Fourth, and last, there is planning for new and untried transit systems, such as dial-a-bus

In this report, all but the third type (transit operations) are considered. The general purpose is to specify data needs as they relate to the over-all strategic transportation planning discussed previously It is shown, for example, that data needs for strategic transit planning can be based on the experience of the five transportation studies previously considered, that for the planning of transit implementation, more data are needed; that for "horizon" types of transit planning, even though means of estimating patronage are not as yet worked out, probably few additional data are needed.

Transit Planning Processes

Study Method —Because most strategic transit planning has been done by transportation studies, as part of the STPP, it is useful to review the five-study experience more specifically than possible in the preceding section. Additionally, to obtain a wider range of experience and opinion, various other groups with transit planning or transit research interests were contacted by the researchers. To supplement this information, a variety of published reports were reviewed for implications on transit planning data needs.

The study method thus involved: (1) preparing a generalized macro-diagram of the strategic transit planning work of the transportation studies, and summarizing data needs, (2) determining data needs for implementation and "horizon" transit planning from published reports and meetings with interested groups, and (3) analyzing the similarities and differences of data needs among the three types of transit planning. A prime objective was to discover ways in which STPP transit planning data might possibly be augmented for the benefit of others more concerned with implementation transit planning

Strategic Transit Planning Process.—The transit planning process shown in Figure 7 basically involves estimating future patronage on proposed alternative transit facilities, or systems, and evaluating such alternatives in terms of cost-benefit analysis and other established planning goals. This generalized process seems to fit any kind of long-range transit planning, whether strategic or implementation planning, and whether done by transportation studies or by transit operators and their consultants

The five transportation studies differed in the emphasis they placed on transit planning, in their methods for estimating patronage, and in their methods of evaluating alternatives. The Buffalo study tested 11 plans, and the Chicago study, four, both studies included rail rapid transit proposals. The Milwaukee study tested two plans, including a separate bus roadway, but no rail rapid transit. The Wilmington study also tested two plans, both incorporating local and express bus service, but not separate bus roadways. The Tucson study, beyond estimating future modal split, did no transit planning

Each study made a detailed inventory of its existing transit network (see Table 11) All information came from secondary sources such as public service commission and transit company records The main purpose of the inventory, and subsequent network description, was to measure the level of service provided—an important factor in modal split relationships Later, the networks were also used in connection with transit travel assignments. Each study obtained an inventory of transit travel through its home interview survey (see Table 12). Additional information was obtained by the Buffalo and Wilmington studies through on-board, person-miles-of-travel (PMT) surveys. Each study (excepting Tucson) then examined potential transit demand and the kinds of transit plans that would best suit the size and density of development in its study area Some consideration of the general approaches taken will be useful to understanding the plans themselves

Chicago was the first of the ad hoc transportation studies to test transit plans by computer assignments. Basically, those plans involved fairly minor modifications of the existing Chicago Transit Authority elevated-subway systems. Other rapid transit corridors were studied, but were not tested by transit assignments Chicago went as far in transit planning as technical capabilities then allowed.

Milwaukee took a somewhat different approach "Threshold" service warrants were established for rail rapid transit and bus rapid transit Based on these warrants, and on general examination of potential transit patronage in CBD travel corridors, rail rapid transit was removed from consideration as an alternative Two alternative transit plans based on the use of buses on expressways were then tested against three alternative land development patterns

Wilmington tested the existing system (1964) and an expanded system including both local and express bus service. Cutting back the existing bus service was also considered, but was rejected as unacceptable without formal testing. The study indicated that (*21*)

TABLE 11

TRANSIT SERVICE INVENTORY DATA COLLECTED BY FIVE STUDIES [a]

INVENTORY DATA
1. List of transit companies and/or operating agencies
2. Total number and type of transit vehicles
3. Transit routes by type of service
4 Total number of miles of routes by type and company
5 Route number, description, and terminal-to-terminal mileage
6. Location of transfer points, terminals, and parking facilities.
7. Location of stops
8 Hours of operation
9 Headway by hour of day
10 Running time by route segment by hour of day.
11. Average turn-around time by time period.
12 Total annual and weekday vehicle-miles and -hours
13 Fare structure
14. Total annual and average weekday costs
15 Accidents by type and location
16 Franchise limitations and other regulatory constraints.

[a] All data listed were collected by the five studies except for item 15 which was collected by Chicago and Wilmington only

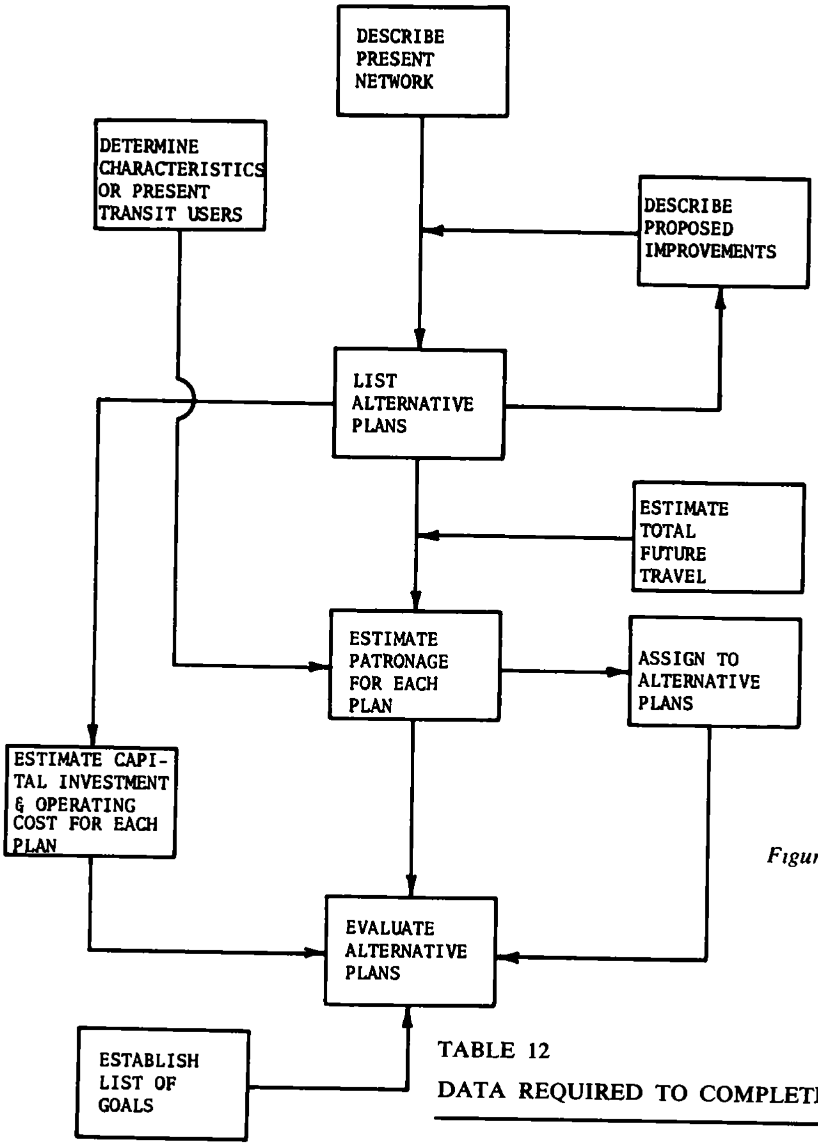

Figure 7 Macro-diagram of transit planning process

TABLE 12

DATA REQUIRED TO COMPLETE PRESENT TRANSIT USAGE INVENTORY

ITEM	DATA REQUIRED, BY TRANSPORTATION STUDY				
	CHICAGO	MILWAUKEE	BUFFALO	WILMINGTON	TUCSON
Annual patronage by type (paid fare, free, school)	X	X	X	X	X
Origin of trip	X	X	X	X	X
Start time	X	X	X	X	X
Destination of trip	X	X	X	X	X
Arrival time	X	X	X	X	X
Boarding location	[a]		X	X	
Boarding time	[a]		X	X	
Disembarking location	[a]		X	X	
Disembarking time	[a]		X	X	
Mode of travel to transit stop	[a]				
Mode of travel from transit stop	[a]				
Transfer made on transit line					
Purpose of trip	X	X	X	X	X
Number of autos in the household	X	X	X	X	
Number of autos available for trip		X		X	
Sex of transit passenger	X	X	X	X	X
Age of transit passenger	X	X	X	X	
Licensed driver			X	X	
Annual family income		X	X	X	
Blocks walked to transit line	X	X	X		X
Blocks walked from transit line	X	X	X		X

[a] Determined for commuter rail passenger

> Rapid (rail) transit proposals were not considered, since forecast travel to the Wilmington CBD was not sufficiently large in any corridor to justify even the consideration of a single rail transit route. . . Bus systems, even without their own right-of-way, and without utilizing an exclusive lane on expressways, are capable of carrying 5,000 to 7,500 passengers *per hour*, or approximately 25,000 to 35,000 passengers during the two peak-hour periods daily. Consequently, the Program concentrated on developing and evaluating alternative bus systems. .

Buffalo tested 11 alternative transit plans—some, however, involving the repeat testing of particular corridors with alternative types of equipment. For example, in the corridor north of Buffalo's CBD, tests were run with a proposed expressway included and excluded, with rail rapid transit on new right-of-way and on existing railroad right-of-way, and with conventional rail rapid equipment and the Westinghouse Transit Expressway. In effect, six tests concentrated on a single corridor, though all tests dealt with extensive networks. This differs substantially from the approach taken in Milwaukee and Wilmington, where gross estimates of patronage were made and rail rapid transit eliminated from further consideration.

Tucson did not test alternative transit plans. The explanation was that (*22*):

> Planning for transit service will continue to be handled primarily by the privately-owned bus companies of Tucson. Governmental influence in the form of federal assistance with local governmental planning participation is also likely to develop in accordance with present federal legislation and the expansion of current federal programs. In the absence of any significant demand for mass transit facilities in Tucson by 1980, and with the bus companies capable of handling matters of routing and scheduling, this report will not be further concerned with this element of transportation service.

In conducting tests, only the general operational characteristics of the various plans and equipment needed description: top speed capability, acceleration and deceleration rates, station spacing, headways, number of seats per vehicle, and peak-hour load factor, for example. These elements provided both necessary network inputs for transit assignments, and the factors required to convert ridership outputs to equipment needs, and hence to capital and operating costs.

Generalized estimates of capital investment costs (based on experience in other cities) generally were found acceptable by the studies. Working out the exact construction costs of a new rapid transit line, of course, involves many complicated engineering feasibility studies, which, like those required in highway route location studies, are usually beyond the scope of the STPP. The evident lack of detailed construction cost data underscores the need for a secondary data "repository" noted in the previous section. (Some other transportation studies have included detailed feasibility studies made by outside consultants. This course of action is needed if a referendum is going to be taken.)

The four studies that tested alternative plans were able to pay closer attention to choosing representative unit operating costs. Each used different values, in part reflecting different years and hence inflation results, and in part reflecting different basic approaches (see Table 13).

Testing essentially means estimating future patronage. In every study, this involved (1) an estimate of total future person trip-making, (2) a modal split to separate transit from automobile users, and, excepting Tucson, (3) assignment of transit users to the various parts of the proposed transit plans. The variables employed by the three studies using formal modal split models are given in Table 14. All the data items listed under "trip characteristics" and "trip-maker characteristics" were collected in origin-destination surveys; travel time and accessibility measures were obtained in highway and transit network inventories; and parking cost data were obtained from secondary sources.

Evaluating alternative transit plans is the most difficult step in the transit planning process. Chicago evaluated alternative transit plans on a "least transportation cost" basis. Alternative transit plans were evaluated independently of the highway plans; only costs and benefits directly related to the transit system and passengers were considered. Construction and equipment costs for each alternative were compared to the resulting benefits: each person-mile transferred from the bus service to a new rail service

TABLE 13

ESTIMATED TRANSIT OPERATING COSTS USED BY FOUR TRANSPORTATION STUDIES

TRANSPORTATION STUDY	YEAR THAT TRANSIT PLANS TESTED	ASSUMED OPERATING EQUIPMENT	ESTIMATED OPERATING COST ($)
Chicago	1960	Rail rapid transit Local bus	0.03/person-mile [a] 0.04/person-mile [a]
Buffalo	1963	Rail rapid transit Local bus	0.60/vehicle-mile [b] 0.70/vehicle-mile [a]
Milwaukee	1964	Local bus	0.56/vehicle-mile [a]
Wilmington	1965	Local bus	0.75 and 1.00/vehicle-mile (two tests) [c]

[a] Based on experience of local, existing systems
[b] Based on experience elsewhere
[c] Assumed

was considered to represent a savings of $0.01; in addition, diversion of bus passengers to new rail service produced savings in time, convertible to a dollar value assuming a person-hour to be worth $0.85. The method, although direct, has many limitations. The limitations were recognized by the Chicago study (*23*).

> The evaluation provided is the same as that used to gauge the quality of express highway plans—i.e., the one with the least total cost. It can be seen that there is really little difference between transit plans when this measure is applied. The plan recommended does provide benefits when a requirement of ten percent return on public investment is imposed. This ten percent figure is used to account for the possibility of other, possibly more rewarding, investment opportunities for the public dollar. *If either this earning requirement or the period of amortization of the new improvements were relaxed, then all, according to these measures, would be profitable plans.* The measures are crude and they cannot account for some of the community values for simply having such services. Nor should they be the final arbiter of plans so nearly alike. Other, less measurable, factors must enter the total appraisal. (Italics added.)

Milwaukee did not use a formal benefit-cost approach to evaluating alternative transit plans. Early in the testing of the feasibility of transit improvements the Milwaukee study eliminated rail rapid transit from further consideration. Based on initial patronage estimates, it was concluded that an express bus service could provide the needed capacity at a service level comparable to rail transit, but at considerably less cost.

Buffalo used the largest number of variables in evaluating alternative transit plans. The "Modal Choice Simulation Process" carefully measured the impact of each transit alternative on the highway network. As persons were diverted from the highway network to the transit network, the reduced congestion on the highway network was converted to travel savings. The savings were "credited" to the transit improvement. All costs (except for fare) were summed for each of the 11 transit alternatives tested. The alternative with the "lowest transportation system cost" was selected as the "best" transportation system. The study qualified its findings, however (*24*).

> This report could not and does not make final recommendations. Rather, it evaluates the potential usage and the transportation economics of alternative transit improvements. *The question of how much to invest in public transportation facilities is difficult to answer because values other than transportation economics must be considered. The final decision is one which must be made by the community as represented by responsible public officials.* (Italics added.)

Wilmington recommended a transit improvement plan, but tested only two alternatives—expanding local bus service and adding express bus service, as against doing nothing. Costs and revenues were estimated for the improved service; there were two cost estimates (high and low) and three revenue estimates (high, medium, and low).

Data Needs for Strategic Transit Planning.—Despite some differences in their strategic transit planning processes, the same basic data were used by the four transportation studies that prepared long-range transit plans. The surveys and survey items used by the four transportation studies are listed in the previous section. In this section, further details are given in Tables 11 and 12.

TABLE 14

VARIABLES USED IN MODAL SPLIT MODELS BY THREE TRANSPORTATION STUDIES

DESCRIPTION OF VARIABLES USED IN MODEL	VARIABLES USED, BY TRANSPORTATION STUDIES		
	CHICAGO	MIL-WAUKEE	BUFFALO
Trip characteristics			
Number of trip purposes used	2	7	2
Trip length			X
Time of day			X
Orientation to CBD	X		
Tripmaker characteristics			
Auto ownership	X	X	X
Workers per household			X
Network characteristics:			
Travel time			X
Parking cost			X
Accessibility		X	

The data collected in origin-destination surveys and network inventories were adequate for the purposes of the over-all strategic transportation planning process with one exception—the on-board, transit passenger survey. It is recommended that the PMT survey be established as a basic part of the data collection phase of the STPP. Otherwise, the data needs for strategic transit planning are satisfied by the data collected for the established STPP, and no significant changes are suggested.

Implementation Transit Planning Process.—The few rapid transit or rail commuter facilities built recently in the United States—for example, in Cleveland and Philadelphia—have tended to be single routes rather than systems. Broadly speaking, planning for such routes has been planning for implementation, following the preliminary cost and patronage estimates needed for a decision to go ahead, more exact estimates were prepared to determine actual construction details. Relatively little strategic evaluation of long-range transit system alternatives was involved—this system versus that system—possibly for lack of transit planning funds, but also possibly because, unlike freeway system planning, few alternatives have presented themselves.

Although transportation study data are probably the best so far developed for making long-range, areawide appraisals of future transit patronage, perfect modal split and transit assignment models have yet to be devised. Recognizing this, implementation transit planning has tended to develop some of its own models (and accompanying data requirements) in hopes of attaining better results. Moreover, in focusing on the details of single routes, there are specific reasons why transportation study data clearly must be augmented—just as more data are required for highway route location planning. This can be illustrated by the following case history in the Philadelphia region.

The Philadelphia-Lindenwold Rapid Transit Line—the nation's newest—connects downtown Philadelphia and suburban Lindenwold, N.J., some 14 miles to the southeast across the Delaware River. "Lindenwold" planning studies go back at least to 1935. The first detailed patronage forecasts, for a route more or less like the present one, were made in 1955 by a consulting firm making its own origin-destination studies. (O-D data then available from results of the Pennsylvania Department of Highways' *1948 Origin-Destination Survey of the Philadelphia-Camden Area* were not used.) The follow-up study, "Plan for a High Speed Mass Transit System between Philadelphia and Camden and South Jersey Suburbs," prepared by Louis T. Klauder and Associates in 1959, adjusted the 1955 patronage estimates The next study, "Delaware River Port Authority (DRPA) Proposed Southern New Jersey Haddonfield-Kirkwood Line Rapid Transit," prepared in 1960 by Simpson & Curtin, Transportation Engineers, used the 1955 O-D data still again with different trip estimation methods After official approval of this report by the Governors of Pennsylvania and New Jersey, DRPA proceeded with detailed planning and construction without necessity for public hearings or voter referendums.

Penn Jersey Transportation Study 1960 data were not used until establishing final fare structures and preparing a revenue bond prospectus for DRPA's capital program in 1968 The key task was estimating daily, and hence annual, Lindenwold ridership for each year through 1985 (*25*). For this purpose, Simpson & Curtin relied primarily on its own 1967 surveys and analytical methodology. This involved taking about 94,000 roadside interviews on Delaware River bridges—some for the separate purpose of examining proposed toll changes—and handing out about 14,000 postcard questionnaires to transit riders in the rapid transit corridor. Multiple regression analysis, incorporating both travel survey results and socioeconomic factors, produced equations for predicting the proportion of 1967 zone-to-zone person trips that would use transit. Predicted transit trip interchanges were assigned to the various transit facilities in the corridor, to determine the station-to-station rapid transit use The process was repeated for 1985 with total person trips estimated by the Fratar method, and modal split models reapplied, with intermediate-year use interpolated

Penn Jersey survey data for 1960, and projected data for 1975, were used, as were Delaware Valley Regional Planning Commission (DVRPC) projected data for 1985. Specifically, these data included: *1960 traffic zone data* factored to 1967 for (1) total employment, (2) dwelling units/residential acre, (3) automobile ownership, (4) Philadelphia CBD parking costs, and (5) auto driver and auto passenger trip interchanges internal to New Jersey traffic zones; and 1985 *traffic district data* (allocated to traffic zones by the researchers) for (1) the first three items just noted, plus (2) Philadelphia CBD employment.

Two principal problems were encountered with the data:

1. Because Penn Jersey, and later DVRPC, undertook few analyses at traffic zone level, such data proved awkward to assemble and to reconcile against control totals, this would not normally be a problem
2. Only preliminary district-level 1985 socioeconomic data were available from DVRPC when the study was made, in distributing these to zonal levels, the researchers drew on some separate, more detailed demographic projections, including their own, and then modified DVRPC district estimates as deemed necessary

Despite technical difficulties of using these STPP data, however, the researchers accepted them where they were judged reasonable and so used them *wherever they met the needs of their planning process.* The Penn Jersey-DVRPC data, however, did not fully meet those needs. The 1960 transit travel file was deemed inadequate for the researchers' purpose because (1) the home interview sample was too small, (2) there was no way to relate home-interview-reported transit travel to particular transit routes and service levels, (3) there was no direct evidence on car availability, boarding and alighting locations, or connecting bus route identification, and (4) "linked" transit trips obscured intermodal transfer information.

This is the major point to be illustrated. For transit implementation planning, as for almost any kind of implementation planning, more detailed data are needed than can be provided in the STPP. It is recommended that the STPP not attempt to anticipate these needs, and that special surveys, designed specifically to obtain the required data, be conducted in addition to the surveys for the STPP.

Data Needs for Implementation Transit Planning.—Based on the evidence of the Lindenwold experience, implementation transit planning uses many types of data needed for strategic transit planning. Such data would include population, employment, land use, and person-travel patterns throughout the broad corridors served by a rapid transit line Both present and projected data can be employed usefully. And, of course, like all implementation planning, that required for transit benefits greatly from being done within the context of an over-all strategic transportation plan—in a sense the sum-product of all kinds of strategic planning data.

However, the detailed patronage estimates needed for planning such things as the number of turnstiles at each rapid transit station clearly must be based on more fine-grained data than can be produced in strategic transportation planning process surveys. Although the recommended PMT survey data would be helpful, other equally detailed data appear to be needed, which should best be collected outside the STPP.

Transit Planning and New Transit Equipment —Various new systems of transportation are presently being developed, including Urbmobile, SupraCar, Skybus, Commucar, Metran, StarrCar Perhaps some of them will provide improvements over current transportation system components

When one looks at the new transit systems, and thinks about such "horizon" transit planning, familiar questions come to mind: What will the new systems cost? Will the systems be accepted and used? Will enough people use them to make them good public investments?

To the list must be added a new question: How can any truly revolutionary system be integrated with the existing transportation system? This can complicate long-range planning tremendously. Because defining a "balanced" transportation system proves difficult with two conventional travel modes (the free-routed automobile and the schedule-routed transit vehicle), any new *combination* mode that attempts to make the best of both concepts will make a "balance" even harder to specify.

This implies that methods of testing the "goodness" of new systems must be extremely rigorous and that planning goals must be even more carefully specified than at present The most common objection to past transit planning is that the goals against which alternative transit plans have been tested were too restricted. Things that people presumably value were not included in the evaluation process—the reduction of air pollution, the preservation of high-density urban centers, etc

Many of these personal and community values can be listed (see Table 15) and many seem amenable to measurement. For example, the number of persons displaced due to the construction of a new transportation facility can be measured, the amount of reduction in air pollution that results when vehicular travel is reduced can be measured. Other goals, such as "atrract new industry" or "maintain central business district," are not as easily measured, primarily because of the large number of factors involved in private industry investment decisions

There can be little question that confusion of planning objectives, or goals, has been an important contributing factor in the occasional furor over the meaning of "balanced" transportation systems. Clearly, whether planning transit or highways, goals should be more explicit than they are now. Although Table 15 indicates that more planning data would be needed, this project cannot specify which might be the most effective—obviously more research would be required.

Although various groups are approaching such questions (including the Stanford Research Institute, the Battelle Memorial Institute, and several others visited by the researchers), answers are proving elusive; however, some preliminary answers are available *(26)* Potential use of a new system is still the main stumbling block What do travelers really want and expect from a transportation system? In an affluent society, perhaps cost is not very important In a society with more leisure time, perhaps speed is not very important either. Discussions with the groups just named suggest that much more needs to be learned about public attitudes and wishes.

Such attitudes cannot be determined from the basic surveys of the strategic transportation planning process, based as they are on public response to available travel modes "Attitudinal" surveys, such as taken by the Milwaukee and Wilmington studies, are a step in the right direction, but probably cannot go far enough. More innovative, special surveys seem called for.

Programs to develop methods of estimating costs, use, and evaluating new transportation systems are under way. In the course of designing these research programs, new data needs are certain to become apparent Although some could be anticipated here, a complete list of the required data cannot be specified until the establishment of a refined process for testing the new transportation systems This may take years, and seems unlikely to affect data needs for the current STPP.

TABLE 15

POSSIBLE GOALS OF TRANSIT PLANNING AND THEIR PRESENT MEASURABILITY[a]

DESCRIPTION OF TRANSIT PLANNING GOALS	MEASURABLE
Transportation-related goals:	
Provide choice of travel modes	Yes
Provide mobility for non-carowners	Yes
Reduce need for highways and parking facilities	Yes
Reduce highway congestion and accidents	Yes
Minimize transit system operating costs	Yes
Minimize transit riders' travel time	Yes
Environmental and land use-related goals:	
Encourage desired land development pattern	?
Maintain strong CBD	?
Further racial integration	?
Reduce air pollution	Yes
Encourage economic growth and attract industry	?
Minimize dislocation problems of highway construction	?

[a] This is not intended to represent an exhaustive list of goals for transit planning, but it does include the goals most often mentioned in the literature concerning transit planning

Highway Route Location (or Project) Planning

Historically, one of the principal purposes of the early transportation studies was to project future traffic volumes for purposes of designing particular highways Over many years, emphasis shifted toward choosing the best of alternative transportation system plans Traffic simulation became one of the main tools used to evaluate plans. Traffic assignment outputs still constitute the necessary traffic volumes for systems design purposes.

Partly because of emphasis on system, a certain gap has opened between the strategic transportation planning process and the highway route location (or project) planning process. Route location planning engineers have stated that systems planners have not provided adequately detailed traffic estimates for use in route location and design operations. Systems planners have contended that the traffic estimates called for are of a spurious level of detail. It is in part to close this gap that this particular investigation was made.

Route location planning may be defined as that activity that takes the broad corridor definition and forecasted demand from systems planning, applies detailed local area considerations, and translates them into a preliminary design This preliminary design reflects decisions on preliminary location, basic type of roadway, number of lanes, and basic interchange design, and then rates the over-all design on a large number of technical, social, and economic effects. Route location planning deals also with proposed highways (generally lower-volume roads) that are not treated explicitly in the metropolitan plan.

The present investigation describes the route location and preliminary design process as carried out by a representative highway agency, lists the data used in this process that must be provided by the STPP or obtained from other sources, and assesses the sensitivity of various route location planning decisions to errors in the traffic estimation component of the data. The investigation also considers the actual needs of route location planning for accurate traffic forecasts. Conclusions and recommendations are given for future interaction of the systems planning and route location planning processes

Research Method.—This review presents a composite route location planning process based—very broadly—on that used by the New York Department of Transportation and drawing from findings of a literature search, and from personal experience. The route location planning process described here is a technical process, and this process should not be confused with the administrative procedures by which route location plans are advanced to the stage of official approval and implementation.

Largely in response to public pressures (and as mandated by the Bureau of Public Roads in 1969), route location planning activities now must specifically account for many factors that were given less attention in the past. Two public hearings are now required, the first dealing with generalized corridor locations and the second with more detailed location and design. These new requirements are creating revised administrative route location planning procedures, which may, in turn, cause some alteration to the technical route location planning process reported here.

The Route Location Planning Process

Route location planning is the vital link between the STPP and the final design and construction of major highways in defined urban travel corridors (see Fig. 8). Systems planning usually provides the critical traffic data input to urban route location planning. Additional data from other sources, described subsequently, include design-hour volume (DHV) factors, physical, social, economic, and environmental considerations; and design criteria

Systems planning may be done (1) by state highway departments or their consultants, (2) by ad hoc transportation studies, or (3) by regional planning agencies. Route location planning is more consistently undertaken by state highway departments or their engineering consultants. Route location planning also increasingly involves a "design team" concept, where, with continued highway department leadership, local planning goals are brought forward by technicians outside the highway field. Frequently, these design teams include representatives from the systems planning agency, and this seems one appropriate way of helping close the gap between systems planning and route location planning.

Steps in the Route Location Planning Process —Figure 9 shows the stages at which the several inputs and outputs of the route location planning process are required in order to make decisions on the mainline route and basic interchange design. Although the process may vary for specific route locations due to differences in demand levels, the character of the demand, geography of the corridor, the sensitivity of the highway plan to social and political factors, and the whole range of other factors that affect highway design decisions, Figure 9 may be considered representative of most route location planning studies

The initial inputs to the process are systems planning considerations, and mainline design-hour volume (DHV) traffic factors developed from both system annual average daily traffic (AADT) forecasts and traffic count and inventory records. When related to design criteria, these determine the functional type of facility to be built—generally, whether or not access control is required. This may be a policy decision, however, and not necessarily a decision obtained directly from analysis of the input data.

Next, the number of through lanes is determined, generally following American Association of State Highway Officials (AASHO) methodology This involves selection of a K factor (deciding whether to satisfy traffic demand

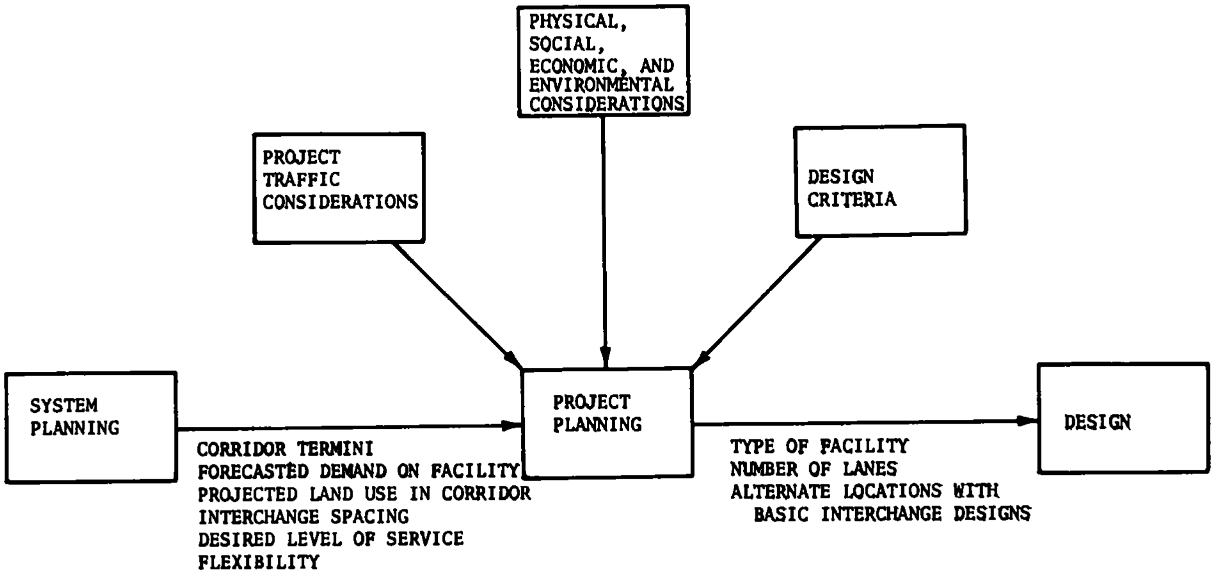

Figure 8 Project planning in the over-all process.

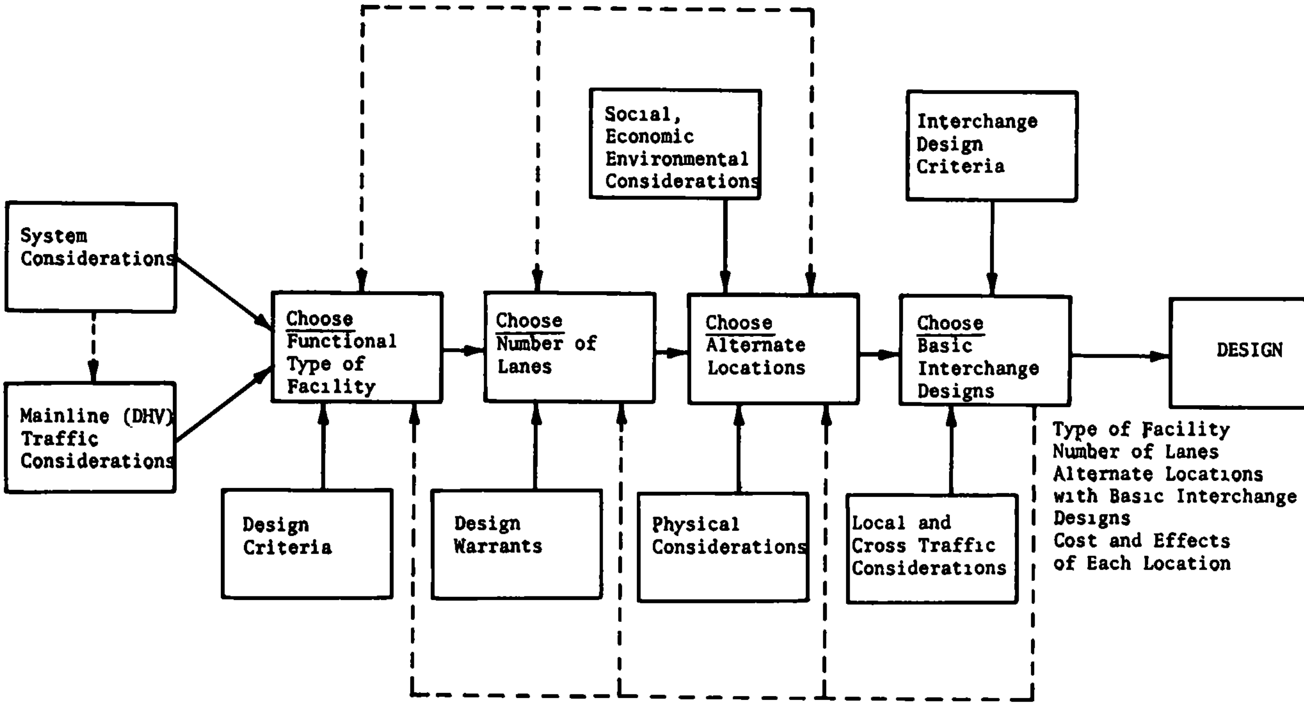

Figure 9 The project planning process

at the 30th, 50th, or some other specified "highest" hour); selection of a *D* factor, or proportion of traffic in each direction; and selection of a *T* factor, or proportion of heavy commercial vehicles (*27, 28*). An additional input required for this decision is the set of design warrants that relate the number of lanes to volume and character of demand for each type of facility at each level of service.

Several alternate route locations are then determined Additional sets of data required for this task are measures of physical, social, economic, and environmental influences in the corridor. Much criticized in recent years because physical and economic considerations have been the prime determinants of final locations, this task now gives social and environmental factors a considerable amount of importance. The present form and handling of such inputs appear rather haphazard, but it must be recognized that reduction to a form in which engineers can apply them efficiently to route location planning is a difficult task (*27*).

The final major decision involves choosing basic interchange designs for each location. This requires additional input of local and cross traffic data in the corridor, and the use of interchange design techniques that relate interchange and ramp capacities to the volume and character of the traffic making the several turning movements.

The output of the process is the type of facility, number of lanes, several alternative locations, and the basic interchange designs for each location. There may, of course, be several important feedbacks in the process, some of which are shown in Figure 10. A familiar example involves revision of initial design geometrics because of limiting physical or economic factors in final right-of-way location. Obviously, the route location planning process does not always follow the simple step-by-step procedure outlined, but can become more complex.

Data Requirements for Route Location Planning

Planning Data—Prior to systems planning, most route location planning data were developed by route location planners themselves. As indicated by Table 16, however, systems planning now generally provides the following "systems factors," some of which are informational rather than data, such as: (1) corridor termini, (2) forecasted demand on the facility, (3) projected land use in the corridor, (4) desired level of service, (5) desired interchange spacing, (6) relationship of corridor to systems plan, (7) present and future transportation network in the corridor, (8) present and forecasted travel and traffic characteristics on other facilities in the corridor, and (9) future trip ends in the corridor.

Route location planners will do the necessary review, and possibly adjust some of these systems planning inputs—particularly items 2, 3, and 4 This need is dictated by the difference in planning scale: route location planning looks at the specific facility as it functions in a corridor, whereas systems planning is more concerned with its function in the total urban transportation systems Items 7, 8, and 9 can be developed jointly between route location planning and systems planning.

Most of the remaining data inputs must come from the special studies typically undertaken by route location planners. As Table 16 indicates, however, systems planning provides some inputs beyond systems factors and other traffic data. Under "social, economic, and environmental

TABLE 16

DATA AND ESTIMATES REQUIRED FOR THE ROUTE LOCATION PLANNING PROCESS

DATA AND/OR ESTIMATES REQUIRED	DATA AND ESTIMATES REQUIRED, BY GROUP RESPONSIBLE	
	SYSTEM PLANNING	ROUTE LOCATION PLANNING
System factors		
Corridor termini	X	
Relationship of corridor to system plans	X	
Projected land use in corridor	X	
Level of service	X	
Interchange spacing	X	
Mainline traffic.		
Forecasted demand on facility	X	X
Level of service	X	X
Seasonal variation		X
Weekly variation		X
Daily variation		X
Peak-hour variation		X
Directional variation		X
Traffic mix		X
Physical factors		
Topography		X
Subsurface conditions		X
Right-of-way constraints		X
Utility locations		X
Social, economic, and environmental factors		
Residential and neighborhood character and locations		X
Present and future economic activity in the corridor	X	X
Property values		X
Replacement housing availability		X
Governmental unit boundaries		X
Cultural and recreational areas		X
Education districts and buildings		X
Fire districts		X
Public health and safety districts		X
Religious institution patterns		X
Noise, air, and water pollution factors		X
Public utilities		X
Local and cross traffic factors:		
Present and future corridor transportation network	X	X
Present and projected travel on other facilities	X	X
Future corridor trip densities	X	X

factors," for example, systems planning can describe present and future economic activity in the corridor. Even so, it should be evident from the subheadings in the table ("Property values," "Replacement housing availability," etc.) that a variety of special detailed studies is required for route location planning—all clearly beyond the broader scope of the STPP.

Design Criteria—On completion of the route location planning process, and the selection of a final route location, actual construction plans are drawn up. In this final design process, highway designers draw on several basic references for design criteria. Perhaps the most important of these is the *Highway Capacity Manual* (*28*) and the AASHO "policy" publications. The latter, for at least 20 years, have presented a synthesis of design practices in several state highway departments; the *Policy on Geometric Design of Rural Highways* (*29*) was last updated in 1965 and the *Policy on Arterial Highways in Urban Areas* (*30*) was due to be updated in 1970. AASHO also publishes a *Policy on Design Standards, Interstate System* (*31*) and *Standard Specifications for Highway Bridges* (*32*).

Accepting guidance from such general references, most state highway departments must nevertheless develop their own specific design policies. These vary somewhat, depending on topography, extensiveness of state systems, financial considerations, past design practices, and other factors. For example, a highway department in a state having relatively small urban areas may feel it can consistently design urban freeways to provide level of service C, another department in a state with many larger urban areas may recognize it can only afford level of service D.

On these grounds, it is perfectly possible, even with the same traffic estimation inputs, that two entirely different highway designs could result. Variations in design criteria, or differences in their application due to differences in design policies, are further subject to interpretation by highway designers. Good design remains a highly skilled art requiring much engineering judgment, it will probably never be systematized to the point that given traffic inputs will automatically produce given highway and interchange designs. These qualifications should be borne in mind throughout the following discussion of the impact of traffic estimation errors on design

Impact of Traffic Estimation Errors

Traffic data used in route location planning can, perhaps, best be evaluated (1) relative to the impact of errors in those data on various planning decisions, and (2) relative to measures of effectiveness of the resulting physical facility A high level of sensitivity would suggest additional research to develop more accurate means of traffic estimation; a low level of sensitivity would suggest that more accuracy is not needed.

This section reports a theoretical examination made to determine the sensitivity of capital cost, traffic service, and other location and design matters to a range of error in design-hour volumes (DHV).

Impact of DHV Factors on STPP Estimates.—It is important to distinguish between traffic assignment and design-hour volume traffic data. STPP traffic assignment outputs (typically in terms of ADT) provide only the starting point for deriving DHV data for design purposes. *Errors in STPP outputs can be either offset or compounded by errors in the subsequent derivation of DHV data.* Because the two sources of potential traffic estimation error are virtually inseparable, the examination for sensitivity, although it explicitly concerns DHV data, also implicitly concerns STPP data.

A brief review of the derivation process will be helpful

When hourly two-directional volumes are arrayed in descending order for every hour of the year, different types of highways display typical "functional" curves such as shown in Figure 10. Because highways cannot be designed to accommodate traffic for every hour of the year, standard practice attempts to accommodate all by the *N*th highest hours (depending on where the "knee" of the functional curve is expected). The relationship, expected *N*th hour volume/expected AADT, is called the *K* factor, values commonly range from 0.10 to 0 15 After the *K* factor has been estimated, it is necessary to estimate the proportion of design-hour traffic moving in the predominate direction. This is called the *D* factor; values commonly range from 0.55 to 0.65. Finally, the number of heavy commercial vehicles (six-or-more-wheeled vehicles) in that predominate direction during the design hour are estimated by a *T* factor, and weighted to account for their using more highway capacity than smaller vehicles, *T* values commonly range from 0.02 to 0.05, and typical weights are 3 to 5, depending on grades and truck-type mix. A simple formula for DHV derivation is.

$$\text{DHV} = (\text{AADT})(K)(D)(1 - T + Tw)$$

Derivation of DHV's from AADT's provided by the STPP is extremely sensitive to the values chosen for *K*, *D* and *T* By simple demonstration, application of one combination of design factors to an AADT of 60,000 could produce a DHV of 3,432 vph, application of another combination, 6,240 vph—the difference between a four-lane freeway with low level of service and an eight-lane freeway with acceptable level of service

This difference can be expressed in reverse fashion. a STPP-produced AADT of 30,000 reduced by one combination of factors could yield a DHV of 3,509 vph, a STPP-produced AADT of 60,000 reduced by another combination of factors used in this illustration is particularly extreme; both can and do occur in actual practice

The following sensitivity analyses concern the effect of traffic estimation errors in the *combined* AADT-DHV derivation process.

Construction Costs Sensitivity.—As traffic increases, the number of lanes required to provide a given level of traffic service increases, and construction costs rise. Figure 11 shows the one-direction DHV traffic ranges within which four-, six-, and eight-lane urban freeways are required to provide levels of service C and D—the usual choice in urban freeway design

Each plateau on the two curves can be partitioned into zones where the number of lanes is insensitive to the estimated DHV, and into other zones that are sensitive. For example, there is little danger in specifying the need for a six-lane freeway providing level of service C when the estimated DHV is 4,000 vph—the midpoint of that plateau —because the traffic estimate could err by ±25 percent without affecting the number of lanes. However, suppose that the estimated DHV is either 3,200 vph or 4,800 vph (values near the extremes of the plateau range), then a very small traffic estimation error could result in under-design or over-design by the margin of a lane in each direction.

Figure 12 shows zones of sensitivity and insensitivity at level of service B for 10 percent, 20 percent, and 50 percent estimation errors If the assumption could be made that traffic estimates are equally likely to occur at every volume level shown on this figure (that is, between 0 and 5,000 vph), it could be inferred that for a 10-percent estimation

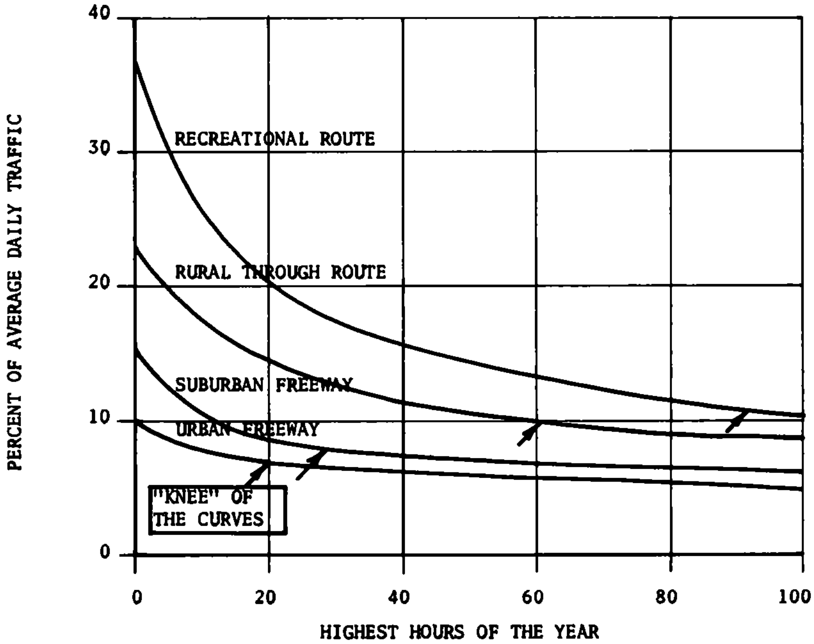

Figure 10. Hourly traffic related to average daily traffic for typical highway types. Adapted from Matson, et al (64, p. 374, Fig 23–1)

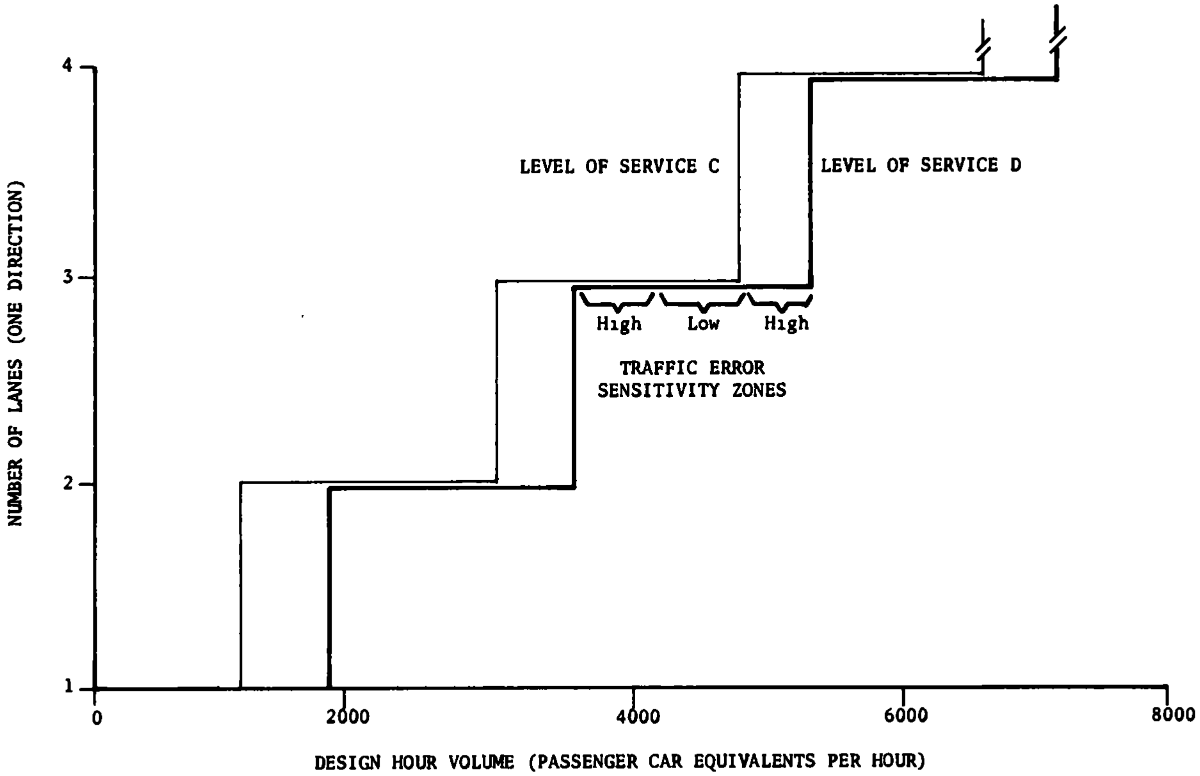

Figure 11 Traffic lane requirements for given design-hour volumes on urban freeways Source Highway Capacity Manual (28).

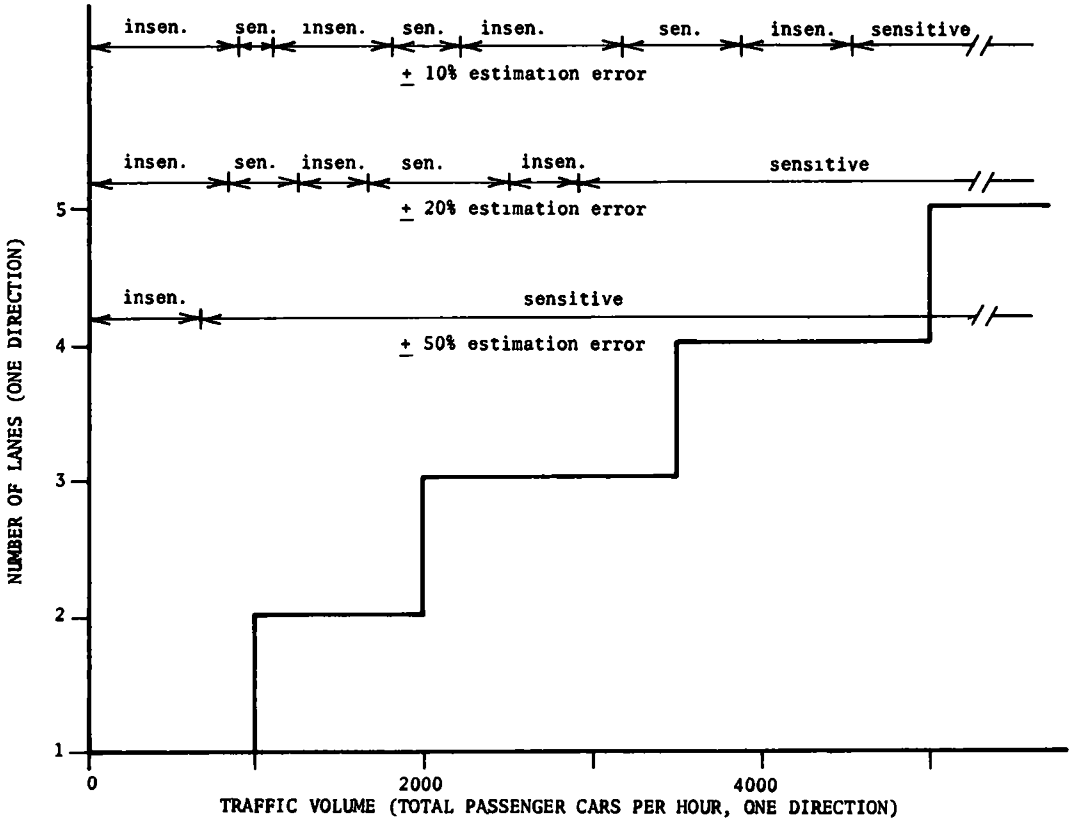

Figure 12. Number of lanes versus traffic volume for level of service B, showing sensitive and insensitive zones.

error the number of lanes is sensitive in 35 percent of the cases and insensitive in 65 percent of the cases. Similarly, at 20-percent error, lane numbers are sensitive in 67 percent of the cases, whereas at 50 percent estimation error the number of lanes is sensitive in 87 percent of the cases

Obviously, it is desirable to keep estimation error as low as possible, because this decreases the number of decisions that have to be made in "sensitive" areas.

Dealing with Traffic Estimation Errors —It is necessary to realize that forecasts are made for periods of 20 or more years into the future and for fairly lengthy sections of road along which traffic volumes will vary—generally being higher toward the center of a city and lower at the outskirts. Thus, there is no escaping the fact that, at some points in time and in space, traffic volumes will be estimated that lie in areas that are sensitive in making decisions as to the best number of lanes.

Because forecast errors must be assumed (and are actually probable in the light of the well-known "law" that "if anything can go wrong, it will go wrong") the systems planner and the route location planner must jointly consider appropriate defenses against estimation errors There are three kinds of defenses that should be employed.

1. Traffic volume forecasts ought to be accompanied by a statement indicating the expected range of error of the estimate. (Research is needed to develop techniques for estimating error ranges.) This procedure will, at the very least, warn all users that an error is possible.
2. When estimates are made in "sensitive" volume ranges, land ought to be purchased to provide room for an additional lane in each direction if the future volumes should exceed "best" estimates.
3. Planners ought to be advised of the probable effects on transportation costs of allowing changes in density in critical parts of the urban area. This is analogous to posting limits on the floor loading of buildings so that dangerous overloads, or costly reconstruction, will be averted. Research into the costs of such changes and into means of controlling densities ought to be undertaken at an early date.

The foregoing should not be interpreted as suggesting that long-range traffic volume forecasting as part of the STPP is a useless activity. Quite the contrary. Without the STPP, traffic volume forecasting is a hopelessly crude and narrow process, because manual techniques cannot comprehend system interactions. Moreover, the STPP is needed to establish the location (spacing and terminals) of corridors and the fundamental trip generation and mode split forecasts

If forecasts are subject to error, it must also be realized that design decisions are basically "limited-step" decisions that are buffered by subjective determinations as to level of service to be provided. Frequently, criteria for making such decisions are not formally established. In the research that was conducted, for example, attempts were made to find traffic volume criteria for determining expressway interchange designs. In the words of the subcontractor's report (*33*):

> It was found that a set of criteria for choosing the basic type of interchange from given traffic volumes and turning movements does not exist, and that the choice of basic interchange type is generally handled individually and relying heavily on the design engineer's experience rather than on such a set of criteria For the four basic interchange types, T and Y, Diamond, Cloverleaf, and Directional, the AASHO Policies give qualitative guidelines for the applicability of each type, but quantitative decisions on type are left to trial and error, i.e., laying out the interchange, assigning traffic to its ramps, and evaluating its effectiveness with respect to traffic with the help of the *Highway Capacity Manual* and other traffic references and its economy based on cost estimates
>
> An attempt should be made at developing such a set of criteria While it may turn out that this criteria would be somewhat meaningless due to the high variability among interchange conditions, the research done in attempting to develop the criteria should yield valuable information on the nature of interchange design decisions

The positive approach to eliminating the present gap between the STPP and route location planning is (1) to recognize the inherent weaknesses associated with both operations, and (2) to act jointly to minimize their harmful effects. The three-step process suggested previously is one direction. But, in the long run, further intensive research is needed to improve knowledge of estimates, decision processes, probable errors, and safeguards against errors

Metropolitan Planning

As in studies of data needs for other related kinds of planning, the study of data requirements for metropolitan planning was undertaken for two main reasons. These were (1) to determine possible joint uses of data on grounds of economy and efficiency, and (2) to understand better the related processes in order to improve coordination with transportation planning.

In this section are reported the results of examination of:

1. Comprehensive metropolitan planning, prepared along generally conventional lines, as in Chicago's plan "Diversity Within Order."
2. Urban growth models, in which the development of urban areas is simulated through the use of computer models.
3. Social indicators, in which the condition of society is evaluated through the use of statistics measuring performance in relationship to goals.

These related kinds of work have great significance for transportation planning, for two reasons. First, metropolitan planning and growth modelling have to do with the location of the urban activities that must be served by transportation systems. If the locations of activities can be planned ahead of time, together with the intensity of land use, then the transportation planning process is more easily accomplished. Second, transportation planning and metropolitan planning are more and more being undertaken jointly; hence the need for improved understanding of planning methods and data needs for metropolitan planning.

All of this work was done at a much more general level of detail than similar work done for the transportation planning process. This was necessary for several reasons. First, only a limited amount of time could be spent on this part of the research project. As a result, it was impossible to prepare micro-diagrams of the comprehensive planning process, and to determine the exact kinds of data that were used in each small step along the way Second, the metropolitan planning process is in itself far more general, far less factual, and less formalized than the transportation planning process It would be extremely difficult to be more specific on data needs than the 50 or more kinds of data that are specified here

Conventional Metropolitan Planning

Research Method—The methods of determining data needs for metropolitan planning were basically very simple. Documents were obtained from metropolitan planning agencies that described, in general terms, the planning process employed and the plans or alternative plans produced (*34-39*) Two textbooks on land use planning also were obtained.

These documents were then carefully examined. The planning process used was diagrammed in simple fashion, or a copy of the study's planning flow diagram was obtained. Major goals were listed. The number of alternative plans prepared and evaluated was noted. Finally, data were listed that were indicated in various reports as having been used in the process of preparing and evaluating alternative plans.

As these reports were examined, data items were considered as having been used even if there was some doubt as to whether they played a significant part in the planning process Thus, data needs reported here may be slightly inflated. It was felt, however, that it would be better to err on the side of adequacy rather than to suggest that plans can be prepared with inadequate information.

Three metropolitan planning processes were examined in this phase of the project These included the New York, Chicago, and Milwaukee metropolitan areas. New York and Milwaukee were selected because they represented major planning efforts, in combination with transportation planning operations. Chicago was selected because its work represented a more conventional city planning approach with a strong input of architectural and aesthetic considerations. All three were considered to be at the forefront in terms of quality

In addition to the three metropolitan planning processes, two planning textbooks were examined These were *Urban Land Use Planning* (*40*) and *Principles and Practice of Urban Planning* (*41*).

Difficulties of Determining Data Needs.—Several difficulties were encountered in determining data needs for metropolitan planning. These are described as follows.

1. *Process too generalized.*—In the case of strategic transportation planning, it is possible to diagram the planning process in detailed fashion and then to determine exactly what data items have been selected for use out of the lists of data that were actually collected. Card forms or survey forms make the latter part of this task easy. In the case of metropolitan planning, however, the exact process for reaching conclusions is usually diagrammed only in highly generalized terms. Furthermore, many of the kinds of data either are not (or cannot be) recorded in list format. Hence, it is difficult to identify data needs precisely.

2. *"Background" data.*—In the metropolitan planning process, a number of items of data may be collected and used to increase the understanding of planners, and these data items may, in fact, help him to reach certain decisions. However, in formal statements of the planning process, these data may not appear at all. Hence, the fact of their "use" may remain in doubt, and there may even be no formal record of their existence.

3. *The problem of scale.*—The metropolitan planning process operates for a very large area, and at a very coarse level of detail At this level, many kinds of data are submerged in larger aggregates, and may disappear altogether or may be of marginal utility. Thus, data on neighborhood schools or on utility costs for site development may have no impact on metropolitan decision-making because they may remain constant whatever the metropolitan plan. As a result, the question of their use remains in doubt.

All of these things make a precise determination of what data were collected and used very difficult

Data Needs for Metropolitan Planning—The data needs of the several metropolitan planning processes and the requirements suggested by the two textbooks (*40, 41*), are given in Table 17 and are reviewed in the following

1. *Population Data*—In general, each of the metropolitan planning processes and the two textbooks called for population data, such as are provided by the census, as the basis for making forecasts of urban growth The exact kind of population data required varies, depending on the forecasting technique being used In some cases, for example, data on birth and death rates are required in order to permit cohort survival population forecasts to be prepared and in order to estimate mobility between censuses.

The Tri-State Transportation Commission and the Southeastern Wisconsin Regional Planning Commission collected, through the use of the home interview survey, data on the mobility of population within their areas. These data were primarily used for research purposes; it is not clear whether they were used directly in estimating the future size or location of the population. Neither of the two texts suggested that direct data on the mobility of the population be collected.

2 *Economic Data.*—The three metropolitan planning processes that were studied, together with the two textbooks, all call for economic data to be used in developing aggregate forecasts. These forecasts are generally for the purposes of determining employment and space needs for different types of economic activities The exact data needed depend on the type of economic forecasting model used.

3 *Land Use Data*—All the sources that were examined called for surveys in which land is measured and categorized by type of activity. Data on municipal or county zoning were also generally obtained.

The textbooks called for information on the suitability of land for development. This included data on whether the land is subdivided or in larger tracts, on physical characteristics, and on proximity to activities of different kinds. The three metropolitan planning studies appeared not to have gone quite so far in studying vacant land.

TABLE 17

COMPARISON OF DATA REQUIRED FOR CONVENTIONAL PLANNING, GROWTH MODELS, AND TRANSPORTATION PLANNING

ITEM	DATA REQUIRED [a] FIVE METRO PLANNING PROCESSES	TEN GROWTH MODELS	"BASIC" STPP	JOINT USE OF DATA
A Population data				
Population numbers, characteristics	5	10	√	√
Birth/death rates	5	3	√	√
Mobility	1	2		
Household numbers, characteristics	5	7	√	√
B Economic data:				
Income and expenditures, by industry type	5	2	√	
Employment	5	6	√	√
Family income and expenditures	5	4		
C Land use data.				
Land area, by type of activity	5	10	√	√
Zoning (for use and density)	5	9	√	√
Subdivided/open	2	1		
Site suitability for development, by type	2	3		
Rail access	2	1		
D Characteristics of the land:				
Topography	5	5	√	√
Soils and subsoils; mineral resources	5	1		
Drainage and flooding	4	1	√	√
Vegetation, forestation	2	0		
Climate	2	1		
Access to deep water	5	2		
E Transportation data:				
Trips of persons, vehicles	5	3	√	√
Highway network (length, speed, cost)	5	8	√	√
Transit network (length, speed, cost)	5	4	√	√
Inter-city transportation systems	5	0	√	
Inter-city travel data (air, rail, bus)	1	0	√	
F Building data:				
Numbers of dwelling units	5	6	√	√
Qualitative measures of housing	1	3		
Floor area, by type of activity	3	4		
Building value	2	3		
Tenure	2	2		
Occupancy rates	2	2		
G. Utilities data.				
Sewerage systems	4	2		
Water supply systems	5	1		
Power systems	3	0		
Solid waste disposal sites	4	0		
H. Public service data (space and service areas):				
Education	5	6	√	√
Health	4	3		
Protection (fire, police)	3	3	√	√
Recreation facilities	5	3		
Other public services	4	1	√	√
Cemeteries	5	0		
I Data on appearance.				
Aesthetics	2	0	√	
Historic sites	1	0	√	
J Plans for land use:				
Public	5	8	√	√
Private	4	6		
K Cost data:				
Transportation construction costs	4	0	√	√
Building costs (site development)	1	2		
Utilities construction costs (major)	3	0		
Maintenance costs (building)	2	2		
Land values	4	4	[b]	

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[a] Numbers indicate how many processes used each type of data Check mark indicates use of data

[b] Only for expressway or transit rights-of-way

4. *Characteristics of the Land* —Basic information on the physical characteristics of land (primarily vacant land) appears to have been gathered, or is recommended to be gathered, by the sources studied. Data on topography, drainage, and flooding are most commonly obtained. There is less call for information on soils and subsoils, on vegetation, and on climate or access to navigable water. It is apparent that topography, drainage, and flooding seriously affect the potential of sites for development, whereas the other items are less important.

5. *Transportation Data.*—All of the metropolitan studies that were examined considered the transportation planning process to be a partner in the metropolitan planning process Hence, all of these metropolitan planning processes called for the kinds of data typically used in the urban transportation planning process

The basic information that was called for directly, or whose need was implied, had to do with planning the intraurban transportation planning systems. Thus, trip data, and highway and transit network data were called for There was less clarity on the need for a measuring of interurban networks or the volumes of trips using intercity modes of transportation. Except for the Tri-State Transportation Commission, there was little mention of the need for data on the movement of goods either within or between cities.

6. *Building Data.*—While the three metropolitan planning studies obtained information on numbers of dwelling units, there was much less agreement on need for or use of other data on housing, or for measures of non-residential floor space. Qualitative measures of housing were not obtained in the three metropolitan areas (except as these may have been available from the 1960 census on housing) and data on building values and tenure were not available.

Of the two textbooks mentioned, Chapin's (*40*) calls for the greatest amount of data on buildings, including measurements of floor area and building value The other text, *Principles and Practice of Urban Planning* (*41*), does not deal with housing in detail and makes no direct call for information on quality, floor area or value of buildings.

7 *Utilities Data.*—There is a substantial degree of variation on the amount of data required on utilities when preparing metropolitan land use plans. Data on sewerage and water supply systems are commonly gathered, together with information on solid waste disposal sites Data on power systems appear to be infrequently obtained

8. *Data on Public Services.*—Although data are generally obtained on public services, the kinds of data are restricted and the use of such data is even more restricted Data are generally obtained on the land areas needed for public services of various types, and on the extent of the service areas of schools, parks, and other public services. Space needs are generally accounted for in most urban land use planning but, at the metropolitan planning scale, details on service areas become submerged in the larger picture. Hence, data on public services are not very well used in the metropolitan planning process.

9 *Data on Appearance.*—Both Chapin (*40*) and *Principles and Practice of Urban Planning* (*41*) call for data on aesthetics Exactly how these data would be collected over an entire urban area (that is, how they would be collected separate and distinct from normal data on stream beds, topography, and vegetation) is not clearly specified, nor is it indicated how these data would be used in developing the metropolitan plan.

10. *Plans for Land Use* —Either directly or indirectly, calls are made for data to be assembled on existing public and private (particularly institutional) development plans so that these may be evaluated and incorporated within the plan for an entire urban area

11. *Cost Data.*—There is substantial variation in the collection of data on costs for metropolitan planning Southeastern Wisconsin Regional Planning Commission collected the most data, with information on transportation construction costs, utilities costs, and land values. The Tri-State Transportation Commission collected data on transportation construction costs and such data were also available in Chicago.

In general, however, there is a notable lack of information on costs of urban development in the planning process. Southeast Wisconsin obtained (but did not use) data on land values, but such data were not obtained either in the Tri-State study or in the Chicago study. This is an area where additional data are vitally needed.

12. *Public Attitudes and Preferences.*—Chapin (*40*) calls for surveys of public attitudes and preferences toward different kinds of urban development. All of the three metropolitan agencies, to a greater or lesser degree, ascertained preferences on alternative plans.

Data Needs for Metropolitan Growth Models

During the last decade many attempts have been made to develop and refine methods that will quantify and/or locate growth in the metropolitan environment. The result of this research has led to a growing family of models that are designed to describe urban development or land use.

Metropolitan growth models generally were developed as extensions of the transportation planning process, to facilitate that process. The planning of transportation facilities has, since 1955, incorporated a land use inventory into its data base and assumed or derived a modified land use configuration in its long-term projections

Increasingly, metropolitan growth models are being and will be used in conjunction with more conventional techniques for metropolitan land use planning.

Accordingly, an extensive analysis was made of data used in metropolitan growth models. Ten growth models were selected for examination:

1. The University of North Carolina Model (UNC) (*42-45*).
2. The Delaware Valley Regional Planning Commission Model (DVRPC) (*46*).
3. The Schneider Model (*47*).
4. The Bay Area Simulation Study Model (BASS) (*48*).
5. The Chicago Area Transportation Study Model (CATS) (*49*).
6. The Empiric Model (*50-51*).
7. The Pittsburgh Model (*52-53*).
8. The Penn Jersey Model (*54-56*).
9. The Opportunity-Accessibility Model (*57*).

10. The San Francisco Community Renewal Program Model (CRP) (*58-59*).

Research Method—To determine the data needs of metropolitan growth models, reliance was placed on published, descriptive reports The published reports were in some cases brief and general journal articles, but full documentation, including coding manuals, was examined when available Where models have undergone substantial modification, the latest published description was used as the source for listing data needs It was attempted to list fully those data specifically called for in the models. Those items only alluded to were not included in the preliminary listing Where analysis of composite input variables was clearly possible the multiple discrete data items were listed, rather than the combinations of these data items, although the combinations were used in the model.

Qualifications on Data Needs—The ten models that were examined vary greatly in quantity and detail of needed input data, aggregative level of description, nature of forecasts and allocations, cost of implementation, and operational status of the model Some models output only space allocated to a specific activity (e.g., residential), others include several activities (e.g., commercial and industrial as well as residential), another does not differentiate between activities. Some models have one or a number of linked submodels that output population and economic or employment forecasts; others require as input independently produced forecasts. Some require transportation planning data, such as trip information, whereas others produce such intelligence as an output. Economic detail is required by some and disregarded by others.

The model developers as a body, although attempting to simplify and condense model requirements, indicate that many other variables that have not been incorporated into their simulations may have a significant determining effect on the form and development or the urban configuration. In individual cases, some factors suspected to be of importance were not included because: (1) no accurate measurements were known, (2) data collection costs were too high, (3) data collection was too time-consuming or available data were not at the appropriate level of detail, (4) not enough time was considered available to evaluate the sensitivity or relevance of such data, (5) it was felt that too large a body of information could not be adequately handled by the present generation of computers, or (6) it was not known how to formulate the relationship of raw data and its effect on land use. At other times, however, model developers felt that the level of detail presently specified for the model could be reduced. Other than citing data collection and use difficulties, model developers often felt that model construction could be altered to affect more feedback loops, modify the output forms or include a larger area for simulation. The most often cited area for needed future research revolved about a better understanding and use of socioeconomic information. Following this in frequency was a desire to better understand and incorporate market considerations of development.

The discrete data requirements of many models were difficult to discern from available reports. Some specified detailed description of the components used in accessibility measures and household profiles, others did not Some called for specific forecasts and updating of the base data; others only implied that such an input is used. Some variables were judgmentally derived and others were rigidly quantified. Some models were developed and calibrated to a specific locality, the authors stating that, when they were used in an area that differed greatly in size or complexity of activity and population composition, other factors and relationships might have to be incorporated into the models.

Early in some model reports a list of data requirements was described that, later in the same report, was then modified. In such reports, it was often difficult to determine exactly which data items were deleted and which were added Some reports included a program manual specifying discrete data items that were then never acknowledged in the verbal model descriptions or, in some instances, were said to be unimportant to model operation. Data specifications were at times modified during model calibration; such items might be of importance in other geographic locations. Some variables and their relationship to land accrual were discussed at great length and then never appeared in subsequent model algorithms. Some reports dealt mainly with the history and theory of land use model development and provided only a general description of data needs. Also, as several models were undergoing modifications, data needs must be considered as appropriate only to the specific form of the model described.

Data Needs of Metropolitan Growth Models.—Data needed by the various metropolitan growth models are given in Table 17. Some observations may be made from a brief examination of this table, as follows:

1 There is a substantial variation in the number of different types of data required by the various models. The BASS, CRP, and Penn Jersey models each called for more than 20 different types of data. This is a large quantity of types to be collected and managed, with most of these data required to be registered to small geographic units within the urban area In contrast, the Schneider and Opportunity-Accessibility models each call for less than ten types of data

2. Ten types of data are used commonly by most models. All of the models call for population and land use data, with the possible exception of the Schneider model, which can subsist on floor area data instead of population, if floor area is available. Nine models use zoning data. Eight need some form of highway network data over which to measure accessibility. Eight models also call for use of existing public agency plans (for land use) After these high-frequency data uses, however, the degree of similarity begins to drop off rapidly.

3 It is interesting to observe what data are *not* used in the models. It is typically the data employed in more detailed, "conventional" land use planning that are not used. Data on aesthetics are not used, and information on utilities is rarely used. Data on public services other than education are not used very much Similarly, data on characteristics of vacant land (except topography) are rarely used.

4. It is surprising that so little use is made of economics in these models. Most of the models are empirical models, describing what happens in terms of the succession of

growth—in terms of the placement of buildings on available land, for example. Even Schneider's theories are descriptive of growth in terms of the units of growth—"urban stuff" or floor space. Almost no work is done with a comprehensive view and measurement of urban land values, the cost of building, the costs of maintaining buildings, etc. But, from another viewpoint, of course, this is not surprising at all· such data are really not available. (Where indications are made of the use of such data, they are found, in most cases, to be only partial.) If more data on economics had been available, they would probably have been used

Data Needs for Social Indicators or a Social Report

More and more, people are going to evaluate metropolitan land use plans—and, indirectly, transportation plans—in terms of goals that are socially oriented. These are goals that define the condition of all, or parts of, an urban society.

The name "social indicators" has been applied to statistical measures that define the condition of society. A series of these indicators constitutes a "social report." According to Bauer (*60*, p. 1), social indicators are a body of statistics or other information that "enable us to assess where we stand and where we are going with respect to our values and goals, and to evaluate specific programs and determine their impact." *Toward a Social Report* (*61*) defines a social report, in effect, as a "comprehensive set of statistics reflecting social progress or retrogression."

A number of sets of national goals have been developed, among which is the report of the President's Commission on National Goals (*62*). The 11 goal areas of the President's Commission are:

GOAL AREA	NO. OF SPECIFIC GOALS
The individual	6
Equality	3
Democratic process	11
Education	5
Arts and sciences	8
Democratic economy	9
Economic growth	9
Technological change	5
Agriculture	5
Living conditions	10
Health and welfare	10
Total	81

There are 81 specific goals falling in these 11 areas. A careful examination of the listing as described by Bauer (*60*) suggests that the list may not be complete. For example, only indirect mention is made of transportation and safety. Nevertheless, the list is extensive and although a number of goals might be added to it, few would be taken away.

Bauer (*60*) makes the point that there are no statistical measures that cover all of these goals. In fact, there are no social indicators at all for 33 of the 81 goals of the President's Commission. Bauer further points out that the relevancy of indicators in the other 48 goals is not always very great.

Toward A Social Report (*61*) lists seven basic goal areas, these include

1 Health.
2. Social mobility.
3 Improved physical environment.
4. Income.
5. Public order and safety.
6 Learning, science, and art.
7. Participation

One clear conclusion of *Toward A Social Report* is that there are inadequate data for measuring performance in terms of the foregoing goals, except, perhaps, in the area of income.

In sum, both reports conclude that there are inadequate data useful in preparing a social report

Would typical transportation and land use planning data be useful as social indicators? A judgmental examination, matching transportation and metropolitan planning data against the 81 specific national goals reported in Biderman's article, "Social Indicators and Goals" (in Bauer, *60*), suggests that only in a minor way would such data be useful as social indicators. Transportation data appear to serve well in only four of 81 specific goal areas. Metropolitan planning data appear to serve well in only 13 specific goal areas—and nine of these bear on living conditions

Would data collected as part of an enlarged program of measuring social progress be useful in transportation planning? In a general way, any such data would be helpful if they provide valid measures of social conditions, as the purpose of transportation and metropolitan planning is to make improvements that will benefit individuals and society. Thus, it would be desirable to encourage further collection of data measuring social conditions.

In the present state of the art, however, it seems clear that there are only minor connections between transportation planning and metropolitan planning on the one hand and social indicators on the other. There are equally minor connections between their respective sets of data.

SENSITIVITY

Research Plan

In this section, attention is focused not so much on kinds of data required for the STPP as on amounts, or accuracy, of data. How sensitive is the STPP to data errors? If errors in data substantially affect the plan, then more data (i.e., data at higher sample rates) must be collected, or data need to be collected more frequently. If the data do not affect the plan markedly, then fewer data can be gathered

The plan for research work on sensitivity had to assume, as a beginning point, the existence of a basic STPP such as is shown in Figure 3. The first stage of the sensitivity research was then to identify those sets of data—and forecasts—used in the "basic" STPP that had a clear impact on the recommended plan.

The second phase of the research work was to design and conduct a series of tests to measure how sensitive the planning process is to errors in those data identified in the first phase. In some cases, tests could be made analytically In other cases, computer tests were required. In the case of transit, the only way to test the impact of certain errors was to deal with an actual situation. These tests are described in the appropriate sections herein.

Identifying Critical Data and Forecasts

The search for data and forecasts critical to the development of a strategic transportation plan began with a careful examination of the "basic" STPP (Fig 3).

An early conclusion was that data obtained by survey affect the strategic plan only indirectly. Forecasts intervene between the plan and the data at every step Under these circumstances, plans are based directly on forecasts, not on data. And the errors of forecasts are apt to be much greater than errors of data. So, in this section, when sensitivity is discussed, it is really sensitivity to *forecast* errors, not data errors. This has important implications for data collection.

The "basic" STPP is, as shown in Figure 3, a series of interrelated steps that gradually focus on two important steps—Step W (Plan Testing) and Step X (Plan Evaluation).

Any variable that is used in Steps W and X is a critical variable. These critical variables are·

1. Numbers of trips in a zone (trip density).
2 Trip length.
3 Relative travel costs (incorporating accident, time, and operating costs) on express and non-express facilities
4. Network data (including speeds and capacities).
5. Data defining mode split, including "personal attitudes" and auto ownership.
6. Comparative transit-highway network speeds.
7. The capital recovery factor (interest plus amortization).
8 The capital costs of highways.
9. The capital costs of transit.

Lying behind the "number of trips," or trip density variable, are the variables of (10) type of land use, (11) land use density, (12) automobile ownership rates, (13) aggregate employment estimates, and (14) aggregate population estimates. Of these, density of land use and automobile ownership (both by zone) are more critical because these two variables directly affect trip production on a zonal basis. Unfortunately, the five variables that determine trip production rates interact in such a complex way that it would be very difficult to assess their relative impact on the transportation plan.

It can be seen by inspection that the foregoing variables (1) through (9), plus the variables (10) through (14), are the main products of the various steps shown in Figure 3. Thus, if the sensitivity of the STPP to these variables is determined, the sensitivity problem will largely have been solved.

The variables identified in the preceding section were assigned to one or more of three separate testing procedures, according to the ability of the testing procedure to deal with each variable. The test design is as follows:

TYPE OF TEST	VARIABLE BEING STUDIED
Analytic tests	Trip density—over-all Construction cost Trip length Travel cost differential
Computer tests	Trip density—localized Network speed—by class and link Network capacity Trip length
Case study of transit	Transit speeds (relative to highways) Trip generation Personal attitude Automobile ownership Employment per family

Analytic Study of the Sensitivity of the STPP to Selected Variables

One of the most important planning tasks for a metropolitan area is the determination of the "correct" amount of expressways. Two models that grasp this problem of determination have been selected for sensitivity analyses These models can be used to find the level of expressway construction that will result in the minimum total cost solution for a region of uniform trip density served by uniform grids of roadway facilities.

The models analyzed are the Optimum Spacing model (*65, 23*) developed by Creighton, Schneider, and Hoch and the Direct Assignment model by Schneider (*66, 67, 68*). These models are similar in that they both deal with the total transportation cost of uniform grids of local, arterial, and expressway facilities subjected to demands of uniform trip end densities. The Optimum Spacing model yields the expressway spacing which for a given trip end density, construction cost per mile, average trip length, and travel cost differential between expressways and non-expressways results in the least total cost. The Direct Assignment model yields use of each facility class (local, arterial, and expressway) given the trip end density, average trip length, and the grid spacing of the three facility systems From this information one can compute total costs and find the expressway spacing that results in the minimum total cost. When this is done the two processes are seen to have used the same data: (1) average trip length, (2) trip end density, (3) expressway construction cost, and (4) travel cost on expressways and non-expressway facilities.

The construction cost, c, of new expressways for this analysis is:

$$c = 1{,}120{,}000 + 520\rho \text{ (dollars/mile)}$$

in which ρ is the number of trip ends per square mile. This expression was found to be fairly accurate in the Chicago area (*23*).

Assuming a capital recovery factor of 0.11, no depreciation, and the effective use of the facilities in a year to be 340 days, the daily cost per mile of new expressways is·

$$c = 362.35 + 0.1682\rho \text{ (dollars/mile/day)}$$

The travel cost differential between expressways and non-expressways (needed for the Optimum Spacing formulation) was taken to be $0.06 per mile. To make the Direct Assignment travel costs roughly comparable to the foregoing differential, the following costs were selected:

Expressway	$0 06/mile
Arterial	$0.12/mile
Local	$0.14/mile

Output sensitivity for both models was examined at trip end densities of 10,000 per square mile and 20,000 per square mile for a variety of average trip lengths. The smaller density corresponds to fully developed residential sections, whereas the larger density is found within the city limits of most large cities in the United States. Sensitivity to a particular parameter was determined absolutely and relative to the other input parameters.

Sensitivity of Spacing to Average Trip Length

Figures 13 and 14 show the sensitivity of the two optimum spacing formulas to changes in average trip length. Figure 13 is the case for a region with a trip density of 10,000 trips per square mile, and Figure 14 is for the case of a density of 20,000 trips per square mile

The two formulas show different degrees of sensitivity, resulting from their differing underlying assumptions of the choices made by travelers in using local, arterial, and expressway systems. Neither model can be considered completely accurate in this respect; a better understanding of network choice is clearly a needed area for future research.

If trips were to decrease in their average lengths from 6 miles (a common average in major cities), then it can be seen that the optimum spacing of expressways would be extremely sensitive to trip length.

On the other hand, as trip lengths increase, the sensitivity of optimum expressway spacing to trip length begins to decrease, especially in the Chicago Area Transportation Study (CATS) model. An increase in mean trip length from 6 to 7 miles suggests that optimum spacing should decline from 5.3 miles to 5.1 miles (in the CATS formula) and from 5.3 miles to 4.7 miles in the Direct Assignment formula. The latter is a significant change, whereas the former is fairly insignificant—the variations required in laying out a system over an actual city will frequently exceed 0.2 mile.

Figures 13 and 14 have been converted in Figures 15 and 16 to permit *direct reading of changes in optimum expressway spacing, in miles, resulting from 1-percent changes in the independent variable,* for different levels of the independent variable. All subsequent figures are displayed in this fashion. The effect of larger percentage changes in the independent variables—up to 10 or 15 percent—can be approximated in these later figures by multiplying the sensitivity mileage reading on the Y-axis by the appropriate percentage. This practice cannot be carried too far, however, or the results would become meaningless For larger errors, the sensitivity must be recalculated.

Figure 15 shows the sensitivity of optimum expressway spacing to trip length, using the Direct Assignment model. Figure 16 shows the same, but for the CATS model. In both figures, Case A is the low-density example (10,000 trip destinations per square mile) and Case B is the high-density example (20,000 trip destinations). Both figures suggest that for trip length changes over 6 miles, there is relatively small impact on optimum spacing, whatever the density.

At first this may seem surprising, but it should be remembered that all the independent variables in the optimum spacing formula are found under a radical sign, which tends to diminish the impact of changes in individual variables on the dependent variable.

Sensitivity of Spacing to Trip End Density

Figures 17 and 18 show the sensitivity of optimum expressway spacing to trip destination densities in the Direct Assignment and CATS models. As before, Case A is the low-density example and Case B is the high-density example.

These figures show that sensitivity varies markedly as a function of density. At medium-to-high densities (more than 15,000 trips per square mile), the optimum expressway spacing is not very sensitive to changes in trip density. In the lower density ranges—5,000 to 15,000 trip destinations per square mile—the best spacing is fairly sensitive.

These statements have to be interpreted with considerable care. What the foregoing says is that the optimum expressway spacing varies little, in terms of distance, as a result of a 1-percent change in trip density, when trip densities are high. However, the cost of a wrong estimate may be high in terms of congested expressways and arterials, or in terms of greater investment in expressway length.

Sensitivity of Spacing to Construction Costs

Figures 19 and 20 show the sensitivity of optimum expressway spacing to construction costs, expressed in daily dollar costs. Figure 19 is based on the Direct Assignment model, and Figure 20 is based on the CATS model. Case A is low density and Case B is high density.

Both sets of data show that spacing results are more sensitive when construction costs are in the high range than in the low range. However, in general, spacing is not very sensitive to construction costs—it takes a 1-percent change in construction costs to produce, generally, less than a 0.1-percent change in spacing

Sensitivity of Spacing to Travel Costs

The sensitivity of expressway spacing to travel costs is shown in two different fashions, because the two models treat these costs differently.

In Figure 21, the relationships between optimum expressway spacing and travel costs (cents per mile) on expressways is shown. Except for high travel costs ($.09 per mile or greater, which suggests travel in congested circumstances) this figure indicates that optimum spacing is insensitive to travel costs.

In Figure 22, optimum spacing sensitivity is plotted against the cost differential (arterial travel costs minus expressway travel costs). As the differential between these two costs gets less and less, optimum spacing sensitivity rises (in absolute terms). A lack of differential indicates that expressways are running congested; hence, the two figures, although apparently different, are actually telling the same story.

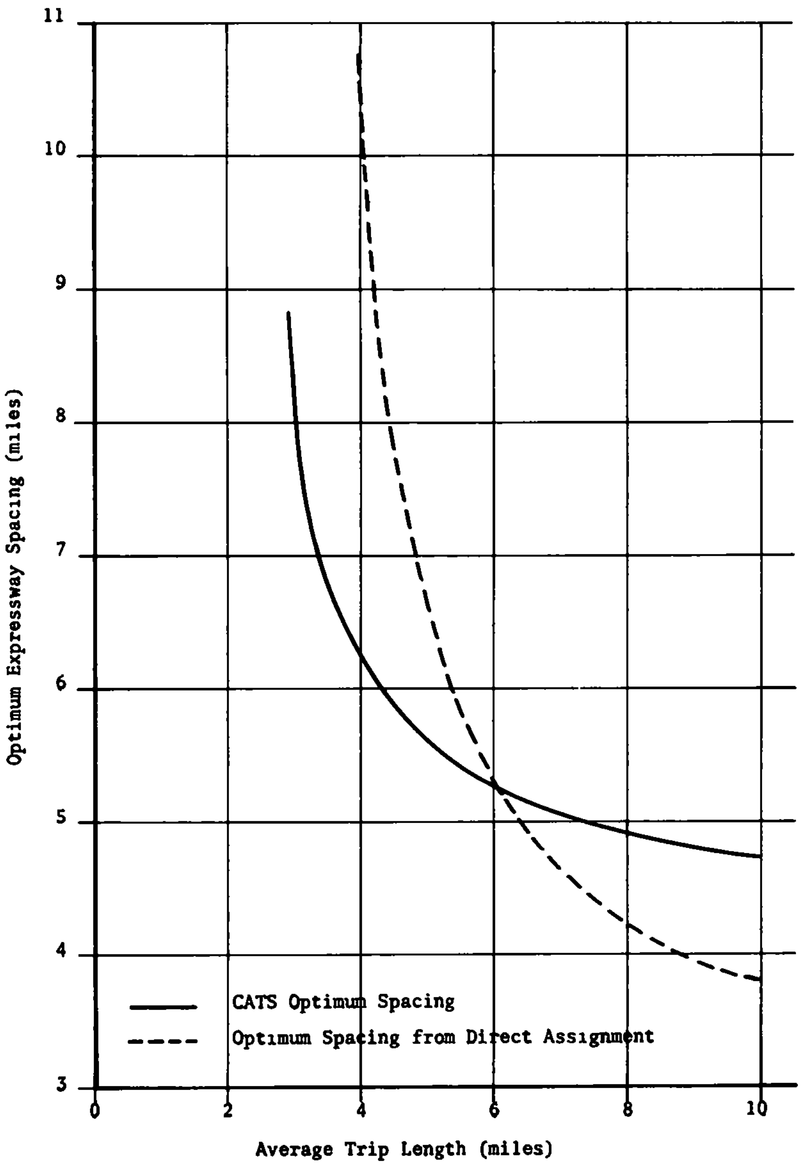

Figure 13. Optimum spacing versus average trip length. Trip density=10,000/ sq mile.

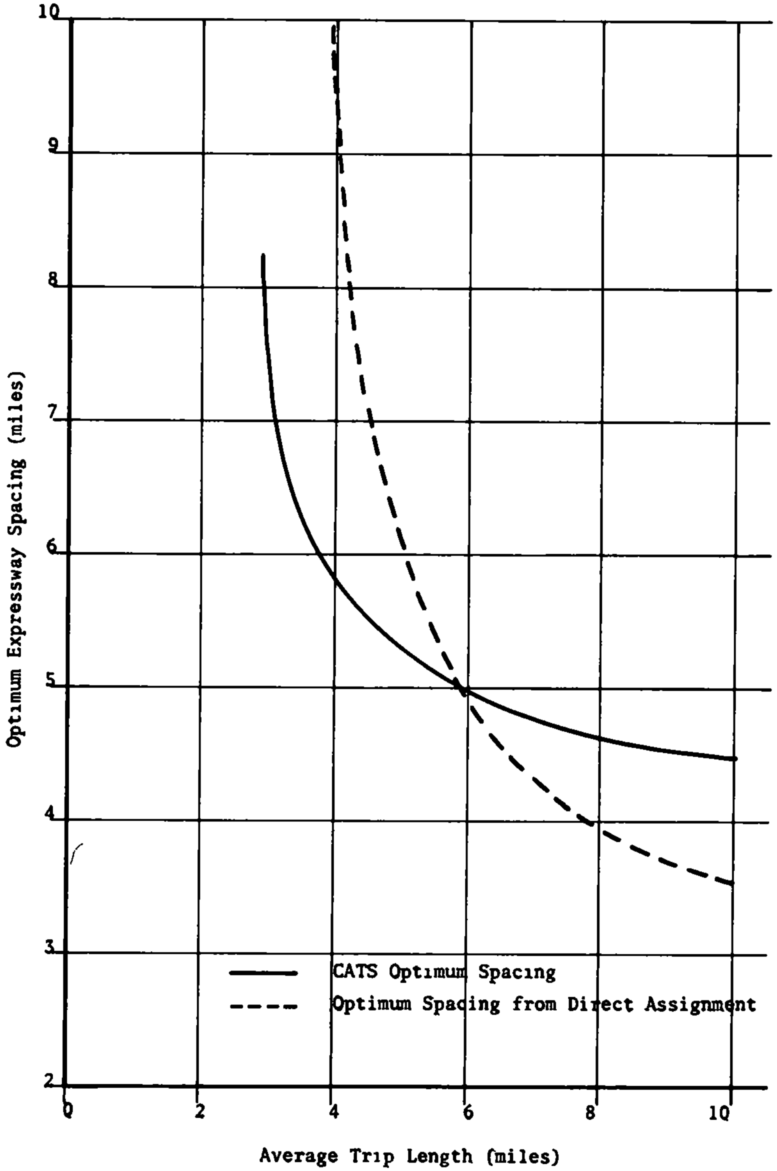

Figure 14. Optimum spacing versus average trip length Trip density= 20,000/sq mile.

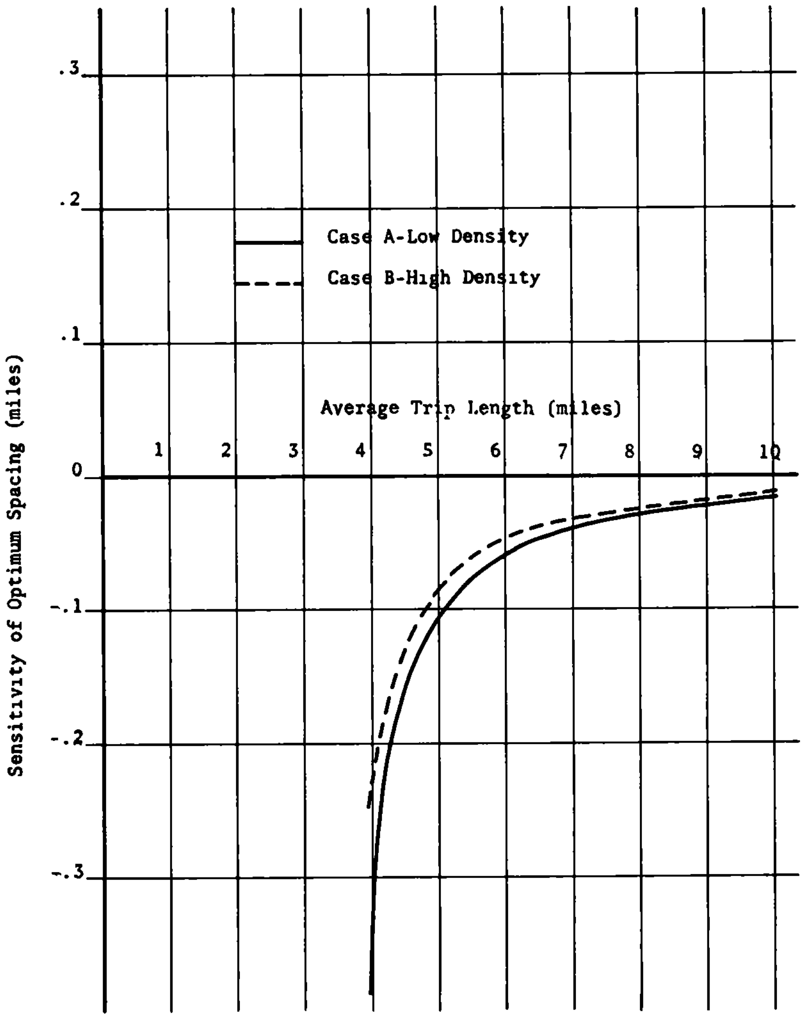

Figure 15 Sensitivity of optimum spacing to average trip length of the direct assignment model

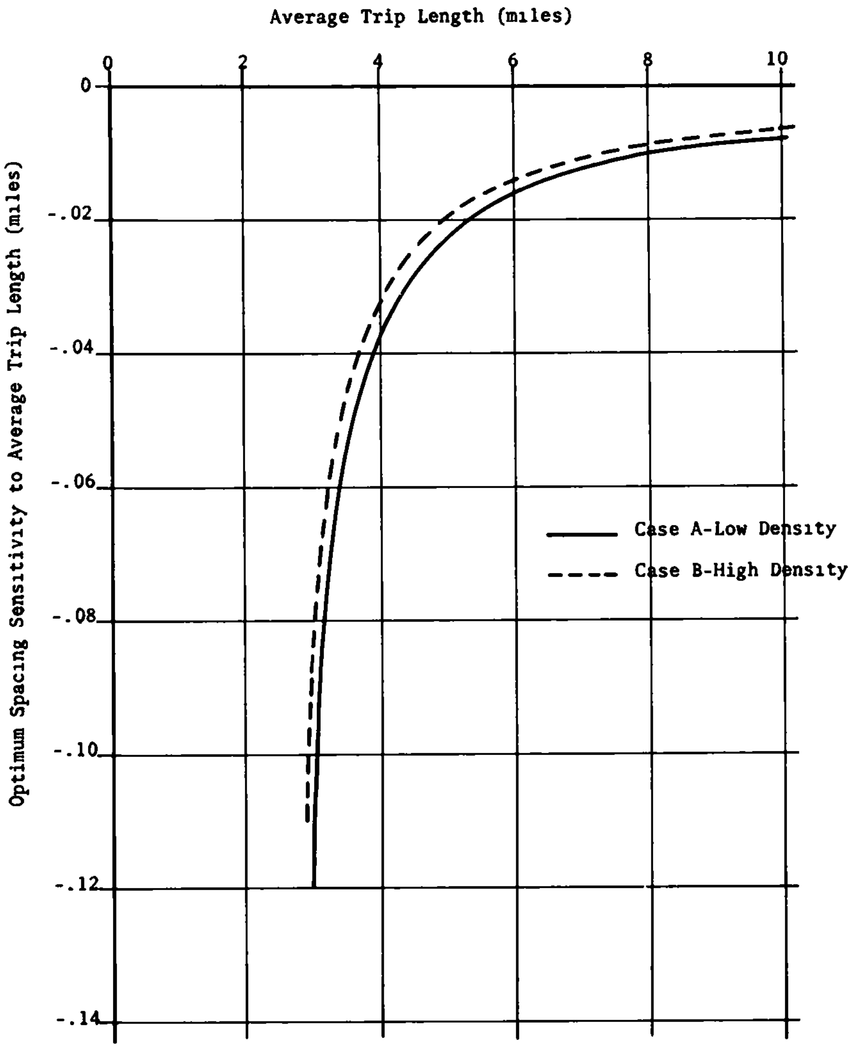

Figure 16 Sensitivity of the CATS optimum spacing model to average trip length

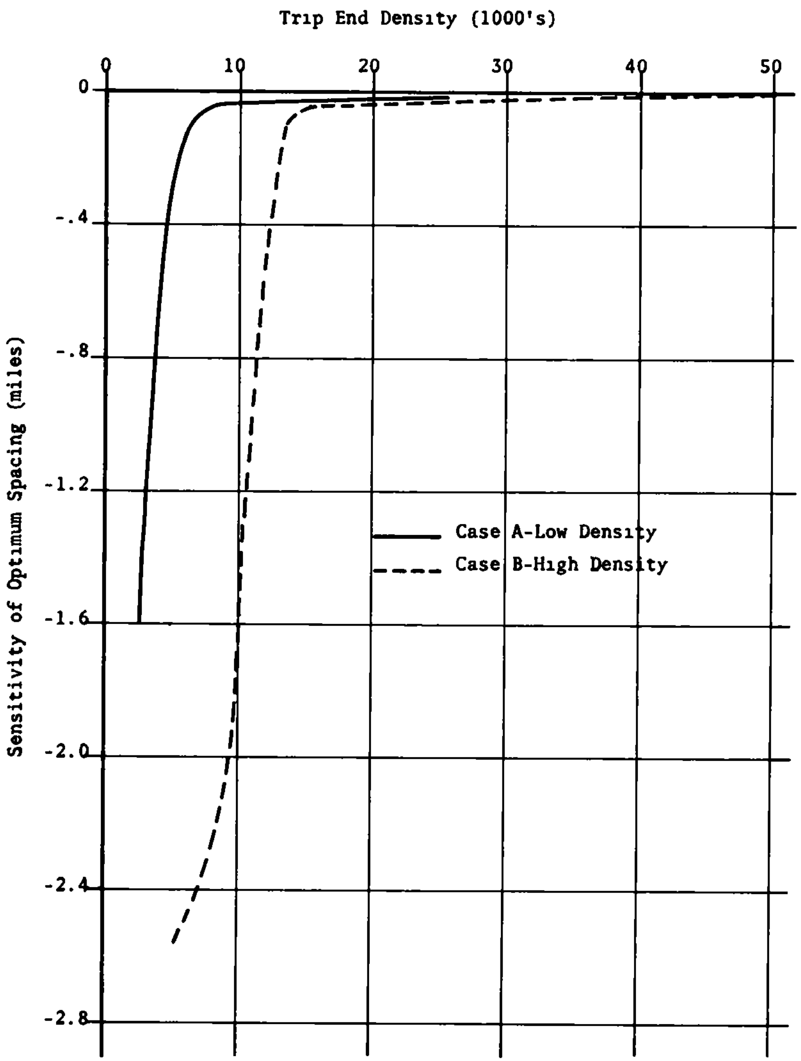

Figure 17. Sensitivity of optimum spacing to trip end density of the direct assignment model.

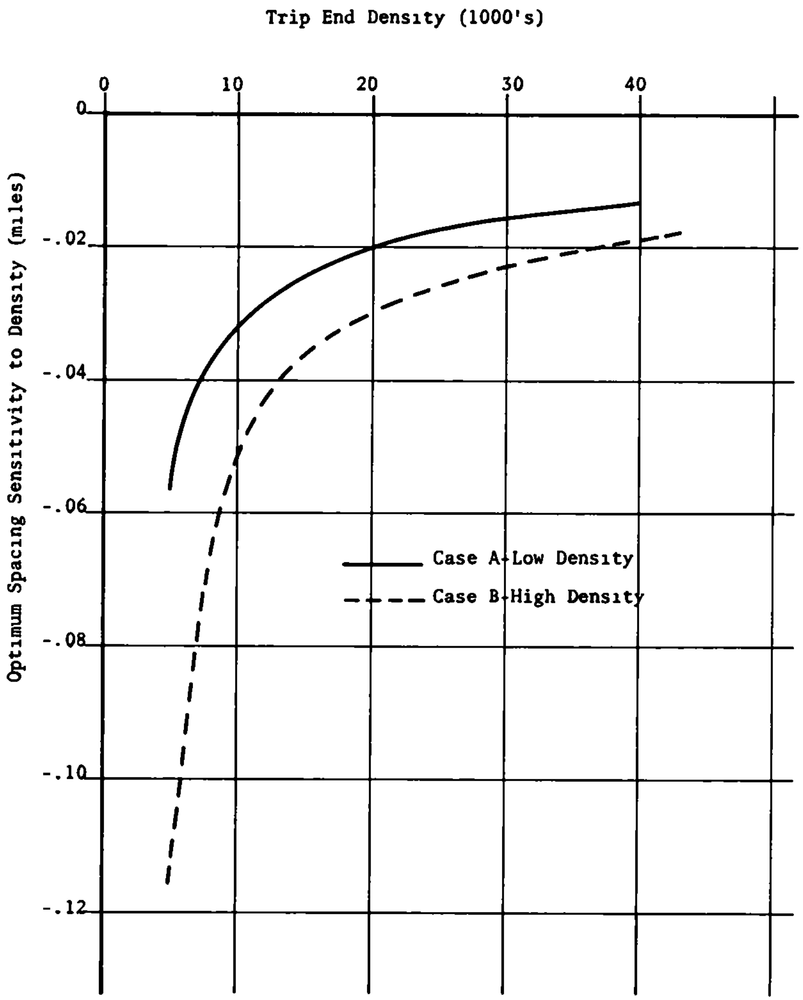

Figure 18 Sensitivity of the CATS optimum spacing model to average trip end density

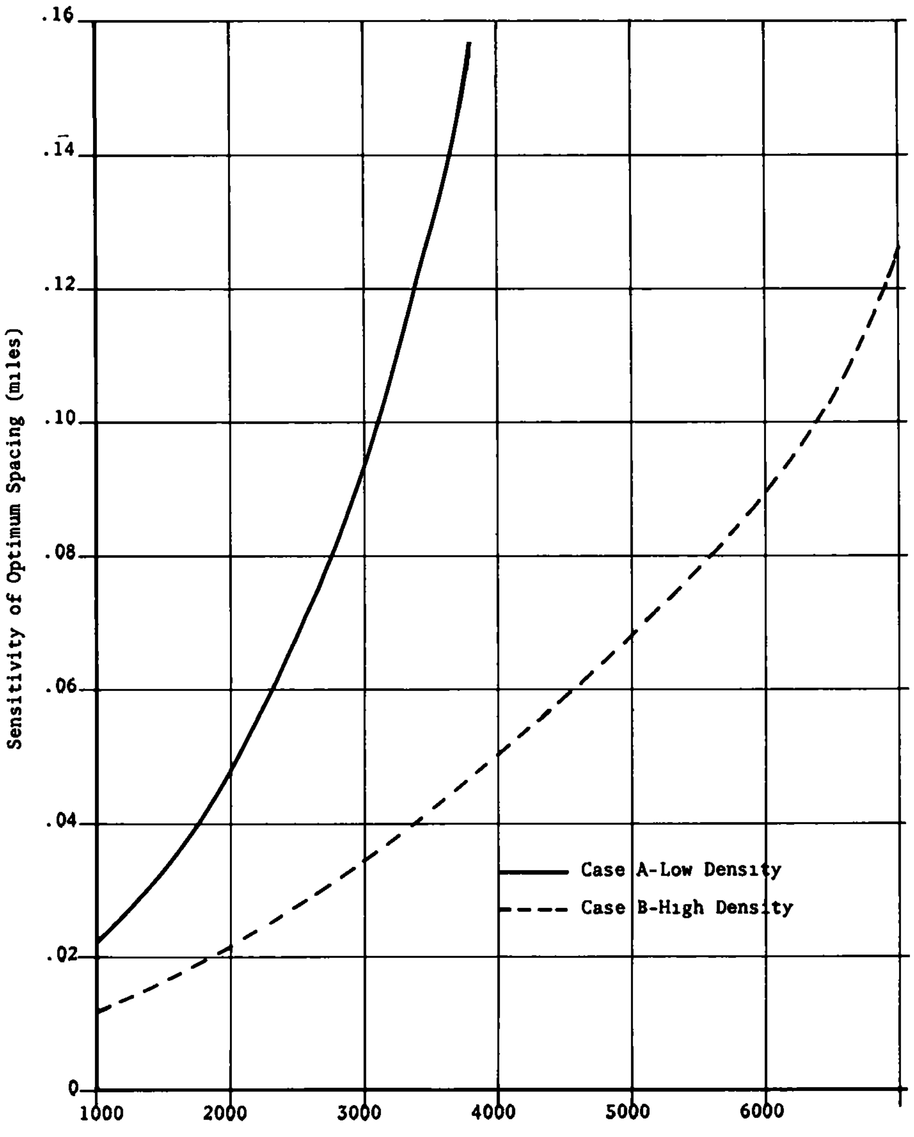

Figure 19 Sensitivity of optimum spacing to construction cost of the direct assignment model

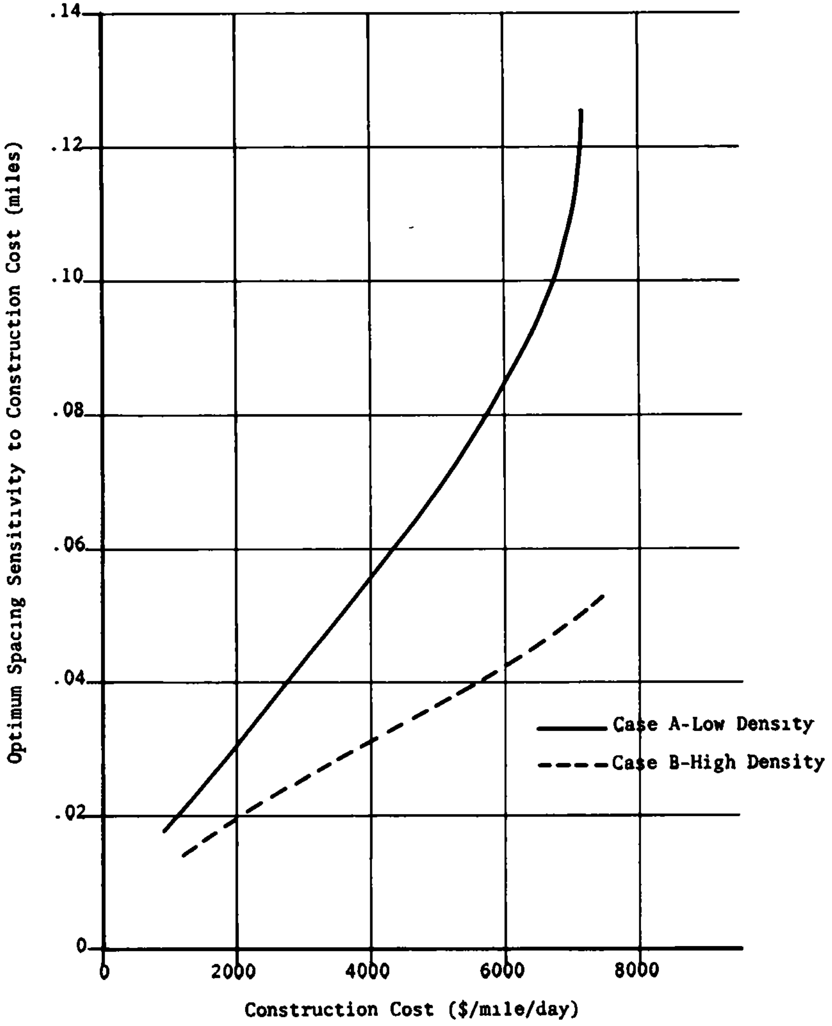

Figure 20 Sensitivity of the CATS optimum spacing model to construction cost

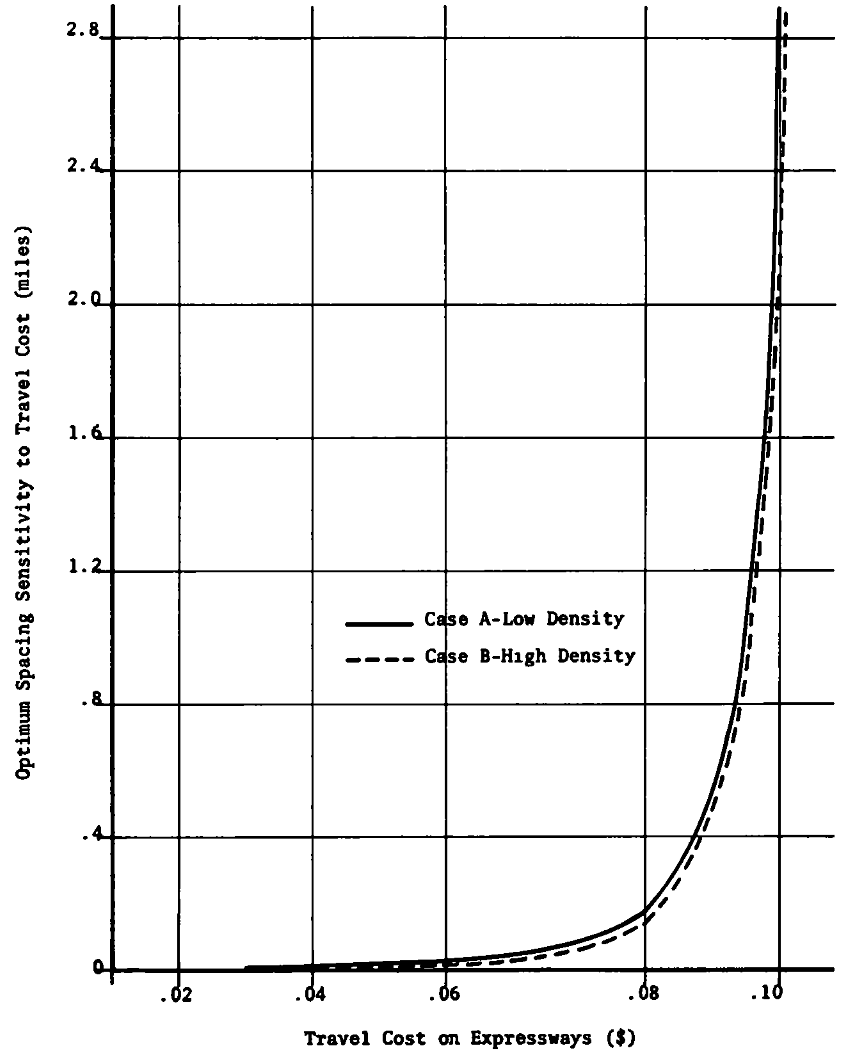

Figure 21. Sensitivity of optimum spacing to travel cost of the direct assignment model.

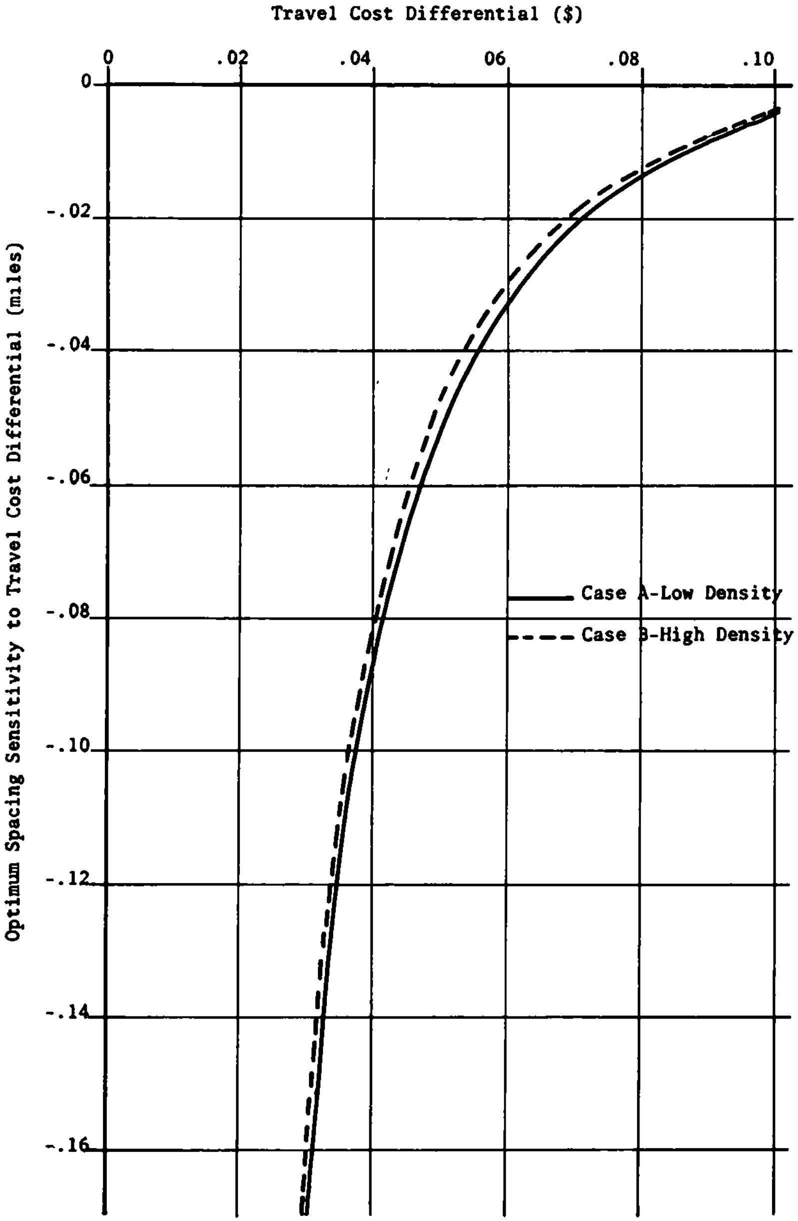

Figure 22 Sensitivity of the CATS optimum spacing model to travel cost differential.

Conclusion

The study of the sensitivity of the optimum spacing of expressways to errors in estimates of four critical variables is a complex and difficult matter. The figures shown here indicate that there is no easy way to determine sensitivity because, even for a single variable, sensitivity changes as a result of the relative magnitude of the variable. For example, optimum spacing is sensitive to errors in trip length when trip lengths are low, but insensitive as trip lengths increase

This means that it is difficult to generalize about the needs for accuracy of estimates. This is true not only for single variables, but even more so for combinations of variables

One approximate way of assessing the relative impact of estimating errors in the four variables studied here is given in Table 18. This table suggests that trip density and travel cost on expressways (or travel cost differential) can create substantial errors in a determination of optimum spacing—errors in excess of 2 miles It would appear, then, that considerable care should be given to both measuring and estimating trip density and travel cost

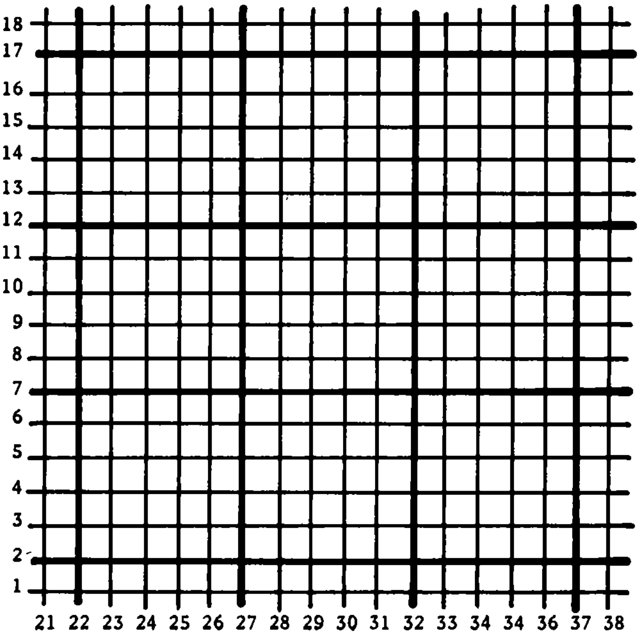

Figure 23 Test network

TABLE 18

MINIMUM, MID-POINT, AND MAXIMUM ERRORS OF ESTIMATES OF OPTIMUM EXPRESSWAY SPACING (DIRECT ASSIGNMENT MODEL) RESULTING FROM 1-PERCENT CHANGES IN INDEPENDENT VARIABLES

INDEPENDENT VARIABLE	APPROPRIATE ERROR (MILES)		
	MINIMUM	MID-POINT	MAXIMUM
Trip length	0.02	0.04	0.33
Trip density	0.05	0.05	2 5
Construction cost	0.01	0.05	0.12
Travel cost	0.05	0 05	2 4

Source Figs 15, 17, 19, and 21

Computer Tests

This section describes a series of tests that were designed to measure the variation in the assignment output as a function of variations in the assignment input. Errors in the description of the characteristics of the transportation network itself are examined in terms of their impact on assignment output results such as total vehicle-miles of travel, split between the expressways and surface arterials, system speed, total hours of system travel, and total system costs The impact that differences in trip length assumptions and trip density estimates have on assignment output also is examined.

Test Design

In designing these tests the use of actual data for existing cities was considered. Such experiments were not performed primarily because of their lack of generality, but also because of their extensive data and computer requirements. There were also several options available in terms of generating trip interchanges to be used in the sensitivity tests. It was decided to use the Opportunity model to generate trip interchanges for testing primarily because of the researchers' greater familiarity with this technique. There were also questions of the size, type, and spacing of facilities to be used in these tests. These factors and decisions are discussed in the following sections

The Test Network—The test network consisted of 18 streets running east-west and 18 streets running north-south In most of the tests these streets are assumed to be spaced 1 mile apart Four streets running east-west are expressways and are spaced 5 miles apart, and four streets are expressways running north-south, also spaced 5 miles apart. This network is shown in Figure 23. The numbers are the street names that are referred to throughout the discussions. Expressway free speed was set at 60 mph and arterial free speed was set at 30 mph Arterials were assumed to be two lanes in each direction, and each arterial intersection was assumed to be signalized. Left turns are possible everywhere, and a separate signal phase is provided at arterial intersections Expressway entrance and exit ramps are coded at 30 mph, with a yield requirement for merging. Expressway to expressway ramps were coded at 60 mph. Expressways were assumed to have three lanes in each direction Expressway capacity was assumed to be 1,500 vehicles per lane per hour. Arterial capacity was assumed to be 600 vehicles per lane per hour. There are 1,296 one-way through links in the network. All turning movements are possible and represented as an actual link in the network. Therefore, there are 2,592 turning links in the network, making a total of 3,888 links in the network.

Trips.—Three matrices of trip interchanges were generated to use in connection with these tests. The basic zone system consisted of 648 half-mile zones. Each zone consisted of the two ¼-sq-mile areas facing a street. This permitted the assignment of trips to the midpoint between street intersections. An assumed density of vehicular trip ends of 10,000 per square mile was used. The Opportunity model was used to calculate trip interchanges. Three l values were used: 3.6×10^{-6}, 1.6×10^{-6} and 0.75×10^{-6}.

This resulted in average trip length of approximately 4.1, 6.4, and 9.1 miles, respectively, and a total of slightly more than 3 million trips in each matrix. The trip assignment technique used in these tests was an all-or-nothing assignment to a minimum time path. A capacity restraint was considered to be desirable. Rather than use a 24-hour capacity that presumes a peak-hour constant, directional split, turning movement proportions, etc., an hourly capacity was used. Trips were split into two periods: peak-hour travel, which was assumed to be 40 percent of the trips, or a 4-hr period in non-peak-hour travel that was assumed to be 50 percent of the trips over a 9-hr period. There were no attempts to differentiate trip purpose or average trip length between peak and off-peak.

The Basic Assignment

The base assignment (Test 28) against which several sensitivity runs were to be compared is given in Table 19. Total vehicle-miles of travel assigned was about 22 million. The percentage of vehicle-miles on expressways was 59.3 percent over-all. During the peak hour 57.5 percent was assigned to expressways, in the off-peak period 60.4 percent was assigned to expressways. Total vehicle-hours of travel in the system was 913,000, with 459,000 attributable to expressways and 454,000 attributable to surface arterials. System speed over-all was 24.3 mph. System speed was estimated to be 21.6 mph during the peak hours and 26.4 mph during the off-peak hours. Expressway speed system-wide over 24 hr was 28.6 mph, with speeds of 23.8 mph during the peak hour and 32.7 mph during the off-peak. Arterial speeds were 19.9 mph during all hours, and 19.3 mph in the peak and 20.3 mph in the off-peak. Total operating costs came to $777,000 during a 24-hr period, which is $0.0351 per vehicle-mile of travel. The average trip length was 6.51 miles over all, but during the peak hour it was slightly shorter (6.46 miles), and during the off-peak hours, slightly longer (6.53 miles), reflecting the tendency to travel farther on expressways to save time.

Sensitivity to Speed

Because the routing and assignment of travel through a network is usually accomplished using the minimum time path, link speed is a critical factor. The concern of this section was to establish the sensitivity of the assignment process to errors in speed. Assignment output characteristics that were examined are total vehicle-miles of travel (VMT), percentage of travel using expressways, total vehicle time, and average vehicle density for expressways and surface arterials. Tests include varying the speed of a single facility and also varying the speed of an entire class of facilities.

Lowering the Speed of a Single Surface Street (Test 31).—The first test consisted of lowering the legal speed of street 09 from 30 to 15 mph. This resulted in a reduction of the average volume on street 09 from 7,642 to 2,700 during the peak hours. In terms of speed, this represented a 50-percent reduction, in terms of time, a 100-percent

TABLE 19

EXAMINATION OF ASSIGNMENT SENSITIVITY TO SPEED CHANGES

CHARACTERISTIC	BASE ASSIGNMENT	TEST 31 [a]	TEST 32 [b]	TEST 33 [c]	TEST 34 [d]	TEST 35 [e]	TEST 36 [f]
VMT	8,807,373	8,819,266	8,796,666	8,795,847	8,861,008	8,578,432	9,072,957
Exp. VMT	5,060,404	5,053,338	5,018,502	4,999,942	5,153,191	4,433,665	5,626,158
Art. VMT	3,746,969	3,765,928	3,778,164	3,795,905	3,707,817	4,144,767	3,446,799
VHT	407,053	410,890	407,258	409,653	411,911	414,408	403,274
Exp. VHT	212,826	212,536	208,173	211,952	216,730	190,567	220,884
Art. VHT	194,227	198,354	199,085	197,701	195,181	223,521	182,390
Speed (mph)	21.6	21.4	21.5	21.4	21.51	20.7	22.4
Exp. speed	23.8	23.8	24.1	23.6	23.78	23.3	25.5
Art. speed	19.3	19.0	19.0	19.2	19.00	18.5	18.9
Cost ($)	327,367	328,454	328,966	324,498	333,805	289,504	352,511
Exp. cost	213,093	212,996	210,405	208,417	219,675	159,972	246,007
Art. cost	114,274	115,458	118,561	116,081	114,130	129,532	106,504
Cost/VMT (¢)	3.72	3.72	3.74	3.69	3.77	3.37	3.89
Trips	1,362,498	1,362,498	1,362,498	1,362,498	1,362,498	1,362,498	1,362,498
Avg. trip length (miles)	6.46	6.47	6.46	6.46	6.50	6.30	6.66
VMT/exp. mile	35,142	35,093	34,851	34,722	35,786	30,789	39,071
VMT/art. mile	7,434	7,472	7,496	7,532	7,357	8,224	6,839
VMT/street mile	13,592	13,610	13,575	13,574	13,674	13,238	14,001
% VMT on exp.	57.5	57.3	57.1	56.8	58.2	51.7	62.0

[a] Legal speed on street 09 lowered to 15 mph
[b] Legal speed on street 09 increased to 45 mph
[c] Legal speed on street 12 (exp.) lowered to 45 mph
[d] Legal speed on street 12 (exp.) increased to 75 mph
[e] Legal speed on *all* expressways lowered to 45 mph
[f] Legal speed on *all* expressways increased to 70 mph

increase. The reduction in volume represented a 65-percent decrease. Streets 08 and 10, the parallel streets on either side, showed large increases in volume when the speed on street 09 was reduced, as indicated in the following:

	NO. OF VEHICLES		
STREET	BASE (RUN 28)	SPEED ON 09 = 15 (RUN 31)	CHANGE (%)
08	7,256	8,627	+19
09	7,642	2,700	−65
10	7,510	9,196	+22
Total	22,408	20,523	−08

Street 09 lost an average of 4,942 veh-miles of travel per mile. The adjacent streets picked up an average of 3,057 veh-miles of travel per mile, or about 62 percent of the decrease in street 09.

Another way of seeing how this error in speed is propagated through the network is to take a cross section through the region at right angles to street 09. The result of this cross-section analysis is shown in Figure 24. Only through travel (links) was considered. Notice that all parallel streets are plus or minus 4 percent, except street 09, which is depressed, and streets 08 and 10, which are adjacent to street 09. The impact of reducing the speed of street 09 from 30 to 15 mph is quickly dissipated on the adjacent parallel streets.

What is the over-all effect of lowering the speed of a single street? Several over-all characteristics are given in Table 19 for the base assignment and for the assignment with street 09 coded at 15 mph (Test 31).

The over-all vehicle-miles of travel (VMT) are slightly greater when street 09 is slowed to 15 mph. An additional 11,893 miles of travel are placed on the network. However, expressway VMT is down by 7,066 veh-miles of travel, whereas surface streets gained 18,959 miles of travel. All of these differences are relatively small, representing about 0 1 percent of the arterial VMT.

Total vehicle-hours of travel (VHT) are up from 407,053 to 410,890, an increase of 3,837 hr or 0.9 percent of the total At $3.00 per vehicle-hour, this would be about $10,000, which might be significant.

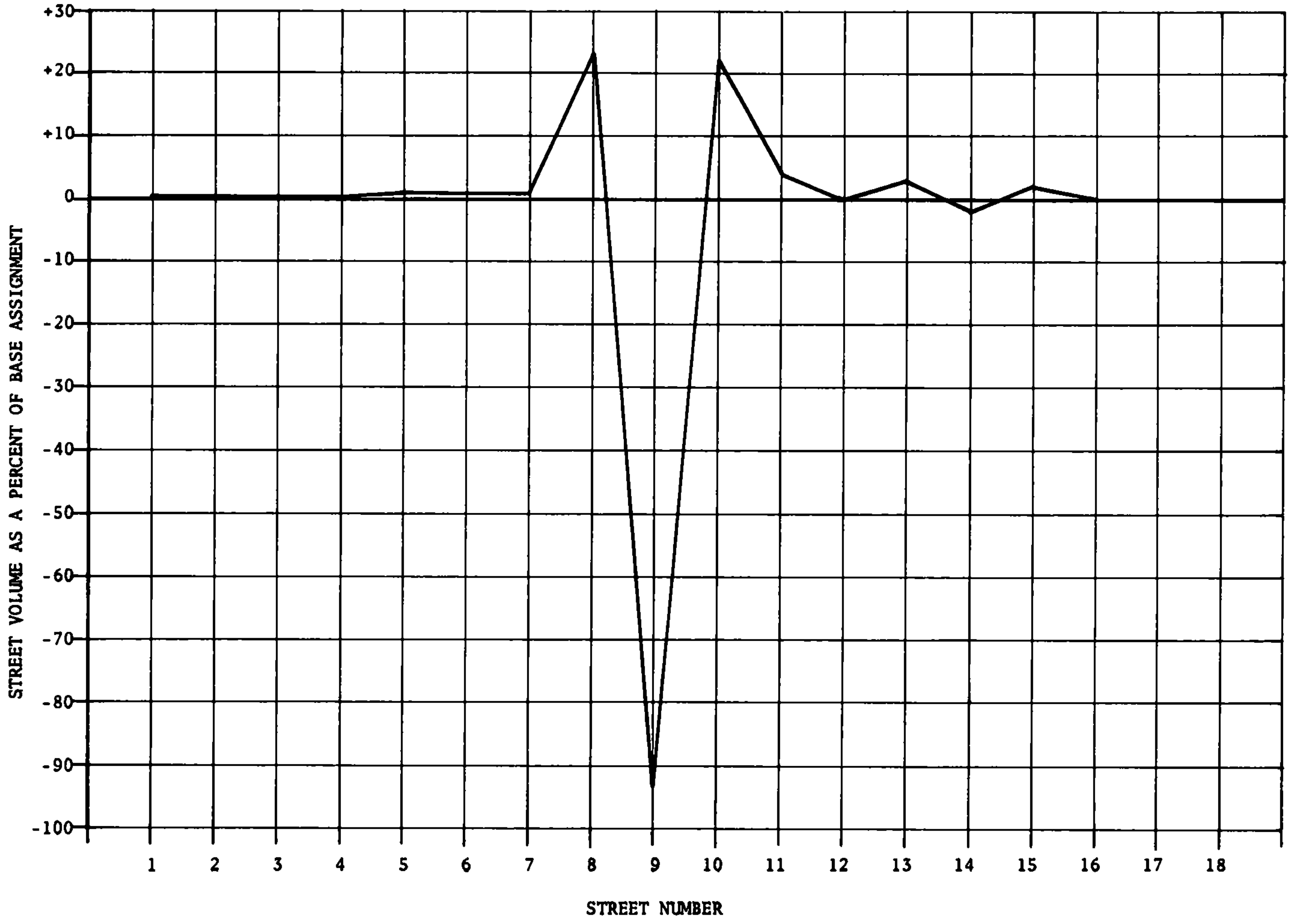

Figure 24. Cross section of region on street 30 showing impact of lowering speed on street 09 to 15 mph.

Increasing the Speed of a Single Surface Street (Test 32).—The second test involved increasing the speed on street 09 from 30 mph to 45 mph. As a result, the average volume on the street increased from 7,642 to 12,842 vehicles during the peak hours. The volume of traffic on the adjacent parallel streets, streets 08 and 10, decreased as follows:

STREET	NO. OF VEHICLES		CHANGE
	BASE (RUN 28)	SPEED ON STREET 09 = 45 (RUN 32)	(%)
08	7,256	6,484	−11
09	7,642	12,842	+68
10	7,510	6,667	−11
Total	22,408	25,993	+16

Street 09 gained 5,200 vehicles as a result of increasing its legal speed from 30 to 45 mph; that represented a 68-percent increase, which is similar to 65-percent decrease experienced when the speed on street 09 was reduced to 15 mph. This increase in traffic was picked up in part from the two adjacent streets, which both declined. The combined decrease, however, was only 1,615 vehicles, which is only about 31 percent of the increase in street 09. The remainder was spread over the next two streets.

The territory over which this increase in speed draws traffic is shown in Figure 25, a cross section of the region along street 30. The volumes of all streets parallel to street 09 when street 09 has a speed of 45 mph are shown as a proportion of their volume when street 09 has a speed of 30 mph. Although the bulk of the impact is within three streets on either side of 09, there is a small effect continuing for an additional three streets on either side.

Test 32 in Table 19 shows the over-all effect of increasing street 09's speed to 45 mph on the entire region. Total VMT decreased by 10,707 veh-miles. This compares fairly closely, but in the opposite direction, to the 11,893 veh-miles of travel gained when street 09's speed was decreased to 15 mph. Expressway VMT decreased by almost 42,000 veh-miles, whereas surface arterial VMT increased by about 31,000 veh-miles. Thus, increasing the speed of street 09 reduced expressway VMT by 0.8 percent and increased surface arterial VMT by 0.8 percent.

Total vehicle-hours of travel increased by 205 hours, or only 0.05 percent Expressway VHT decreased 4,653 hours, whereas surface arterials VHT increased 4,858 hours.

Over-all, the effects of a major speed error for a single street are nominal. Total VMT, total VHT, and the split of travel between expressway and arterials are affected only slightly.

Lowering the Speed of an Expressway to 45 mph (Test 33).—The third test of the sensitivity of the assignment process to variations in network speed was to lower the speed on street 12, an expressway, from 60 to 45 mph.

The result was to decrease the average volume on the street from 36,644 vehicles to 31,287, a decrease of 5,357 vehicles, or 15 percent. The two adjacent expressways are only moderately affected, as follows:

STREET	NO. OF VEHICLES			
	BASE (RUN 28)	STREET 12 = 45 MPH (RUN 33)	CHANGE	CHANGE (%)
07	37,073	38,334	+1,261	+3.4
08	7,255	7,313	+58	+0.8
09	7,642	7,767	+125	+1.6
10	7,510	7,723	+213	+2.8
11	7,034	7,109	+75	+1.1
12	36,644	31,287	−5,357	−14.6
13	7,156	7,312	+156	+2.2
14	7,810	8,092	+282	+3.6
15	7,622	7,794	+172	+2.3
16	6,937	7,027	+190	+2.8
17	35,793	35,741	−52	−0.2
Total	168,376	165,499	−2,877	−1.7

Most of the decrease is taken up by adjacent local streets.

Over-all (see Table 19, Test 33), the effect is to reduce total VMT by 11,526 veh-miles. This is comparable to the impact of the 15-mph increase in speed of a surface arterial that resulted in a 10,707 decrease in total VMT. Expressway VMT is down 60,462 and surface arterial VMT is up 48,936 veh-miles. These are differences of −1.2 percent and +1.2 percent, respectively.

Total VHT are increased by 2,600 hours, with expressway VHT down by 874 and arterial VHT up by 3,474.

Both arterial speeds and expressway speeds decline slightly, with an over-all reduction in system speed from 21.6 to 21.4 mph.

Increasing the Speed of an Expressway to 75 mph (Test 34).—The next test of the sensitivity of the assignment process to variations in network speed was to increase the speed on street 12, an expressway, from 60 to 75 mph.

The result was to increase the average volume on the street from 36,644 vehicles to 45,643 vehicles, an increase of 8,999 vehicles, or 25 percent. The impact of this change on adjacent street vehicular densities is as follows:

STREET	NO. OF VEHICLES			
	BASE (RUN 28)	STREET 12 = 75 MPH (RUN 34)	CHANGE	CHANGE (%)
07	37,073	35,869	−1,204	−3.3
08	7,255	7,109	−146	−2.0
09	7,642	7,209	−433	−5.7
10	7,510	6,744	−766	−9.8
11	7,034	5,826	−1,208	−17.2
12	36,644	45,643	+8,999	+24.6
13	7,156	5,976	−1,180	−16.5
14	7,810	7,103	−707	−9.1
15	7,622	7,130	−492	−6.5
16	6,837	6,759	−78	−1.1
17	35,793	34,671	−1,122	−3.1
Total	168,376	170,039	+1,663	+1.0

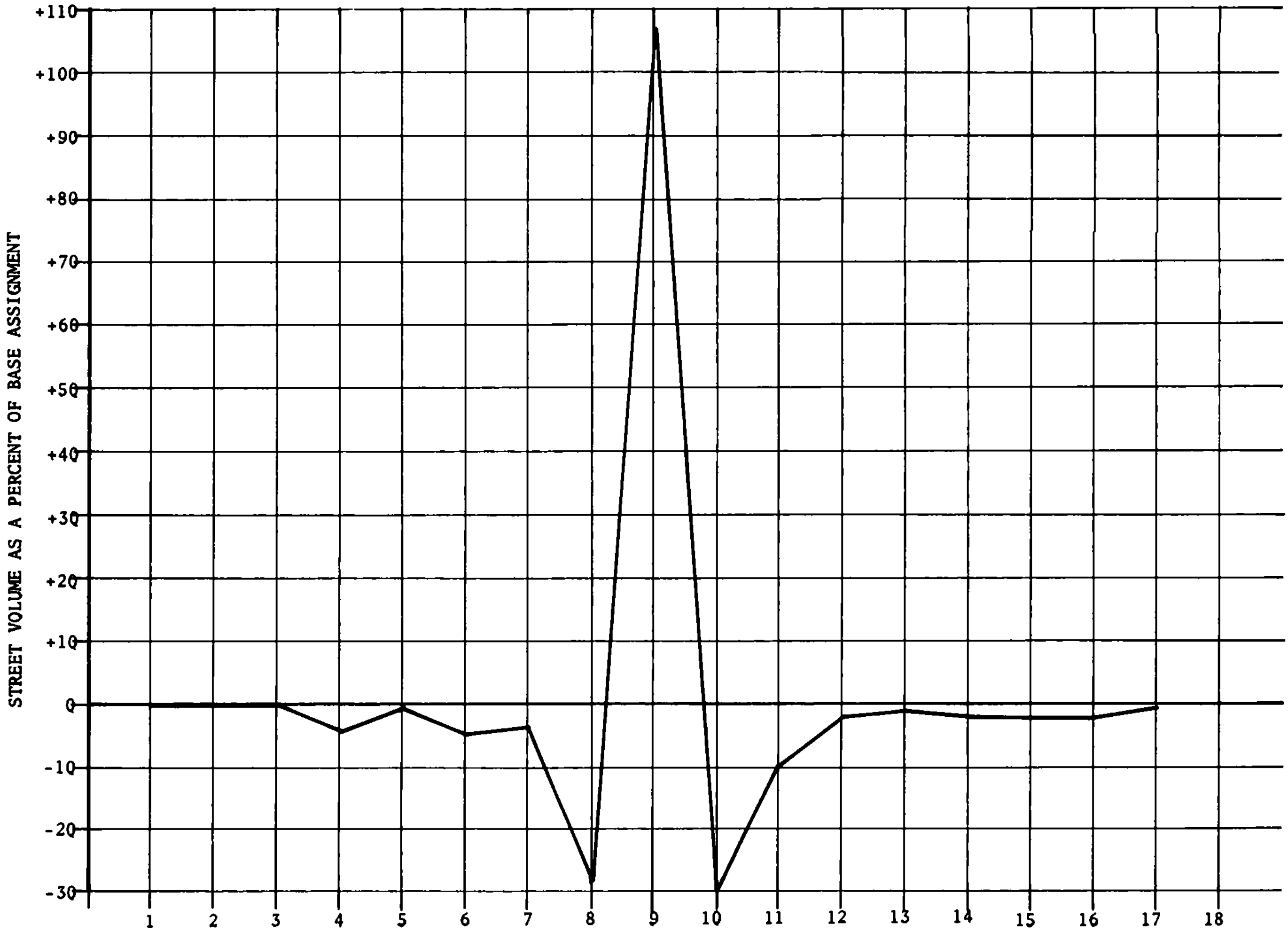

Figure 25 Cross section of region on street 30 showing impact of increasing speed on street 09 to 45 mph

For streets in the area bounded by the next two parallel expressways the over-all volume is 170,039, which is 1,663 more vehicles than before increasing street 12 to 75 mph. This represents a 1-percent increase in traffic in the entire corridor The largest relative decreases in adjacent streets were found on streets 11 and 13, each of which decreased 17 percent (about 1,200 vehicles) Streets 10 and 14, parallel arterials 2 miles away, declined more than 700 vehicles, or about 9 percent. Streets 09 and 15, parallel arterial streets 3 miles away, declined more than 400 vehicles, or about 6 percent. Streets 08 and 16, which are 4 miles away, were only slightly affected and experienced declines of 2 percent and 1 percent, respectively. The two parallel expressways experienced declines of 1,204 and 1,122, representing declines of 3 percent. In summary, 82 percent of the absolute gain in traffic on street 12 that resulted from increasing its speed from 60 to 75 mph came from streets in the corridor defined by the parallel expressways on either side. Some 56 percent of the absolute gain came from arterial facilities in that corridor, with the largest declines occurring on the streets immediately adjacent

The over-all effects are summarized in Test 34 in Table 19 Total VMT in the region increased by 53,635 miles, or 0.6 percent. Expressway VMT increased by 92,787, or 1.8 percent, whereas arterial VMT declined 39,152, or 1.0 percent

The average trip length increased by 0.1 mile as a result of people driving farther out of their way to take advantage of the 75-mph expressway. Arterial speed declined very slightly. Expressway speed is constant, indicating the tendency to travel additional miles on the faster facility until its greater relative congestion drives the speed back down. Use of expressways is up 0.7 percent.

Decreasing the Speed on All Expressways to 45 mph (Test 35) —An assignment was made in which expressway free speeds were set to 45 mph. The over-all results of this are given in Table 19.

Total VMT declined by 228,941 miles, a decrease of 2 6 percent. Expressway VMT declined by 626,739 miles, a decrease of 12 4 percent. Arterial VMT increased by 397,119 miles, an increase of 10.6 percent.

Over-all speed declined almost 1 mph, from 21.6 to 20.7

Expressway speeds declined 0.5 mph and arterial speed declined 0.8 mph. Average trip length declined 0.1 mile, from 6 4 to 6.3 VMT on expressways declined significantly from 57.5 percent to 51.7 percent, a decrease of 5 8 percent.

Increasing the Speed on All Expressways to 70 mph (Test 36).—The final test of sensitivity to speed consisted of increasing expressway free speed to 70 mph The results of Test 36 are given in Table 19

Total VMT increased by 265,584 miles, an increase of 3.0 percent. Expressway VMT increased by 565,754 miles, an increase of 11 2 percent Arterial VMT decreased 300,170 miles, a decrease of 8.0 percent.

Over-all speed increased by 0.8 mph Expressway speeds increased by 1.7 mph as a result of increased use Arterial speeds declined slightly, and this seemed to be somewhat surprising A detailed examination of this run indicated that expressway ramps to arterials had inadvertently been coded to 70 mph. This resulted in more turning movements onto expressways from arterials and then off again than would have occurred if the free speed had been left at 30 mph. The speed for arterial through movements did in fact increase slightly from 22 1 to 22.5, which is in the expected direction.

Average trip length increased from 6 46 to 6.66, an increase of 0 2 mile, as travelers drove farther to take advantage of the higher speeds on expressways. VMT on expressways increased 4.5 percent, a significant increase

Sensitivity to Trip Length

To examine the sensitivity of the assignment-simulation process to trip length, three assignments were run and compared.

The impact of trip length would be expected to be twofold. First, the longer the trip length, the higher the probability that any trip could save time by deviating from the shortest or most direct route. This effect would be expected to be manifested in a higher proportion of total travel on expressways. The second effect would be via the mechanism of capacity restraint. For a given number of trips, a longer trip length would result in more vehicle-miles of travel on the system. This in turn would depress speeds on the network. Just how it would affect the split between expressway and surface streets would depend on the total load on the system as well as the relative spacings of those facilities. After expressway speeds and arterial speeds come into balance, subsequent increments of VMT would be expected to be spread evenly over all facility types (assuming that the growth in VMT results from an increase in trip origins and destinations across the board).

Average Trip Length of 4 Miles (Test 39).—An assignment of travel was made to the basic network using a trip interchange matrix consisting of 3,420,000 trips These were split into two groups: one of 40 percent that was assigned during a 4-hr period assumed to represent the peak, and one of 60 percent assigned over a 9-hr period assumed to represent the off-peak portion of the day.

The results of this assignment are summarized in Table 20 (Test 39). During the peak period, the 5,552,561 veh-miles of travel are split 41.8 percent on expressways and 58.2 percent on surface arterials.

The over-all speed is 25.1 mph. Expressways have an average speed of 37.5 mph and surface streets have an average speed of 20.3 mph.

The over-the-road trip length is 4 06 miles. The VMT per mile of expressway is 16,122, as compared to 6,411 per mile of surface arterial.

Average Trip Length of 6 Miles (Test 28) —An assignment of trips was made using a longer trip length intended to approximate a 6.0-mile average trip length The results of this assignment are summarized in Table 20 (Test 28).

Total VMT during the peak hour amounted to 8,807,373, or almost 60 percent more than in the previous test. This resulted in a substantially different split between expressways and surface arterials. The split was 57.5 on expressways and 42 5 on surface arterials. This is almost an exact reversal of the split of the assignment using a 4-mile average trip length.

Average speed in the entire system is 21.6 mph, with expressways running at 23.8 mph and arterials at 19.3 mph These speeds are significantly lower than the system speeds obtained with the 4-mile average trip length assignment.

The VMT per mile of expressway are 35,142, as compared to 7,434 per mile of surface arterial street. Therefore, the ratio of vehicle-miles of travel on expressways to vehicle-miles of travel on surface streets is 4 73. This compares to a value of that ratio of 2.51 that was obtained in the prior assignment using a trip length of 4 0 miles.

There are 144 miles of six-lane expressways with a capacity per lane per hour of 1,500, or 1,296,000 veh-miles of expressway capacity per hour and 5,184,000 veh-miles of expressway capacity during 4 hours. Arterials were assumed to have a capacity of 600 vehicles per lane per hour. With a network of 504 miles of four-lane surface arterials this gives a total of 1,209,600 veh-miles of surface arterial capacity per hour and 4,838,400 veh-miles of surface arterial capacity during 4 hours. This gives a combined total of just greater than 10 million miles of capacity during the peak hours (10,022,400). This would place the run with an average trip length of 4.0 miles at a volume-to-capacity ratio of about 56 percent, in contrast to the run with an average trip length of 6.46 which is at about 88 percent capacity.

Average Trip Length of 9 Miles (Test 25).—Lastly, an assignment was run in which the average trip length was estimated to be 9 miles (see Table 20). There were a total of 3,156,204 trips in this trip matrix as compared to about 3,406,244 and 3,420,000 in the previous two assignments, or a reduction of about 7 percent Therefore, the split between expressway-arterial use and the system speeds is not completely comparable, although the difference is slight If one thinks of total VMT with a trip length characteristic, the three runs are compatible.

With this very high volume of vehicle-miles of travel of 11.4 million, the expressway percentage of VMT is 60.7 percent. Average speed has been driven down to 19.6 mph, with expressway at 19 9 mph and arterials just about equal in speed, at 19 2 mph Total vehicle-miles of travel assigned represents about 114 percent of vehicle-miles of capacity.

The average VMT per mile of expressway is 48,203 during the peak hours as compared to 8,891 veh-miles of travel per mile of surface arterial street This is a ratio of 5.42

TABLE 20

EXAMINATION OF ASSIGNMENT SENSITIVITY TO TRIP LENGTH

	TEST 39		TEST 28		TEST 25	
CHARACTERISTIC	PEAK	TOTAL	PEAK	TOTAL	PEAK	TOTAL
VMT	5,552,561	13,919,336	8,807,373	22,159,441	11,422,790	28,735,974
Exp. VMT	2,321,605	5,904,828	5,060,404	13,130,581	6,941,653	19,699,234
Art VMT	3,230,956	8,014,508	3,746,969	9,028,860	4,481,137	9,036,740
VHT	221,018	532,574	407,053	913,288	581,943	1,283,055
Exp. VHT	61,857	149,245	212,826	459,287	348,365	881,918
Art. VHT	159,161	383,329	194,227	454,001	233,578	401,137
Speed (mph)	25.1	26.1	21.6	24.3	19.6	22.4
Exp speed	37.5	39.6	23.8	28.6	19.9	22.3
Art. speed	20.3	20.9	19.3	19.9	19.2	22.5
Cost ($)	171,433	422,519	327,367	776,863	460,660	1,124,691
Exp cost	75,785	188,866	213,092	506,194	323,512	873,023
Art. cost	95,648	233,653	114,274	270,669	137,148	251,668
Cost/VMT (¢)	3.09	3.04	3.72	3.51	4.03	3.91
Trips	1,368,000	3,420,000	1,362,498	3,406,244	1,262,482	3,156,204
Avg trip length (miles)	4.06	4.07	6.46	6.51	9.05	9.10
VMT/exp. mile	16,122	41,005	35,142	91,186	48,203	136,792
VMT/art. mile	6,411	15,902	7,434	17,914	8,891	17,929
VMT/street mile	8,569	21,480	13,592	34,197	17,625	44,339
% VMT on exp.	41.8	42.4	57.5	59.3	60.7	68.6

between expressway volumes and arterial volumes and is comparable to values of 2.51 and 4.73 for average trip lengths of 4.0 and 6.0 miles, respectively.

The impact that changes in trip length have on the split of VMT using expressways versus arterial streets is summarized in Figure 26. Across the range of trip lengths from 4.1 to 9.1, an increase of 0.5 mile in trip length results in an increase of 1.89 percent in the percentage of VMT using expressways. If one takes an average trip length of 0.5 mile, an error of 10 percent in estimated trip length would give an error in expressway-arterial VMT split of about 4 percent (0.0189/0.48).

The Impact of Capacity

The next series of tests involved an attempt to measure the impact that capacity and capacity restrained assignment procedures have on the results of the assignment process.

Free Assignment.—The first test was to determine the differences between the results obtained using a capacity restrained and a free assignment. By free is meant no reduction in the speed of the facility as vehicle loads approach capacity. Two such tests were performed, one with an average trip length of about 4 miles and the other with a trip length of 6.4 miles. These two trip lengths provide systemwide volume-to-capacity ratios of about 55 percent and 88 percent, respectively, during the peak hours.

1. *Free Assignment—Average Trip Length Equals 4 Miles.*—Over-all, 5,619,951 veh-miles of travel were assigned to the system, with 2,490,108 or 44.3 percent of the vehicle-miles of travel on expressways. This represented an increase of 67,390 total miles of travel over the capacity restrained assignment of trips of a comparable trip length (Test 39). Expressway miles increased significantly; almost 180,000 additional vehicle-miles of travel were on expressways, whereas VMT on surface arterials dropped by 111,113.

Over-all system speed is 30.0 mph, in contrast to a system speed of 25.1 mph in the restrained assignment. VHT are down from 221,018 to 187,111, a decrease of 33,907 hours. This suggests that out of a total travel time of 222,000, more than 30,000, or 15 percent, was the result of congestion.

The fairly small difference in expressway use percentages between the capacity restrained assignment value of 41.8 percent and the free assignment value of 44.3 percent is the result of slowing the expressways relatively more than the arterials.

2. *Free Assignment—Average Trip Length Equals 6 Miles.*—With a longer average trip length it is already noted that a substantially higher proportion of the trips will be able to take advantage of an expressway.

When 1,362,498 trips were assigned to the test network with no capacity restraint, a significant number of additional vehicle-miles of travel were generated. VMT increased 230,706, from 8,807,373 to 9,038,079. VMT on expressways increased even more, 644,427 additional miles of travel over the 5,060,404 in the restrained assignment. The arterial VMT dropped from 3,746,969 to 3,333,248, a decline of 413,721.

The result of the use of the capacity restraint was to reduce total system speed from 35.5 to 21.6 mph. The reduction in system speed represents congestion losses of 212,581 hours. These time losses represent 46 percent of the total vehicle-hours of travel.

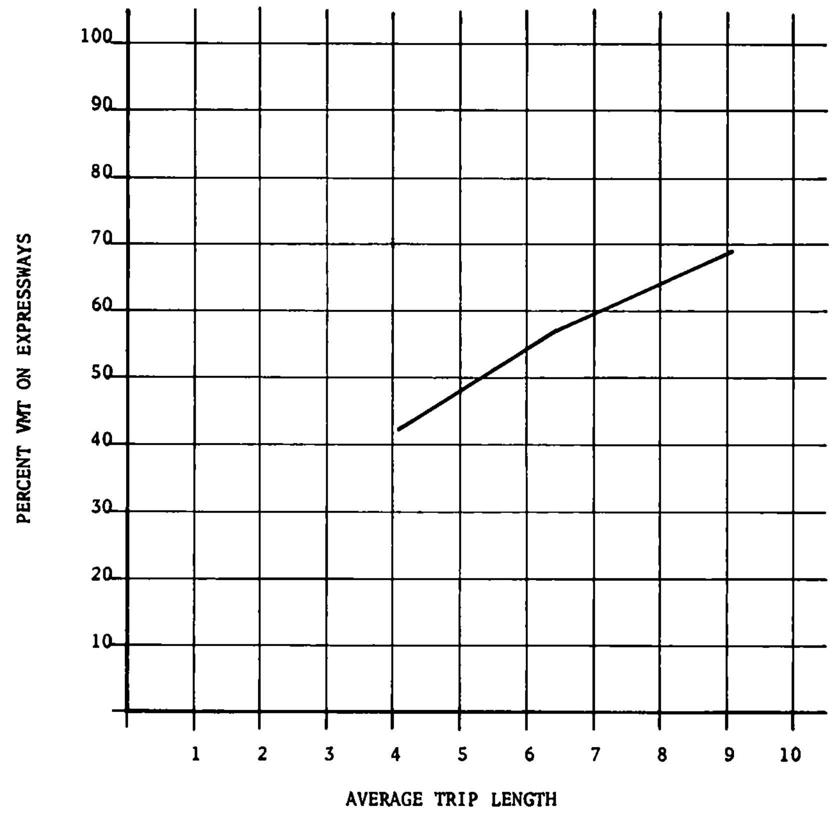

Figure 26. Impact of trip length on percentage of VMT on expressways for test network

The proportion of VMT using expressways in the free assignment is 63.1. The use of a capacity restraint reduces this proportion to 57.5, a reduction of 5 6 percent.

Changing the Capacity of the Network

1. *Decreasing the Capacity of the Expressway System.*— In order to examine the impact that a decreased expressway capacity would have on the assignment results, the capacity per expressway lane per hour was changed from 1,500 to 1,200 vph. This is equivalent to a 20-percent reduction in capacity. The 1,362,498 trips were assigned over the test network with the following results

Total VMT declined from 8,684,653 (Test 29) to 8,593,280 (Test 46), a decrease of 91,373 veh-miles of travel, or 1 percent. Expressway VMT declined 425,485 veh-miles, or 9 percent, whereas surface arterial VMT increased 334,112 veh-miles, or 8.5 percent. The percentage of VMT on expressways declined from 54.5 percent to 50.1 percent as a result of the capacity reduction of expressways.

The reduction in the estimate of expressway capacity resulted in a systemwide capacity of 8,985,600, which puts the system volume-to-capacity ratio at 96 percent The 20-percent reduction in expressway capacity represented a decrease of 10.3 percent in system capacity.

This heavy stress reduced system speed from 22.6 to 20.1 mph. Total VHT increased from 384,120 to 425,632 hours, an increase of 41,512 hours, or 11 percent. A 10-percent reduction in system capacity by an error or difference in estimating expressway capacity increased travel time by 10 percent and decreased expressway VMT by about 9 percent, and decreased system speed by 11 percent

The comparative statistics for the run are summarized in Table 21

2. *Increasing the Capacity of the Expressway System.*— The final test of the impact of errors in capacity on the assignment process results was to increase the capacity of the expressway system by changing the capacity assumption from 1,500 vph per lane to 1,800 vph per lane (See Table 21, Test 47.)

As a result, total VMT increased from 8,684,653 to 8,756,338, an increase of 71,685 veh-miles, which is about 0.8 percent. Expressway VMT increased 237,597 miles, an increase of 5 percent Surface arterial VMT declined from 3,950,373 to 3,784,461, a decrease of 165,912 miles, or 4 percent.

Total VHT decreased from 384,120 to 361,377 hours, a decrease of 22,743 hours, or about 6 percent. System speed increased from 22 6 to 24.2 mph Expressway speed increased slightly from 26.4 to 29.9 mph, arterial speed increased very slightly

The increase in expressway system capacity of 20 percent and total system capacity of 10.3 percent increased speed and VMT and reduced VHT significantly but not quite so much as the corresponding decrease.

TABLE 21

EXAMINATION OF THE IMPACT OF CHANGES IN EXPRESSWAY CAPACITY

	PEAK		
CHARACTERISTIC	TEST 29	TEST 46	TEST 47
VMT	8,684,653	8,593,280	8,756,338
Exp VMT	4,734,280	4,308,795	4,971,877
Art. VMT	3,950,373	4,284,485	3,784,461
VHT	384,120	425,632	361,377
Exp. VHT	179,106	189,767	166,359
Art. VHT	205,014	235,865	195,018
Speed (mph)	22.6	20.1	24.2
Exp speed	26.4	22.7	29.9
Art speed	19.3	18.2	19.4
Cost ($)	319,807.50	320,815.19	303,531.19
Exp. cost	190,234.38	185,110.38	188,556.94
Art cost	120,573.12	135,704.69	114,974.25
Cost/VMT (¢)	3.58	3.73	3.47
Trips	1,362,498	1,362,498	1,362,498
Average trip length (miles)	6.37	6.31	6.43
VMT/exp. mile	32,877	29,923	34,527
VMT/art. mile	7,838	8,500	7,509
VMT/street mile	13,402	13,261	13,513
% VMT on exp.	54.5	50.1	56.8
Exp capacity (vph)	1,500	1,200	1,800

Test to Measure Impact of Error in Trip Generation

The purpose of this test was to measure the impact that an error in estimating zone trip ends might have on network volumes, and, particularly, to find out how far errors persisted from the zone in question.

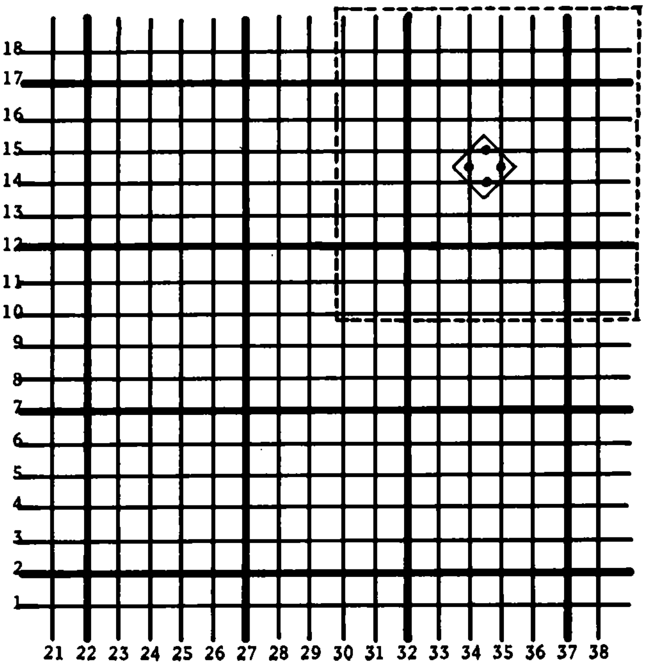

Figure 27. Test network showing four nodes with trip origins doubled.

To measure this kind of error, the trip ends at four nodes in the test network were doubled. The four nodes were: 1432, 1532, 3432, and 3532. These are shown as dots on Figure 27. The section enclosed by the dotted lines was then examined in terms of the differences in two-way trip volumes in the vicinity of the nodes whose trip origins were doubled. Over-all trips assigned in run 54 were about 1⁄12 of 1 percent less than in run 29, against which the comparisons were to be made.

Figure 28 shows the actual trip volumes during the peak hours of the day for run 29, the normal assignment. Figure 29 shows the difference in the link volumes as a percentage of the link volume obtained in the normal run (assignment 29).

The pattern of assigned volume differences is very sharp. In the vicinity of the four nodes, there is a sharp increase in trip volume. For example, on street 15 between streets 34 and 35, there is an increase of 1,996 trips as a result of increasing the origins along that street from 2,000 to 4,000. This increase of 1,996 represents a percentage increase of 27 percent. It is not a 100-percent increase, because the bulk of the traffic on that link neither originates nor is destined to that node. The volume increase in the node origins is quickly dissipated over adjacent links. The adjacent *links* average about 18 percent more volume and links twice removed average only about 10 percent. By the time one reaches links three times removed, the differences are down to about 1 percent.

This test indicates that a large error (100 percent) in a single trip generator is quickly dissipated in the network.

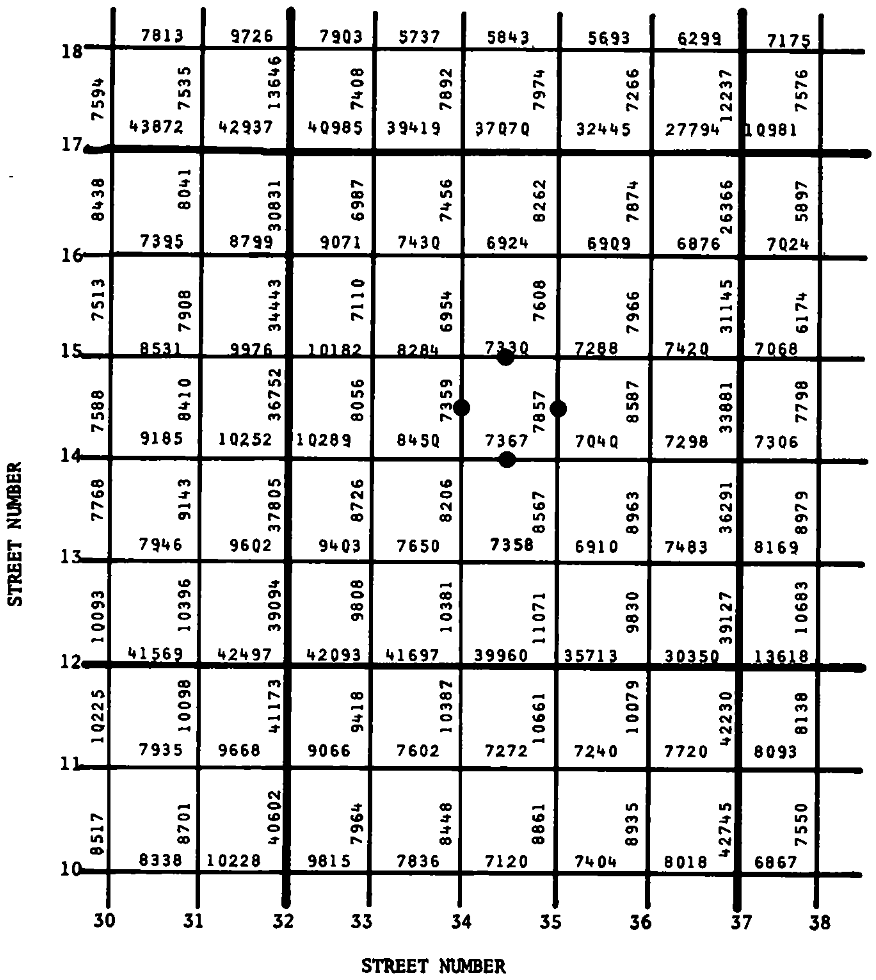

Figure 28. Traffic volumes from Assignment 29 with "normal" trip generation

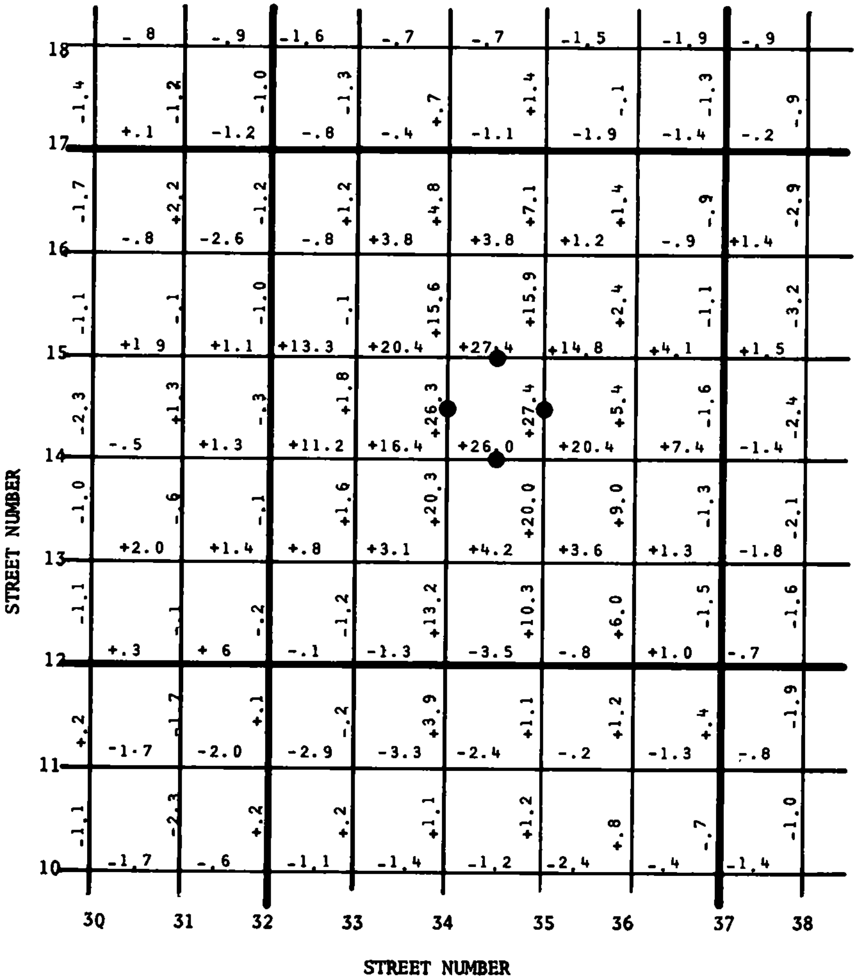

Figure 29. Percentage change in traffic volumes on network when trip generation is doubled at four nodes.

Clearly, however, if the error were made for all generators, network volumes would err at about the same magnitude as the error in trip generation in all parts of the region

Impact of Zone Size on Assigned Link Volumes

To investigate impact of zone size on assigned link volumes, two micro-assignment runs were made over the same network. The first run used a very fine zone structure in which the two block faces on a street segment became a zone and the centroid was the middle of the street segment. Thus the zone size was one-half block. The network consisted of arterial and local facilities spaced at ⅓ of a mile There are 18 of these facilities in each direction, so the area of simulation was about 36 sq miles (See Fig 30.)

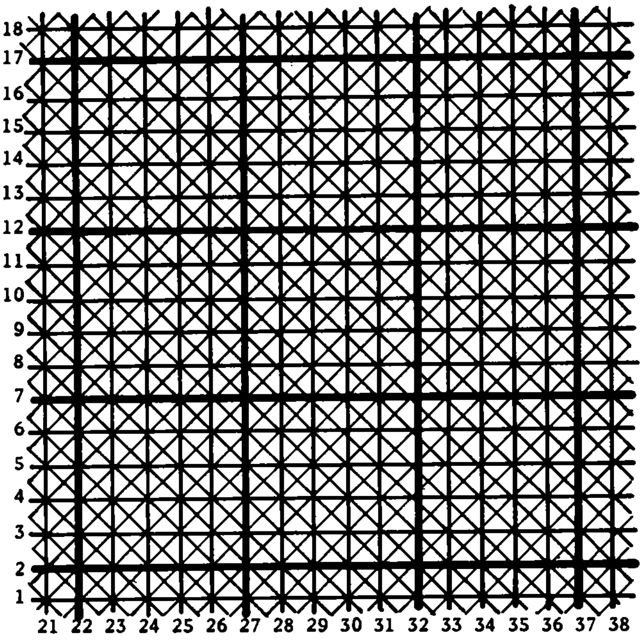

Figure 30 Fine zone system

The second run used the same network but had only 16 zones, each of whose centroids lay on an arterial facility. (See Fig 31.)

Trip end density was uniform throughout the region—10,000 per square mile—and the Opportunity model was used to generate trip matrices for the two runs. The same probability of trip end acceptance was chosen for both runs (4 6 × 10^{-6}). The significant results for the runs are as follows:

ITEM	FINE ZONES	LARGE ZONES
Internal trips (%)	0.25	13
Average trip length (miles)	2.93	3.60
VMT on locals (%)	39	7
VMT on arterials (%)	61	93

Only an insignificant fraction of trips are internal for the fine zone case. These trips are not assigned, but the distortion caused by ignoring them is negligible. For the coarse zone cases, however, 13 percent of trips are internal and are thus not assigned. This is a large distortion, some of which is reflected in average trip length. The average trip length for the aggregated case is much larger than for the fine case, 3 60 miles as opposed to 2.93 miles. The shortest 13 percent of all trips has been ignored in the coarse zone case, and this has increased the average trip length of the assigned trips. The trips also go from centroid to centroid instead of to and from the blocks of their origins and destinations. This distorts the trip length distribution also, but the effect on average trip length is more difficult to analyze.

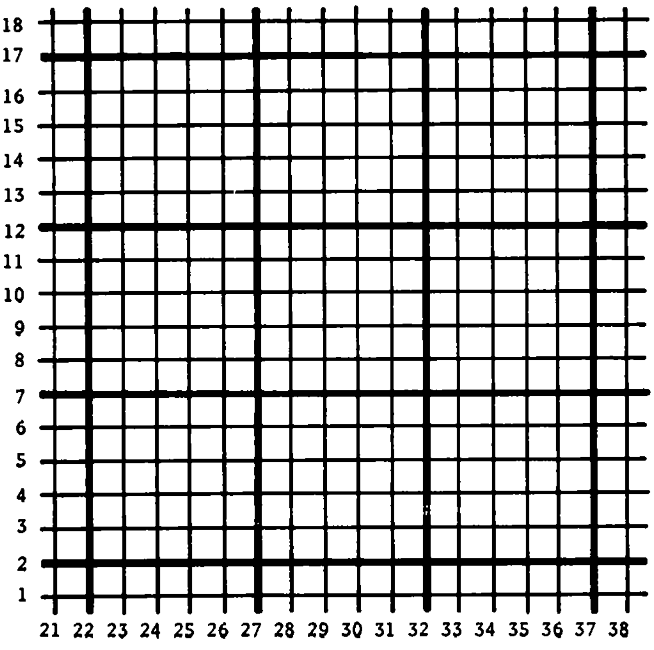

Figure 31 Coarse zone system.

The distribution of vehicular traffic is perhaps the most striking difference between the two cases; for the fine zone system, 39 percent of the VMT occurred on the local streets. This decreased to 7 percent for the coarse zone system. This shows that the network and zone structure must be of similar detail. If one starts with a system consisting of arterials only and the 16 large zones, it would not be advisable to add local facilities without restructuring the zone system because, as shown, only 7 percent of the traffic would use the locals.

Transit Ridership Estimates

The sensitivity of transit ridership estimates to "errors" in base data files was examined. Initially, this analysis was intended to reveal accuracy requirements for basic transportation planning travel inventories. It became clear almost at once, however, that the basic travel inventories play only a minor role in estimating future transit use.

Although travel inventories are needed for the development and calibration of modal split models, the actual inputs to the models consist of:

1. Forecasts of the location of future activities.
2. Assumptions regarding future personal attitudes
3. Basic projections of population and economic growth

Therefore, the sensitivity analysis presented here is concerned with tests of the impact of "errors" in forecasts and assumptions rather than in the base-year data.

The Modal Choice Simulation Process, developed and used by the New York State Department of Transportation, was chosen as the base model for this analysis because extensive files of input and output data were available to the researchers It was possible, therefore, to specify data inputs that were "real" in the sense that they represented a typical range of forecasted values; at the same time, a hypothetical test city and hypothetical test transportation networks were designed to limit the analysis to only the specified objective of measuring the sensitivity of transit patronage estimates to "errors" in data inputs. By designing the test process in this manner, it was possible to eliminate the need for extensive computer use or additional computer programming.

Six tests were conducted, and each test was designed to bear on some often-debated question involving estimates of future transit patronage. These questions can be stated in the form that the arguments (or counter arguments) usually take:

1. If an improved transit system is provided, there will be fewer multi-car families, and more transit riders.
2. If the number of workers per household increases faster than auto ownership, there will be more transit riders
3. Comparative network speeds in the testing networks are critically important.
4. The use of ridership response curves based on present transit service is inappropriate for forecasting future ridership, because elements other than speed are involved in modal choice.
5. A high-speed transit facility will change the activity pattern of a city, promoting more concentrated activity, and resulting in more transit riders.

The technique of testing was (1) to establish a "base estimate" of future ridership on a selected rapid transit link, and then (2), by varying selected data inputs, to determine by manual calculations the amount of change in that ridership.

A test city of 54 sq miles was specified (one of the square-mile zones represented the CBD), person trip density per square mile ranged from 130,000 in the CBD to 3,000 at a distance of 10 miles from the CBD, auto ownership per family increased toward the suburbs The testing networks consisted of a surface bus system, a 9-mile rapid transit line with uniformly coded link-speeds of 37 5 mph, an expressway parallel to the rapid transit with coded link-speeds ranging from 30 mph to 60 mph depending on distance from the CBD, and arterial streets at 1-mile spacing with coded link-speeds of 20 mph, 25 mph, and 30 mph, also dependent on CBD distance. A rapid transit link entering the CBD (representing the system's maximum load point) was taken to be the best summary indicator of the results of each test. Although the various test results could clearly have been different with a different model, different testing networks, and other variations, they are felt to provide good evidence of the *relative* sensitivity of the selected data inputs.

Test 1 assumed there would be no increase in auto ownership rates or in the number of workers per household. In other words, the observed trend toward more multi-car families would be checked by the announcement and ultimate construction of a rapid transit line. The results show the model is relatively insensitive to such assumptions. with a 25-percent reduction of both variables from the base estimate, transit ridership on the selected link increased by only 7 percent (see Table 22). Test 2 reduced auto ownership rates as in Test 1, but increased the number of workers per household to that of the base estimate. Again, the results show model insensitivity to both variables: transit ridership was only about 10 percent greater than the base estimate Considering the magnitude of these input changes, there seems little reason for concern over the accuracy of the forecasted rates—not much would be gained from spending additional funds and time in improving them

The next three tests were designed to measure the impact of changing the urban development pattern, then addi-

TABLE 22

RESULTS OF TRANSIT RIDERSHIP SENSITIVITY TESTS

		TEST RESULTS	
TEST	DESCRIPTION OF TEST	EST RIDERSHIP	CHANGE (%)
—	Base estimate	21,349	—
1	Automobile ownership and workers per household held at base-year levels, rather than both increased as in the "base estimate "	22,768	+7
2	Automobile ownership held at base-year level, but workers per household increased 25 percent, rather than both increased as in the "base estimate "	23,390	+10
3	Person trips to the CBD from all zones increased by 10 percent, and total trip density in the rapid transit "corridor" increased about 50 percent.	24,217	+13
4	Same as test 3 and, in addition, automobile ownership reduced in the rapid transit corridor below base-year level	26,698	+25
5	Same as Test 4, and, in addition, highway network link-speeds decreased and CBD highway network terminal times increased	28,772	+35
6	All "base estimate" data inputs retained but modal split model response surfaces raised 10 percent (simulating "improved" public attitude toward transit).	28,264	+32

tionally changing auto ownership rates, and then additionally changing highway network performance The base transit use estimate was based on the assumption that urban development is insensitive to improvements in the transit network. In Test 3, future development in the test area was rearranged, resulting in an increase in total interchanges of 10 percent between the CBD and the other 54 zones and a 50-percent increase in interchanges between the CBD and the 1-mile-wide rapid transit corridor. The number of transit passengers on the selected transit link increased by about 13 percent. When auto ownership rates were reduced below the base-year level, the number of transit passengers increased by an additional 12 percent (Test 4). When, in addition to the conditions of Tests 3 and 4, the highway network speeds and CBD terminal time penalties were altered to increase door-to-door auto time by approximately 35 percent (Test 5), a further increment of 10 percent was added to the results of Test 4.

Test 6 is directed toward testing the impact of the assumption of a constant response, to a given transit/auto travel time ratio, through time. This assumption is critical to all trip interchange modal split models Specifically, this test shifted the curves of the response surface upward by adding 0.10 to the values determined from base-year data; for example, base-year data indicated that when travel times are equal for auto and transit, 18 percent of the persons making work trips of 3 miles, and having an auto available, would choose to go by transit—in Test 6, the value is increased by adding 0.10, and the response for the above conditions is assumed to be 28 percent choosing transit. Shifting the curves of the response surface upward in the manner described resulted in an increase in volume of 32 percent on the selected rapid transit link.

In summary, there appears little to be gained from the collection of additional, or more detailed, travel data concerning auto ownership or network description The accuracy of forecasting future rapid transit ridership seems more a problem of correctly predicting urban development patterns and public attitudes toward transit. These are not newly discovered problems, they are the same questions that have plagued model builders for years. As far as data needs are concerned, the more pressing requirement is for time-series data relating urban development and new transit services, and for data bearing on the travelers' attitude toward transit

ALTERNATIVE METHODS OF DATA COLLECTION

This section describes the work undertaken to find and evaluate alternative means of data collection. Attention is focused on the main outlines of various new techniques and on the categories of information collected, not on the detailed procedures of the technique itself.

Research Method

A list of data needed for strategic transportation planning was obtained from the results of research work reported previously herein under "Data Needs of the Strategic Transportation Planning Process." These data were divided into "primary" and "secondary" categories Alternative techniques were sought only for collecting primary data.

Various new techniques for collecting needed primary data were found through a review of literature and personal contacts with professionals in the field.

The more promising alternative techniques were examined in detail, using available publications as sources. (Other techniques are cited in the list of references.) Each technique was evaluated against one or more of a series of nine criteria. Finally, a series of conclusions were drawn, based on the available evidence. Observations were made about long-range trends in data collection.

Evaluation Criteria

There are nine criteria that appear to be of value in evaluating data collection techniques These are:

1. *Cost.* Does the proposed technique cost more or less than established techniques? (Cost includes both collection and processing of data.)
2. *Accuracy* Does the proposed technique provide data that are more or less accurate than established techniques?
3. *Speed.* Is the collection and processing of data by the new technique faster or slower than that resulting from established techniques?
4. *Timeliness.* Does the technique provide data when needed?
5. *Operationality.* Is the technique ready to be used?
6. *Invasion of privacy.* Does the technique invade privacy or violate disclosure rules?
7. *Breadth.* Does the technique obtain many or few items of data when compared with existing techniques?
8. *Compatibility.* Can the data obtained by the subject technique be coordinated with or related to other transportation study data when required?
9. *Completeness.* Does the technique provide complete or partial coverage of a particular subject?

Unfortunately, it was not possible to evaluate each new data collection technique against more than a few of the preceding criteria. For example, data on costs and accuracy are rarely available for new techniques, and often are hard to obtain for existing techniques.

Data Needs

In this section attention is focused on primary data needs of the STPP; secondary data are presumed to be available through a variety of regular data collection procedures of private sources and Federal, state, or local governments.

Primary Data Needs

Primary data needs may be grouped into five categories. These are:

1. Population and related data.
2. Land use.
3. Origin-destination data
4. Transportation networks.
5. Volumes and speeds.

The population data are considered as "primary" data here because they are the data directly matched with home-interview origin-destination data to provide current, direct relationships between population and employment on one hand, and trip-making and other related transportation phenomena on the other hand.

Primary data needed for the strategic transportation planning process are given in Table 23 These data needs were obtained from a study of the transportation planning process as conducted in five cities of substantially different size. Although examination of five studies cannot produce a result that is statistically definitive about data needs (many study directors have variations in approaches and consequently may require certain additional data), the findings are certainly reasonable regarding "core" data needs.

Alternative Data Collection Techniques

Search for new data collection techniques was conducted through an extensive examination of publications that normally publish descriptions of new techniques (*70-81*). This search was aided by conversations with professionals, including representatives from the Federal Highway Administration and the Highway Research Board.

This search revealed that a number of technical innovations and proposals have been made in the field of data collection. However, many of the changes represent only extensions or improvements of existing techniques. Such extensions or improvements, unless substantial, are not reported in this section. New techniques, however, such as the automatic vehicle monitoring system, are reported.

The word "new," when applied to data collection techniques, has to be interpreted somewhat loosely. There is rarely anything that is completely new. Some of the "new" techniques reported here probably have been used earlier in other forms. In general the researchers have tried to cover techniques that can, potentially, replace or improve existing techniques.

TABLE 23

PRIMARY DATA REQUIRED BY THE STRATEGIC TRANSPORTATION PLANNING PROCESS

PRIMARY DATA REQUIRED

- Population and related data.
  - Primary population data
  - Dwelling places
  - Automobiles available
  - Employment by land use
- Land use:
  - Land use by type
- Origin-destination data·
  - Person trip origin and destination
  - Person trip destination by mode
  - Person trip destination by purpose
  - Person trip destination by land use
  - Person trip by mode, by time of day, related to auto availability
  - Truck trip destination by land use
  - Taxi trip destination
  - External vehicle trip destination by type, purpose, land use
- Transportation network:
  - Road network
  - Transit network
- Volumes and speeds:
  - Vehicle-miles of travel
  - Person-miles of travel
  - Screen line volumes
  - Speed-volume data
  - Link speeds

Population and Related Data

Data on population, and related data on employment, car ownership, and housing can be obtained for transportation studies through four types of surveys. Two of these survey types are established techniques:

1. The decennial census, or special censuses, conducted by the Bureau of the Census (*82, 83, 84*).
2. Origin-destination surveys—primarily the home interview survey, but also telephone and mail-back surveys (*85-88*).

Further discussion of these two established techniques can be found in "Origin-Destination Data," following, which discusses alternatives for collecting origin-destination data.

There are two techniques that are relatively new and have a potential for providing population data These are the use of social security numbers and the use of commercial "data banks." These are described in the following.

Social Security Records.—An estimated 185 million social security numbers have been assigned since the inception of the program, but many persons having numbers are presumed to have died. How many living persons have numbers is not known—somewhere between 100 million and 125 million may be the correct figure.

It would only be a minor step to have Congress require that all children be assigned social security numbers at birth. This would involve no invasion of privacy. Death certificates could also be required to be reported with a social security number. Under such a system, a very accurate census of the national population could be obtained—and kept current on a month-to-month basis.

From the point of view of location of population, however, current social security records are inadequate. The Social Security Administration keeps only addresses of beneficiaries—persons to whom social security checks are sent. This amounts to approximately 25 million persons, or only 12.5 percent of the population.

Employed persons can be located by the addresses of their employers, who file quarterly returns of social security payments with the Social Security Administration. It is from such reports that the Social Security Administration prepares its report, "County Business Patterns," which gives the locations of all employed persons, by county.

From the foregoing it can be concluded that social security records are not, at present, operational sources for obtaining population data. However, the very high coverage rates of social security numbering systems and the ease with which laws could be passed requiring complete coverage from birth to death make this potentially a powerful tool for population census taking. It is not inconceivable that an annual residence reporting could be required, which would then provide almost the ultimate source of numbers of population, and a source for any desired type of governmental sampling. This trend toward use of a single number to identify each person uniquely is reinforced by the simple fact that computers can deal with large volumes of such data; the availability of such a potential tool is in itself a force leading toward its use

Commercial "Data Banks."—Two firms compile statistics regarding the characteristics of families and individuals in a given area: the Reuben H Donnelly Corporation and R L Polk & Company The statistics compiled by these firms are available on magnetic tape for computer processing.

The Reuben H. Donnelly Corporation (a subsidiary of Dun and Bradstreet, Inc.) has information available on individual families throughout the United States (*89*). The firm uses telephone directory lists and state automobile registration lists as data sources. All families included in either of these two sources are available. These data include family name, type of dwelling unit, length of residence, female name listings, number of cars owned, age of cars, price range and make of cars Tapes can be developed that provide this information for individual census tracts

R. L. Polk & Company provide data for various U.S. cities and some of their suburbs (*90, 91*). Data are obtained every year through a house-to-house canvass The company claims that close to a 100-percent sample of families and businesses is taken, but it must be kept in mind that this information is provided voluntarily and many people probably do not cooperate. The data collected include the size of the family, address, job title and employer's name for all persons in the family over 18, and whether the family owns or rents its home. Data are available on tape, on cards, in statistical tables and on computer-printed maps

In both cases the data provided by these directories would have to be coded geographically to make statistical analysis and graphic output possible. This coding could be accomplished by using a system such as the Census' Dual Independent Map Encoding (DIME) file, described subsequently in this chapter under "Transportation Network Data" The information from the directories could then be related to block face.

The data provided by the Reuben H Donnelly Corporation could serve only a limited function in the transportation planning process. Persons who did not have a telephone or did not own a car would not be included. The primary use of the data would be as a source for sample selection.

The data supplied by R. L Polk & Company are also incomplete. The information provided could be used to update population and dwelling unit data, and could provide work place identification To describe work trips, it would be necessary to match the employer's name (included in the household data) with the employer's address. These employers' addresses would have to be available from another data file. The data from the Polk Company are further limited because only cities and some selected suburbs are included in the survey.

Land Use Data

Land use surveys require two distinct kinds of work—identifying the activity or activities taking place on a parcel of land, and measuring the area of land (or the floor area of buildings) of the parcel Both kinds of work must be coordinated closely in a successful survey, and it is in the linking of activity identification with area measurement that many of the survey problems occur.

Area measurements of parcels or blocks can be accomplished by a variety of standard techniques. The more well-established include (1) measurement of lengths and widths with area calculated by geometric formulas, (2) the use of "equal-area" templates, and (3) the use of planimeters. Area measurements may also be obtained from secondary sources, such as assessors' maps (*92, 93, 94*).

Identification of the activity or activities taking place on a site has been made by a variety of techniques The established techniques include:

1 Field listing (*95-98*).
2. Use of aerial photography (*99, 100*)
3. Use of utility company records (*93*)
4 Use of Sanborn maps (*101*)

There are several techniques that might be used in the future to obtain or maintain identification of the activities taking place on a site. These include use of building permits, assessors' records, census records, regional land use inventories, and commercial data banks These are discussed in the following.

Building Permits or Occupancy Permits.—Once a land use data file has been obtained, it can be kept up-to-date, on a continuing basis, through the use of building permits or occupancy permits. In theory, this operation is simple. Building inspectors, by agreement with some central agency, furnish the central agency with copies of building permits or occupancy permits. (The latter are preferable, because permits are issued for some buildings that are never built.) These are then used to update the land use file, on a parcel-by-parcel basis. Such a system is being used by the Louisiana Highway Department (*102*).

The main obstacles to the use of permits for updating land use files are: (1) the multiplicity of small governments with which any central agency must deal, and (2) the poor record-keeping of some local building inspectors. These obstacles can be overcome in time.

The main advantage of the use of building or occupancy permits for land use updating is that permits are issued as a legal requirement The organization administering this law has an interest in maintaining current, complete records of changes in land use. All the planning agency has to do is to tap into this source.

Assessors' records are often influenced by political considerations. Consequently there may be serious objections raised by local authorities to changes in assessment practice that would include more complete coverage, better area measurements, and land use identification. The increased cost that would precede the preparation of a complete and accurate file of all property must also be considered. The development and implementation of a national policy for assessment practice should receive high priority. The development of a national policy could be aided by the Federal Urban Information Systems Inter-Agency Committee (USAC) as part of its effort to develop a list of standardized data for localities.

Census Records.—The use of census records from the

Census of Manufacturing and the Census of Business for land use survey purposes was investigated. Although it is possible that ultimately some type of national directory of private establishments (by site address) may be developed, using census data in combination with Internal Revenue Service employer identification numbers, this work is not far enough advanced to be considered as a potential source of data in the next five years.

Nevertheless, the potential of unique employer identification numbers equals the potential of social security numbers Ultimately, employer records, which are maintained for taxation purposes, could be a good source for land use data collection.

Assessors' Records—Potentially, assessors' records are good sources for land use data (*103*). Assessors' records may contain parcel measurements or parcel areas, activity identification, and even data from which an estimate of floor area can be determined Although the amount and detail of the data vary, records are available for most parcels in any city or county.

Data from the New York City Real Property Assessment Department was used by the Tri-State Transportation Commission to develop a land use and floor area inventory (*104*). This procedure also was used in Newark, N J (*105*).

The type and detail of data contained in assessors' records and the manner of storage vary greatly. In some areas, such as New York City, all of the data mentioned previously are available on magnetic tape Records from smaller areas, however, are not as complete or well organized In Newark, for example, data were stored on forms.

There are other difficulties, also These include.

1 The lack of detailed activity identification taking place on the parcels or in the buildings Assessors generally concentrate on the building and not on its use.

2 The incompleteness of many files that frequently exclude municipal, church, and other tax-exempt properties.

3 The inaccuracy of rural property measurements.

4 The lack of automatic record-keeping in smaller jurisdictions

5. The lack of inclusion of street area measurements

Commercial Data Banks.—Information is available from R. L. Polk & Company and Dun and Bradstreet, Inc., which deals with business and professional establishments (*89-91, 106*) These data are available on computer tape and could be used for land use identification. Both firms supply information regarding the type of business, the address of the business, and the number of employees at that location. The coverage of the Polk survey is close to 100 percent within city boundaries Dun and Bradstreet listings cover only about 75 percent of the establishments in an urban area, tending to omit small retail and service establishments

The Sanborn Map Company maintains insurance atlases covering central cities and some suburban areas. Residences and commercial buildings are identified, and it is possible to obtain a substantial amount of generalized land use data from these maps However, detailed data as to types of activities carried on in buildings are not available, nor is coverage generally complete for entire urban areas (*101*).

Origin-Destination Data

There is a variety of techniques for collecting origin-destination data, most of which are effective only for a particular type of travel Consequently, most transportation studies have to employ a combination of techniques to sample the universe of travel.

The established techniques include.

1. The home interview survey (*85-88*).

2 The truck-taxi or commercial vehicle survey (*107, 108, 109*).

3. The roadside survey (*110, 111*)

4 The telephone home interview survey (*112, 113*).

5. The employee survey (*114*).

6 The license-plate survey for central business districts (*114*).

Variations on the foregoing include the parking-lot or curb-parking interview (*115*) and the panel survey (*116*). The parking-lot interview should be especially useful in CBD planning, perhaps in conjunction with TOPICS or micro-assignment planning The panel survey is designed especially for time-series studies

New techniques on which attention was concentrated include· the 1970 Census work-trip survey, the mail-back survey, the license-plate traffic survey, the on-board transit survey, and the automatic vehicle monitoring systems

The 1970 Census—The 1970 "Census of Population and Housing" obtained origin-destination data on the work trips of 15 percent of the households in the United States (*117*). Such data, if obtained regularly every 10 years, will be of substantial benefit to transportation planners

The 1970 Census featured a questionnaire that was handled by a mail-out, mail-back procedure in most urban areas. The same questions were asked, regardless of whether the census was conducted by mail or by house-to-house canvass

Eighty percent of the questionnaires were of a short form obtaining only population characteristics (such as age, family composition, sex, and race) and basic data on housing. Twenty percent of households answered a long-form questionnaire. Of those answering the long form, 75 percent responded to questions on work trips; the remaining 25 percent answered a different set of questions not covering work trips The following specific information was obtained·

1 Automobile ownership, in four categories·
   a. No automobile
   b 1 automobile.
   c. 2 automobiles.
   d. 3 automobiles or more
2. Address of place of employment
3. Mode of travel to work, in nine categories:
   a Driver, private auto.
   b. Passenger, private auto.
   c. Bus or street car.
   d. Subway or elevated.
   e. Railroad.
   f. Taxicab
   g. Walked only.

h. Worked at home
i. Other means (specify)

The foregoing data were obtained for all persons in a household who are 15 years of age and older and are making work trips.

When residence addresses of work trips are paired with employment addresses, a 15-percent sample of all work trip origins and destinations will be available, by mode of travel. These data are valuable because they can be correlated with population characteristics, car ownership, income, and housing data

Many advantages result from having such data. First, the data can generally be coded to an extremely fine geographic detail, using the DIME system which is available for 231 urban areas Second, the data are at a high sample rate—15 percent of all households—which will be helpful when dealing with transit. Third, the Census probably will be obtained on a continuing basis, thus providing time-series data Fourth, the data are uniform on a nationwide basis.

There are a few disadvantages to the Census work-trip survey. Because only work trips are obtained, only about 40 percent of all trips and about 60 percent of peak-hour trips are recorded. Second, the time of day when these trips are made will not be known, and hence the proportion of trips made in the peak hour will be uncertain Third, the year of data collection may not coincide with the needs of transportation planners

Nevertheless, the Census work-trip files will inevitably become a major source of data for transportation studies How these data will be used in the transportation planning process will have to be worked out. This will call for some research work. Two projects can be identified.

1. To develop and test plans using Census work-trip data and regular home interview data as alternative sources, to find out whether plans so prepared differ significantly
2. To find a means for converting Census work-trip data (undifferentiated by time) into peak-hour data

The Mail-Back Survey.—Mail surveys to collect origin-destination data from households have been used in varying forms in the past (*118, 119*). A recent test, conducted in conjunction with the Census Use Study in New Haven, is reported here because of its potential for use in conjunction with future national censuses (*120, 121*).

In the New Haven test, 2,400 mail-out, mail-back origin-destination survey forms were distributed These were controlled by 400 home interviews. Over-all, a 2½-percent sample of households was contacted

On the first mailing, 36 percent of the mailed forms were returned. On the second mailing, the total returns reached 49 percent. These were edited, and corrections were made through use of the telephone. To complete the survey, the non-responding households were contacted by telephone, and an additional 37 percent of the 2,400 samples was completed. The remaining 14 percent was contacted through interviews at their homes.

License-Plate Traffic Survey.—The license-plate traffic survey is designed to replace the traditional roadside origin-destination survey. An electronically controlled movie camera is used to photograph license plates of passing vehicles. Questionnaires are then mailed to the vehicle owners requesting origin-destination data. A fast mailing, essential with this type of survey, is achieved by using electronic data processing to search the vehicle registration file and print addresses on the survey forms.

This technique has been tested in Massachusetts and Kansas by the Bureau of Public Roads. The Massachusetts test was conducted primarily to examine the technique A response rate of 60.3 percent was achieved.

A second trial of the technique, conducted in Kansas, was designed to test for bias. Trip data from a license-plate survey were compared with trip data collected in a conventional roadside interview. The two surveys compared favorably when the percentage of trips between the various zonal pairs was studied. The percentage of family business, social recreation, and non-classified trips varied considerably between the two surveys; there was more agreement in the number of work, vacation, and shopping trips There are at least two possible explanations for the discrepancies. Either there was a bias in the response, or people did not understand the various trip purpose categories. The researchers felt that the latter reason was the cause of the variation in reported trip purpose.

The license-plate survey appears to be useful for determining the number of trips between zones. However, some refinement in the survey questions is necessary before dependable trip purpose data can be obtained.

On-Board Transit Survey—A technique that has not been used a great deal for transportation data collection is the on-board transit survey. This type of survey is used to obtain more detailed information and a larger sample of transit trips than is available from a home interview survey (*122*).

The Southwestern Pennsylvania Regional Planning Commission conducted an on-board transit survey in May 1967 (*123, 124*). The survey, designed to provide data useful for both long-range planning and operational planning, included questions concerning origin, destination, and trip purpose. A total of 14 questions were contained on a card that could be sent through the mails. The cards were numbered sequentially for checking purposes.

The operation of the survey placed a large responsibility on transit vehicle drivers. Each driver was given a series of numbered questionnaires to give to all persons entering the bus If a passenger refused to participate, his questionnaire was destroyed. This permitted an accurate count of all persons riding the line.

The advantages of on-board transit surveys are that they obtain large-sample returns at fairly low costs. Thus, they can be used to supplement regular household interviews that often produce few records of transit trips. This kind of data can be useful not only in strategic planning but also in planning transit operations.

Automatic Vehicle Monitors.—A new group of data collection systems being developed are automatic vehicle monitors (AVM). These systems are designed to locate a set of moving vehicles within a given area on a real-time basis. Most of the systems have not yet reached the prototype stage. Research work and background material dealing with this technique are contained in the report, *Public Urban Location Service (PULSE): Background and Conference Proceedings* (*81*). The three basic approaches to an AVM are.

1. Proximity sensing (PAVM) which uses many fixed-location sensors to locate vehicles.
2. Triangulation or trilateration (TAVM) which uses electronic radio-ranging equipment
3. Dead reckoning (DAVM) which uses on-board equipment to follow a vehicle's movement. All three techniques require a vehicle-based unit of varying complexity and a central receiving and processing center.

Another system for locating vehicles automatically is described in the report, *Feasibility Study· Automatic Vehicle Identification Systems* (*80*). As opposed to the PULSE report, which was concerned only with individual city automatic vehicle locating systems, this report advocates a nationwide automatic vehicle identification (AVI) system.

The primary recommendation of the report was that a "nationwide standard for AVI systems should be developed as soon as possible " After all of the various methods of communicating between the vehicle and the sensor were reviewed, a low-frequency induction method was recommended for the nationwide standard. This method uses a passive transponder in the vehicle that emits a 13-digit vehicle identifying code. Power is supplied to the transponder by a transmitting loop antenna buried in the road. Thus, the transponder requires no power from the vehicle to which it is attached. Telephone lines are assumed to be sufficient for communication from the sensor to the central processing unit.

The systems recommended in these reports are technically feasible, but there are other considerations affecting their practicality. The systems are very expensive. Cost figures estimated in the AVI report are only for the transponder and the sensor. Not included are computer processing costs and data transmission costs. Each sensor costs $2,500, not including installation costs. For a system that would place a sensor every 10 miles on rural roads and every 3 miles on urban roads, the total equipment and installation cost for sensors is more than $2 billion (using 1965 statistics on road mileage). The cost of transponders, assuming mass production, is about $15 each. For 100 million cars this would add another $1.5 billion to the total cost.

The PULSE report contained separate reports from 19 companies working on AVM systems. Costs, when they were given in these reports, were impossible to compare because they were based on a wide range of system sizes. Also, in most cases they were not inclusive, but rather consisted only of operating costs. A more realistic cost evaluation would be one that was made on an actual system.

Legal implications of a system that will be able to locate a vehicle periodically were not overlooked The AVI report stated that "it appears impossible at the present time to predict the legislative and judicial future of the AVI concept" (*80*, pp. 6-35). Public opposition to the system may also be high because of the invasion of privacy inherent in this technique. A more detailed study should be conducted before large sums of money are allocated for AVI or AVM system development.

If one of these systems were implemented, it would provide many useful data for the transportation planning process This would include comprehensive data on screen and cordon line counts, trip length distribution, origin-destination data, link speeds, speed-volume relationships, and routes of travel. However, even if the program was initiated and it was required that a transponder be placed on all new vehicles, it would take "13 years before over 90 percent of the vehicle population was equipped." Therefore, this technique will not be readily available for data collection, except on a limited basis.

The possibility was considered of building portable sensors and temporarily installing several hundred on streets in a metropolitan area for the conduct of an origin-destination survey. Then, if a sample of vehicles had transponders temporarily fixed to their bumpers (with voluntary cooperation of the owner), it would be possible to collect some travel data. However, short trips would be missed, and the terminal ends of medium- and long-distance trips would not be recorded The cost of securing transponders to cars would equal or exceed the cost of interviewing in the home or truck-taxi survey and the data would be far less complete. Hence, the automatic vehicle monitor technique is not considered feasible in the near term

Transportation Network Data

Data on transportation networks, both road and transit, are generally obtained from a variety of sources, including maps, engineering drawings, and transit schedules. Some field work may be required, such as obtaining signal timings or data on pavement widths The survey techniques are not formalized in the sense that a home interview is a formal process. Rather, the process is organized around the filling out of coding forms and the preparation of coding maps that define the network in a fashion suitable for use in computer traffic assignment (*125, 126, 127*). For this reason it is unlikely that there can be anything really new in the way of network survey techniques.

However, the ACG/DIME file developed by the Census Bureau does constitute an important extension of network coding (*128-134*). For this reason it is considered as a new technique. The ACG (Address Coding Guide) is basically a systematic file of census block sides giving the range of addresses on each block face. Each block face comprises one record The DIME system has been added to the basic ACG file.

In the DIME system a unique node or vertex number is assigned to each point on a map where two or more map features (such as streets) intersect or take a sharp curve. Each record in the file consists of two node or vertex numbers describing a line. The land on each side of this line is described by a tract number, block number, or some other geographic code The name of the line (such as street name) and address ranges obtained from the ACG file are also included Using the DIME file it is possible to perform computer editing to check data accuracy.

There are many potential uses for the ACG/DIME file. In many cases the file serves as the basic input for a computer-based mapping system. Any record that contains an address can be coded geographically in such systems. Using only information in the file, it is possible to obtain a computer-drawn map of an area's street and highway network.

Volume and Speed Data

There are many techniques for obtaining different kinds of data on the numbers, speed, and density characteristics of vehicles in traffic streams and the volumes of passengers in transit vehicles. The established techniques include:

1. Mechanical or electronic volume counting (*135-139*)
2. Manual short counting (*140*).
3. Transit passenger counts (manual) (*122*)
4. Ticket sampling (*123, 141*)
5. Moving-car method for measuring vehicle speeds (*139, 142*).

There are several relatively new techniques for obtaining some kinds of volume and speed data for vehicles, and transit passenger volumes. These include air photography, ground-based photography for accident studies, and electronic counting of transit passengers.

Aerial Photography.—Aerial photography has been used by many different transportation organizations for a variety of purposes (*142-146*). One of the early experimenters in this field was the Port of New York Authority which, since 1962, has conducted a variety of projects using aerial photography. Although all modes of transportation could be studied using this technique, the emphasis has been placed on highway traffic analysis. All of the projects have been conducted by the Sky Count Aerial Studies Group of the Operations Standards Division (*78*).

The basic components of any aerial photography system are the camera, the camera platform, and the data-reduction equipment and procedure. In New York, both fixed-wing aircraft and helicopters have been used as camera platforms. The helicopter is a better platform for in-depth studies of critical areas, such as intersections, which are 1 sq mile or less in size. The helicopter's hovering ability makes it possible to observe and record the traffic situation over a long period of time. Longer segments of highway—typically 3 miles long—are photographed from fixed-wing aircraft.

Data reduction (the most time-consuming operation in the total system) is done directly from a 9-in. by 9-in. negative using a specially designed light table. Direct measurements are made manually from the negative. The scale for the 2-sq-mile area is about 900 ft = 1 in.; for the 8-sq-mile area it is 1,656 ft = 1 in. The product of the survey is data on vehicle speeds, traffic densities, and volumes.

This technique has been applied to the analysis of highway traffic leaving New York International Airport, crossing the George Washington Bridge, and entering the Lincoln Tunnel. In these applications, comparisons were made between data collected by aerial photography and that collected by conventional methods. It was found that there was a variation of 1 percent or less between volume counts made by the two methods.

Another type of information that can be collected using aerial photography is parking use data. A parking study using aerial photography was recently conducted by the Stark County Area Transportation Study (SCATS) in the Ohio cities of Canton, Massillon, and North Canton (*147*). This study attempted to compare the standard parking data collection methods with the newer aerial photographic technique.

Fixed-wing aircraft were flown at an altitude of either 3,000 or 5,400 ft. The higher altitude was used in Canton where a larger area had to be covered. All three cities were surveyed on the same day with the airplane flying a circuit between them. One of the differences between the Ohio and New York studies was that color film was used by SCATS instead of black and white, which was used in New York. It was felt that by using color film more positive vehicle identification could be made.

The data reduction procedure was also conducted somewhat differently in the SCATS study. Rather than measure directly from the photographs, which were approximately double the scale of those used by the Port of New York Authority, a stereoscope was used. This method allowed adjustment of x and y parallax, making compensation for any possible tilt difference. Also, it provided the operator with a 4.5 magnification, which reduced the scale to about 55 ft = 1 in. for photographs taken at the lower altitude and about 100 ft = 1 in. for those taken at 5,400 ft. Data concerning parking use, duration, habits, accumulation, and turnover were obtained from the photographs.

Data accuracy, cost, time, and manpower were evaluated in the SCATS report. The conclusion was that accuracy did not suffer while, at the same time, manpower costs and time were reduced significantly by using aerial photography for a parking survey.

The variety of data collection applications that are possible with aerial photography suggests that this technique may have increasing use in the future. Color photography should increase ease of vehicle identification. The helicopter provides a platform for low-level urban photography.

Research work should be directed toward solving the major problem of slow and costly reduction of data. Sampling techniques should be studied to determine optimum numbers of exposures needed for different kinds of data. If this work is successful, aerial photography may become competitive with conventional portable equipment for volume counting, with the additional advantage of being able to provide speed data as well.

Ground-Based Photography for Accident Studies.—Television cameras mounted on buildings are being used in Washington, D.C. to study traffic movements at a critical intersection (*148*). The pictures of traffic are recorded continuously on a video disc. This disc is capable of storing 20 sec of traffic movements. If there is an occurrence of interest (i.e., an accident) the 20-sec interval preceding the incident can be transferred from the temporary storage on the disc to a permanent record on film. This transfer from temporary to permanent storage is presently controlled manually, but attempts are being made to develop other types of control mechanisms. One of the proposed automatic control mechanisms would use the characteristic sound of cars colliding to activate the permanent recording system.

Performing Transit Traffic Surveys Electronically.—Research is presently being completed at the University of West Virginia on a system that could be used to conduct transit-passenger-volume surveys automatically.* The research is divided into two main parts. The first is concerned with the development of a data collection device that could be mounted on a bus. The software necessary to process these data is being developed as the second part of the research.

The counting device on the bus operates electronically. It keeps a records of the number of passengers entering and leaving the bus at each stop. Using these data, it is possible to determine the loading characteristics at each stop as well as the total use along any route.

Software, developed to process the data collected, is designed to assist in decision-making regarding scheduling, headways, and number of transit vehicles needed The software appears to be designed for detailed transit planning.

This type of system has many advantages over the traditional method of transit surveys, in which manual counts have been necessary to determine transit use. Once the initial investment in equipment has been made, surveys can be taken at any time to allow for a more detailed analysis. Whereas previously counts were generally taken on one survey day, it will now be possible to conduct transit surveys at different times.

RELIABILITY

The original work program for this research project contained an item "reliability studies." The intention of these studies was to measure the reliability of existing data by a system of check measurements in order to determine whether the data's reliability matched the need for accuracy of the data as determined by the sensitivity tests.

As research work progressed, however, it became clear that the original concept was not adequate. Whereas it would have been possible to have measured the reliability of a few data collection operations, it would not have been possible to generalize from the results. The conclusions could only have been applicable to the city and operation reviewed. Hence, the idea of actual checking of survey data had to be discarded.

This forced a re-thinking of the whole subject of data reliability. In this re-thinking, it became apparent that data reliability is only a real problem in the sample surveys. The surveys of transportation facilities and of land use measure entire universes—in one case, all arterial streets and expressways (and all buses and rapid transit service), and, in the other case, all land use. Measurement of the whole, with the accounting checks that are possible in such surveys, is rarely going to permit results that are wrong in any substantial way. Even errors at the zone level can be caught when land use data are displayed in map form by computer, or when the network is calibrated in the first traffic assignments.

In the sample surveys, however, data reliability is a problem. If one assumes that basic survey workmanship is high-level, there still remains the problem of sampling variability. Accordingly, it was decided to conduct an investigation of the sampling variability of home interview data as the main part of the reliability studies, and particularly of the variability resulting from cluster sampling, which has not previously been studied adequately

Sampling Variability of Home Interview Data

From the standpoint of trip information, the standard home interview survey is a cluster sample. That is, one does not have a random sample of trips or even a systematic sample of trips. When a household falls into the sample, all of the trips made by occupants of the household are enumerated. If the average number of trips per household is seven, this means the average cluster size is seven.

To the extent that the travel performed by an individual member of a household tends to be more like the travel performed by other members of the household than that by non-household members, the reliability or precision of the sample results is lower than would be the precision of a random sample of the same size. This report examines the impact that the similarity of household members (intraclass correlation) has on sample reliability

Variance of a Proportion for a Random Sample

The variance of a proportion for a random sample is given by

$$\sigma^2 = \frac{pq}{n} \qquad (1)$$

in which

σ^2 = variance proportion p;
p = proportion of elements possessing a given attribute;
q = proportion of elements not possessing that attribute, and
n = number of sampled elements.

If, for example, 10 of the apples in a random sample of 100 apples were spoiled, it would be possible to calculate the limits within which the actual proportion of rotten apples in the apple population would fall at a given level of confidence

$$\sigma_p = \sqrt{pq/N} = \sqrt{0.1 \times 0.9/100} = 0\ 03$$

This would be interpreted to mean that about 68 times out of 100 the actual percentage of rotten apples would lie between 7 percent and 13 percent. At the 95-percent confidence level, one would estimate the actual percentage of rotten apples at between 4.1 percent and 15.9 percent.

In this kind of sampling, it is assumed that the sampled apples were randomly selected

Variance of a Clustered Sample

When a sample of clusters is taken, all elements in the cluster are enumerated. When the clusters are of different sizes,

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* Report due in February 1970. For further information contact Dr Seg Elias, Chairman, Industrial Engineering Dept, University of West Virginia, Morgantown, West Virginia, 26506.

$$\sigma_c{}^2 = \frac{1}{m^2}\sum\left(\frac{N_i}{\overline{N'}}\right)^2 (p_i - p')^2 \qquad (2)$$

in which

$\sigma_c{}^2$ = the variance of the proportion *p*;
N_i = number of elements in cluster *i*;
$\overline{N'}$ = average number of elements in cluster;
p_i = proportion of elements in cluster *i* possessing given attribute;
p' = proportion of elements possessing that attribute; and
m = number of clusters.

Returning to the discussion of spoiled apples, assume that the apples were in plastic packages, with a varying number per bag. A sample of 20 bags was selected and every apple in each bag was examined. The results of this hypothetical case are as follows:

BAG	NO. OF APPLES IN BAG	SPOILED APPLES
1	3	0
2	4	0
3	5	0
4	5	0
5	4	0
6	6	5
7	7	0
8	6	0
9	5	0
10	5	0
11	4	3
12	5	0
13	6	0
14	8	0
15	4	0
16	3	2
17	5	0
18	6	0
19	5	0
20	4	0
Total	100	10

Substituting in the equation for variance of a clustered sample results in:

$$\sigma_c{}^2 = \frac{1}{20^2}\left[\frac{1 \times 3^2}{25}(0.1)^2 + \frac{4 \times 4^2}{25}(0.1)^2 + \frac{7 \times 5^2}{25}(0.1)^2 \right.$$
$$+ \frac{3 \times 6^2}{25}(0.1)^2 + \frac{1 \times 7^2}{25}(0.1)^2 + \frac{1 \times 8^2}{25}(0.1)^2$$
$$+ \frac{1 \times 3^3}{25}\left(\frac{2}{3} - \frac{1}{10}\right)^2 + \frac{1 \times 6^2}{25}\left(\frac{5}{6} - \frac{1}{10}\right)^2$$
$$+ \frac{1 \times 4^2}{25}\left(\frac{3}{4} - \frac{1}{10}\right)^2 = 0.00337$$

$\sigma_c = 0.058$

As in the first case, the proportion of rotten apples was 10 out of 100, or 0.1. However, because the apples were selected in clusters and because the condition of the apples in the cluster tended to be homogeneous, the reliability of the sample is not as high. In fact, the standard error of the cluster sample proportion is almost twice as large as that found in the random sample proportion (0.058 as compared to 0.030).

Intra-Class Correlation

The tendency for elements in a cluster to be more similar to each other than to elements outside the cluster can be measured in terms of intra-class correlation. The formula is:

$$[(\sigma_c{}^2/\sigma^2) - 1]/[(n/m - 1] = \rho = \text{intra-class correlation} \qquad (3)$$

In the example,

$$\rho = [(0.00337/0.009) - 1]/[(100/20) - 1]$$
$$= (3.74 - 1)/(5 - 1) = 0.685$$

As the intra-class correlation approaches 1.0, the ratio of the variance of a cluster sample to the variance of a random sample approaches the value of the average cluster size. Even for small values of intra-class correlation, the effect or reliability is significant; for example, with an intra-class correlation of 0.1, the variance of a cluster sample with five elements to the cluster would be 1.4 times larger than that of a random sample.

Negative intra-class correlations are possible. If an element in a cluster is less like other elements in the cluster than elements not in the cluster, the intra-class correlation is negative. In the foregoing case, if each of the clusters had exactly one rotten apple, this would result in a negative intra-class correlation of —0.22. Notice that the limit of the intra-class correlation is the reciprocal of the cluster size minus 1, at which point the variance is zero.

The impact of intra-class correlation on sample size for a specified level of accuracy can be significant. The expression for the number of cluster samples needed to give the same reliability as a random sample is given by

$$n_c/n_r = \rho(\overline{N'} - 1) + 1 \qquad (4)$$

in which

n_c = number of samples in a cluster sample, and
n_r = number of samples in a random sample.

The multipliers of ratios for different values of the intra-class correlation, ρ, and selected values of the average cluster size, $\overline{N'}$, are given in Table 24. The ratio of trips per household in most origin-and-destination studies ranges from 6 to 10. Table 24 indicates that relatively low values of intra-class correlation, 0.2 and 0.3, result in very significant increases in sample size when household clusters were used. As the intra-class correlation approaches 1.0, the multiplier approaches the average cluster size. Thus a 5-percent sample of households given a trips/household ratio of 6 and an intra-class correlation of 0.3 is equivalent to a 2-percent random sample of trips.

Sampling Variability of Home Interview Survey Data

To evaluate the impact that cluster sampling has on the sampling variability of home interview data, a computer program was written. This program performs the calculations required by Eqs. 1, 2, and 3. The home interview survey selected for this analysis was the Buffalo origin-and-destination survey that was conducted in 1962.

Trip Purpose.—The trip information from the Buffalo survey was classified into six trip purpose classes:

1. Home to work and work to home.
2. Home to social recreation and social recreation to home.
3. Home to personal business and personal business to home.
4. Home to shop and shop to home.
5. Other home-based trips.
6. Non-home-based trips.

The results of this analysis are given in Table 25.

For the six purpose groupings analyzed, the assumption of a random sample would seriously understate the estimates of sampling variability. For work travel, the ratio of actual sampling variance to the variance of a random sample is 2.45 For social recreation travel, the ratio is 3.40 and for non-home-based trips the ratio is 3.69. These ratios are, incidentally, the multipliers by which the sample size of a random sample would need to be multiplied to achieve the same sampling error as the random sample Taken together, the average ratio of actual to random sample variances is 3.0.

If one wished to estimate the proportion of all trips that are from home to work or work to home within ±5 percent, 95 times out of 100, the sample size would be $0.0004 = 2.45(0\ 16/n)$, or $n = 400 \times 2.45 = 980$ samples required.

Land Use.—Land use classifications are often used in the calculation of trip origins and destinations. The Buffalo trip file was stratified into the following land use categories by trip destination.

1. Residential land use.
2. Commercial land use.
3. Manufacturing land use.
4. Public building land use.
5. Public open space.
6. All other land uses.

These trip data were then analyzed in terms of their sampling variability. The results are given in Table 26.

The variability of trip proportions by land use at trip destination is less affected by cluster sampling than are trip purpose proportions The proportion of residential trip destinations has a variability that is only 27 percent greater than that which would be expected for a random sample. Over-all, the ratio of the variability of the cluster sample to the variability of a random sample is 1.77, suggesting a cluster sample size of just under twice a random sample to achieve comparable reliability (based on a weighted average of the variance ratios in Table 26).

TABLE 24

RATIO OF CLUSTERED SAMPLE SIZE TO RANDOM SAMPLE SIZE TO ACHIEVE EQUAL RELIABILITY FOR DIFFERENT VALUES OF INTRA-CLASS CORRELATION

INTRA-CLASS CORRELATION	RATIO, BY CLUSTER SIZE			
	4	6	8	10
0	1.0	1 0	1 0	1.0
0 1	1.3	1 5	1.7	1.9
0.2	1.6	2.0	2 4	2.8
0 3	1 9	2.5	3 1	3.7
0 4	2 2	3.0	3.8	4.6
0.5	2.5	3.5	4.5	5.5
0.6	2.8	4.0	5.2	6.4
0 7	3.1	4.5	5.9	7.3
0 8	3 4	5.0	6.6	8.2
0.9	3.7	5.5	7.4	9.1
1.0	4 0	6 0	8 0	10 0

Mode of Travel.—Mode of travel information is necessary in order to estimate vehicular and transit utilization. Buffalo trip data were classified by the following modes of travel:

1. Auto driver.
2. Auto passenger.
3. Bus transit passenger.
4. School bus passenger.
5. All other modes of travel.

The results of this analysis are given in Table 27

The mode of travel information is subject to greater impact from clustering than is land use information. In

TABLE 25

ANALYSIS OF SAMPLING VARIABILITY OF BUFFALO TRIP PURPOSE DATA

TRIP PURPOSE	PROPORTION OF TRIPS	VARIANCE OF A RANDOM SAMPLE [a]	ACTUAL VARIANCE	RATIO	INTRA-CLASS CORRELATION
Home to work and work to home	0.200	1.517×10	3.718×10	2.45	0.18
Home to social recreation and social recreation to home	0.144	1.173×10	$3\ 922 \times 10$	3.40	0.30
Home to personal business and personal business to home	0.076	0.665×10	1.783×10	2 68	0.21
Home to shop and shop to home	0 131	1.182×10	2.875×10	2.65	0 21
Other home-based trips	0 192	1.472×10	4.314×10	2.93	0 24
Non-home-based trips	0 257	1.812×10	6.684×10	3.69	0.34

[a] $\sigma^2 = pq/n$, $n = 105,371$

TABLE 26

SAMPLING VARIABILITY OF BUFFALO TRIPS BY LAND USE AT DESTINATION

LAND USE AT DESTINATION	PROPORTION OF TRIPS	VARIANCE OF A RANDOM SAMLE	ACTUAL VARIANCE	VARIANCE RATIO ACTUAL/RANDOM	INTRA-CLASS CORRELATION
Residential	0.505	2.372×10^{-6}	3.003×10^{-6}	1.27	0.03
Commercial	0.277	1.901×10^{-6}	4.265×10^{-6}	2.24	0.16
Manufacturing	0.061	0.547×10^{-6}	0.942×10^{-6}	1.72	0.09
Public building	0.091	0.783×10^{-6}	1.779×10^{-6}	2.27	0.16
Public open space	0.027	0.250×10^{-6}	0.659×10^{-6}	2.64	0.20
All other land use	0.039	0.354×10^{-6}	1.169×10^{-6}	3.30	0.29

TABLE 27

SAMPLING VARIABILITY OF BUFFALO TRIPS BY MODE OF TRAVEL

MODE OF TRAVEL	PROPORTION OF TRIPS	VARIANCE OF A RANDOM SAMPLE	ACTUAL VARIANCE	VARIANCE RATIO ACTUAL/RANDOM	INTRA-CLASS CORRELATION
Auto driver	0.576	2.317×10^{-6}	7.445×10^{-6}	3.21	0.28
Auto passenger	0.317	2.056×10^{-6}	7.070×10^{-6}	3.44	0.31
Bus transit passenger	0.073	0.643×10^{-6}	2.443×10^{-6}	3.80	0.35
School bus passenger	0.028	0.258×10^{-6}	1.015×10^{-6}	3.93	0.37
All other modes	0.005	0.049×10^{-6}	0.136×10^{-6}	2.78	0.22

general, mode of travel data requires a cluster sample over three times the size of a random sample in order to achieve comparable reliability. School bus use would require a cluster sample of almost four times the size of a random sample for the same accuracy. To estimate the proportion of trips on school buses within ±10 percent, 95 times out of 100, would require 54,571 samples, i.e., $n_c = 400Rq/p$, in which $R = \sigma_c^2/\sigma^2$, or $(400 \times 3.93 \times 0.972)/0.028 = n = 54{,}571$.

Screen Line Crossings—Origin-and-destination studies are conducted mainly to collect data on travel. The accuracy of these data are often evaluated in terms of how well estimates of travel crossing a line compare with actual observations at the line. This screen line check, as it is called, is used not only as a measure of the accuracy of the survey, but also sometimes as a basis for survey adjustment.

Because of the important role that the screen line check plays in survey evaluation, it was felt that the impact of cluster sampling on the reliability of the proportion of trips crossing a screen line should be investigated. Six screen lines were constructed as follows:

1. A north-south line centered in the Buffalo CBD.
2. A north-south line 5 miles to the east of the CBD.
3. A north-south line 10 miles to the east of the CBD.
4. An east-west screen line centered in the CBD.
5. An east-west screen line 5 miles to the south of the CBD.
6. An east-west screen line 5 miles to the north of the CBD.

The results of analyzing these six screen lines are given in Table 28.

The screen line proportions appear to be highly affected by the clustering of trips by households. For the six screen lines analyzed, the variance of the screen line proportion was about five times greater than the variance of a random

TABLE 28

SAMPLING VARIABILITY OF SCREEN LINE PROPORTIONS

SCREEN LINE	PROPORTION OF TRIPS	VARIANCE OF A RANDOM SAMPLE	ACTUAL VARIANCE	VARIANCE RATIO ACTUAL/RANDOM	INTRA-CLASS CORRELATION
North-south CBD	0.151	1.216×10^{-6}	6.283×10^{-6}	5.17	0.52
North-south 5 miles east of CBD	0.122	1.015×10^{-6}	5.350×10^{-6}	5.27	0.54
North-south 10 miles east of CBD	0.048	0.437×10^{-6}	2.654×10^{-6}	6.07	0.64
East-west of CBD	0.046	0.419×10^{-6}	2.202×10^{-6}	5.26	0.53
East-west 5 miles south of CBD	0.118	0.988×10^{-6}	4.166×10^{-6}	4.22	0.41
East-west 5 miles north of CBD	0.135	1.111×10^{-6}	5.310×10^{-6}	4.78	0.47

sample of the same size. This is not surprising, because the probability of crossing any given screen line most likely declines exponentially with increasing distance from the trip origin. Because all members of a household have the same distance between home and the screen line, the intra-class correlation should be high. Table 28 gives a range of from 0.41 to 0.64 and an average of about 0.50 for the intra-class correlation, and a variance ratio of about 5.0. Translated to the sample size required to estimate screen line crossings within ±10 percent, 95 times out of 100, it is found that $n = (400 \times 5 \times 0.9)/0.1 = 18{,}000$.

To obtain accuracy of ±5 percent, 95 times out of 100, would require 72,000 samples.

Required Sample Sizes

Based on the preceding analysis of the variability of cluster samples, it became possible to define the number of samples of home interview data required to provide reliable data for transportation planning purposes.

As usual in such cases, there is no simple answer. Planning uses home interview travel data for a variety of purposes—for checking purposes (as in screen line comparisons), for mode split estimation, and for trip generation studies of one kind or another. In each of these different groupings, a different level of reliability obtains.

Table 29 gives the minimum number of trip samples (to obtain households, divide by 6.6) for different proportions of trips having selected attributes. For example, if one is dealing with trips to a type of land use that has 5 percent of all trips made to it (see line 1 of Table 29) then 13,450 trip samples (2,190 sample households) are needed to make certain, at the 95-percent confidence limits, that the correct proportion is, in fact, within ±10 percent of the 5-percent figure, or, in other words, that the proportion lies between 0.045 and 0.055.

If the proportion of a particular type of trip is required to be studied in a particular area (as in a district), the number of samples indicated in Table 29 must be obtained *for that geographic area.*

TABLE 29

MINIMUM NUMBER OF TRIP SAMPLES REQUIRED TO ENSURE ±10 PERCENT ACCURACY AT THE 95-PERCENT CONFIDENCE LIMITS LEVEL FOR SELECTED ATTRIBUTES AND PROPORTIONS

SIZE OF PROPORTION	MINIMUM NO. OF TRIP SAMPLES REQUIRED			
	LAND USE	MODE OF TRAVEL	SCREEN LINE CROSSING	TRIP PURPOSE
0.05	13,450	25,384	38,000	23,104
0.10	6,372	12,024	18,000	10,944
0.25	2,124	4,008	6,000	3,648
0.50	708	1,336	2,000	1,216

Note. Trip samples above are based on an analysis of Niagara Frontier Study data. To obtain home interview samples, the figures above should be divided by a factor of 6.6, the average number of trips per household.

For estimates of trip length, it is recommended that 1,000 trip records (approximately 150 sample households) be obtained for any area for which trip length is desired to be known within ±10 percent at the 95-percent confidence limits level.

For estimates of trip production by household, approximately 400 *households* would have to be interviewed to obtain trips/household data within ±10 percent, 95 percent of the time. This is too large a number to obtain in each district, unless districts are very large. For purposes of estimating trip production it is recommended that districts be grouped and that trip production rates be calculated in relationship to population and car ownership. These rates can then be applied back against district population and car ownership rates to give reliable measures of district and zone trip production.

CHAPTER THREE

CONCLUSIONS, APPLICATIONS, AND SUGGESTED RESEARCH

The purpose of this project is to determine what data should be collected in the future by transportation studies both for the preparation of new transportation plans and for the continuing review and improvement of existing long-range transportation plans. What policy on data can be assembled out of the investigations that are reported herein? In what direction or directions should a transportation study go regarding data collection?

BASIC DATA POLICY

Before listing the basic data policies that have been synthesized from the work reported herein, the key assumptions have to be spelled out.

1. It is assumed that it is desirable to review present strategic transportation plans periodically to determine whether investment levels, mode-split of investment, and

corridor locations are still valid in the light of the changing city.

2. It is assumed that the STPP described here, with its long-range estimates of trip production, by mode, and traffic assignments, will be the method used to prepare or review the strategic transportation plan.

Based in part on these assumptions, the following data policies are recommended:

1. The collection of data should be regarded as a means to an end, not as an end in itself The planning process defines what data are needed. Research justifies collection of data, especially new kinds of data, for the purposes of increased knowledge, but data collection for research should generally be kept separate from data collection for planning purposes.

2. The collection of data for strategic planning should be kept separate from data collection for the various types of implementation planning. Data should be obtained for implementation planning as needed, but it is uneconomic to mix the two types of operations.

3. Land use data should be maintained in current state for each metropolitan area so that at any given time major uses and density of use will be known for each traffic analysis zone.

4. The major street and mass transportation network data files should be kept current.

5. Vehicle-miles of travel (VMT) and person-miles of travel (PMT) should be measured biennially and converted to daily travel costs by street type within district. Travel cost data should be used to determine whether the STPP needs revision and/or whether land use controls need to be instituted to protect performance of the existing plan.

6. If the transportation plan needs review, only enough origin-destination data should be obtained to measure current levels of certain critical variables such as trip length and household trip production. For trip length, approximately 150 households should be sampled for any area (e.g , district) for which trip length is desired to be known within ±10 percent at the 95-percent confidence limits level. For other variables, see Table 29. These estimates of trip length and trip production can then be used with forecasts of population and car ownership to produce trip generation and other estimates needed to revise a transportation plan.

SUGGESTED RESEARCH

There are four general areas in which additional research is needed in the field of data collection for transportation. These are described as follows.

1 *Improvement of "administrative data" collection, storage and use.* It is shown herein that governments at various levels obtain and maintain substantial data files that could be of significant use for transportation and other planning purposes These files include data having numbering systems that uniquely identify persons, firms, and parcels of land. These files also include census records of various types. Many improvements in these files have been seen in recent years, partly due to the power and economy inherent in computer data processing. Research work having the purpose of improving these files and increasing their usefulness for transportation planning should have a high priority because these files will be kept up-to-date for administrative purposes and the cost of their use for planning purposes will be nominal by comparison with primary data collection.

2 *Improvement of selected data collection techniques.* Funds should be set aside for improvement of selected types of data collection techniques, including such techniques as aerial photography for measuring VMT, special transit surveys, and electronic counting of transit passengers.

3 *Techniques for collecting new data.* Funds should be set aside for research into techniques for collecting new kinds of data. Of particular interest are data on land values, on building values, on the general economics of urban growth and change, and on social indicators. These data are needed because an understanding of what makes a better city and region is needed. Transportation improvements have been blocked because of the basic urban crisis. It is important for transportation planners to try to solve this crisis, not only because reduced tensions will ease the way for transportation construction, but also and more importantly because they need to know what the desired future city is that they will serve with roads and transit systems.

4. *Improvements in the planning process.* It is recognized that improvements are needed, and will continue to be made, in both strategic and implementation planning processes. These improvements may call for new data to be collected. From time to time, therefore, it will be necessary to fund research work into means of collecting new types of data required for improved transportation planning.

REFERENCES

1 Bridwell, L. K., "Improved Street Utilization Through Traffic Engineering." *HRB Spec Report 93* (1967) pp. 1-4.
2. Baerwald, J. E , ed., *Traffic Engineering Handbook.* 3d ed , Inst. of Traffic Eng. (1965).
3. Cleveland, D. E., ed., *Manual of Traffic Engineering Studies.* 3d ed., Inst. of Traffic Eng. (1964).
4. Allderige, J. M , "Working Memo No. 3." Consultant to Creighton, Hamburg, Inc.
5. Allderige, J. M., "Working Memo No 4." Consultant to Creighton, Hamburg, Inc.
6. *Woonsocket TOPICS* Prepared for the Rhode Island Dept. of Public Works by the Rhode Island Statewide Comprehensive Trans. and Land Use Planning Program, Providence (1967).
7. *Preliminary Route Location Study—Downtown Traffic Relief Route Woonsocket, Rhode Island* Prepared for the Rhode Island Dept. of Public Works by the Rhode Island Statewide Comprehensive Trans and Land Use Planning Program, Providence (1967).
8. *TOPICS Program for Lincoln, Nebraska.* Dept. of Public Works, Lincoln (1968).
9 Allderige, J. M., "Working Memo No. 6." Consultant to Creighton, Hamburg, Inc.
10. Wilbur Smith and Associates, *Stamford Traffic Engineering Program A Pilot TOPICS Study.* New Haven (1968).
11. Allderige, J M., "Working Memo No 5." Consultant to Creighton, Hamburg, Inc.
12. Wilbur Smith and Associates, *Rutland TOPICS Improvement Program.* New Haven (1968).
13. *Report on Status of TOPICS Program Ending August 31, 1969.* Bureau of Public Roads (Sept. 1969).
14. "Guidelines for Administering Demonstration Fringe Parking Facility Projects " Attachment to *Instructional Memo 21-1-69,* Bureau of Public Roads (Jan. 1969).
15. *Urban Corridor Demonstration Program—Preliminary Information."* Bureau of Public Roads (Aug. 1969)
16. "Urban Traffic Operations Program to Increase Capacity and Safety." *Policy and Procedure Memo. 21-18,* Bureau of Public Roads (Feb. 1967).
17. Carter, A. A., Jr., *Increasing the Traffic-Carrying Capability of Urban Arterial Streets: The Wisconsin Avenue Study* (in Washington, D.C.). Bureau of Public Roads, Div. of Traffic Operations Research (May 1962).
18. *Micro-Assignment, Volume I. Final Report, Volume II: Program Documentation.* Prepared by Creighton, Hamburg, Inc for the Bureau of Public Roads, Contract FH-11-6755 (Oct. 1969).
19. Pontier, W. S., "Optimizing Flow on Existing Street Networks." *NCHRP Report 113* (1967)
20. Burgwin and Martin, Consulting Engineers, *Lincoln Metropolitan Area Transportation Study, Volume 1: Transportation-Planning Report.* Topeka (1966).
21. "Evaluation of the Recommended Transit Plan." *Tech. Report No. 13,* New Castle County Planning Program, Wilmington, Del. (1968).
22. *Tucson Area Transportation Study, Volume II: Forecasts and Plans (1980).* Tucson (1965).
23. *Chicago Area Transportation Study, Volume III: Transportation Plan.* Chicago (1962) p 95.
24. *An Evaluation of Alternative Public Transportation Facilities.* N.Y. State Dept. of Public Works, Albany (Nov. 1966).
25. *Operating Results Now to 1985, Philadelphia-Lidenwold Rapid Transit Line.* Prepared for the DRPA by Simpson & Curtin. Also, discussions with Simpson & Curtin staff.
26. "Future Urban Transportation Systems: Descriptions, Evaluations, and Programs." *Final Report I,* Stanford Research Inst., Menlo Park, Cal. (1968).
27. "Transportation and Community Values." *HRB Spec. Report 105* (1969).
28. "Highway Capacity Manual." *HRB Spec. Report 87* (1965)
29. *A Policy on Geometric Design of Rural Highways.* American Assn. of State Highway Officials.
30. *A Policy on Arterial Highways in Urban Areas.* American Assn of State Highway Officials (1957).
31. *A Policy on Design Standards: Interstate System.* American Assn. of State Highway Officials.
32. *Standard Specifications for Highway Bridges.* American Assn. of State Highway Officials.
33. Mattzie, D. E., and Mac, I., *The Relationship Between Transportation Planning and Highway Design* Prepared by Rensselaer Research Corp , Troy, N.Y., for Creighton, Hamburg, Inc. (Oct 1969).
34. *Regional Development Alternatives* Tri-State Trans. Comm., N Y. (1967).
35. *Regional Development Guide.* Tri-State Trans. Comm , N.Y (1968)
36. *Diversity Within Order.* Northeastern Illinois Regional Planning Comm., Chicago (1967).
37. *The Plan Study. Methodology.* Northeastern Illinois Regional Planning Comm., Chicago (1968).
38. *A Land Use Plan Design Model, Volume I: Model Development.* Southeastern Wisconsin Regional Planning Comm., Waukesha, Wis. (Jan. 1968).
39. *Forecasts and Alternative Plans—1990* Southeastern Wisconsin Regional Planning Comm., Waukesha, Wis. (June 1966).
40. Chapin, F. S., Jr., *Urban Land Use Planning.* Univ of Ill. Press (1965).
41. Goodman, W. I., and Freund, E. C., eds., *Principles and Practice of Urban Planning* Internat. City Managers' Assn. (1968).

42 Chapin, F. S , Jr , and Weiss, S F , "A Probabilistic Model for Residential Growth." *Trans Research,* Vol. 2, Pergamon Press, pp 375-390 (1968).

43 Chapin, F S , Jr , and Weiss, S. F , *Factors Influencing Land Development.* Inst for Research in Social Science, Univ of N C (Aug 1962)

44. Chapin, F S , Jr , and Weiss, S F , *Some Input Refinements for a Residential Model* Inst for Research in Social Science, Univ of N C. (July 1965).

45. Donnelly, T G., Chapin, F S , Jr , and Weiss, S. F , *A Probabilistic Model for Residential Growth* Inst for Research in Social Science, Univ of N.C (May 1964).

46. Seidman, D R., *"The Construction of an Urban Growth Model" DVRPC Plan Report No 1,* Tech Supp , Vol. A (undated).

47 Schneider, M , "Access and Land Development." *HRB Spec Report 97* (1968) pp. 164-177

48 *Jobs, People and Land Bay Area Simulation Study.* The Center for Real Estate and Urban Economics, Inst. of Urban and Regional Development, Univ. of Cal , Berkeley (1968).

49. *Chicago Area Transportation Study, Volume II· Data Projections* Chicago (1960) pp. 16-33

50 Hill, D M., "A Growth Allocation Model for the Boston Region" *J Amer. Inst of Planners,* Vol. XXXI (May 1965) pp 111-120

51. Hill, D M., Brand, D , and Hansen, W B , "Prototype Development of a Statistical Land Use Prediction Model for the Greater Boston Region" *Hwy Res. Record No 114* (1965) pp. 51-70

52. Lowry, I. S , *A Model of Metropolis* RM-4035-RC, The Rand Corporation, Santa Monica (1964)

53 Lowry, I S , "Seven Models of Urban Development. A Structural Comparison." *HRB Spec. Report 97* (1968) pp 121-163.

54 Harris, B., *Basic Assumptions for a Simulation of the Urban Residential Housing and Land Market.* Inst. for Environmental Studies, Univ. of Penn (July 1966).

55. Harris, B , *Linear Programming and the Projection of Land Uses* Penn Jersey Trans Study.

56. Harris, B , Nathanson, J., and Rosenburg, L., *Research on Equilibrium Model of Metropolitan Housing and Locational Choice.* Planning Sciences Group, Inst. for Environmental Studies, Univ of Penn (Mar. 1966).

57 Lathrop, G. T , and Hamburg, J R , "An Opportunity-Accessibility Model" *J Amer. Inst of Planners,* Vol. XXXI (May 1965) pp. 95-103.

58. Arthur D Little, Inc , "Model of San Francisco Housing Market" *Tech. Paper No 8,* San Francisco Community Renewal Program (Jan. 1966).

59. Robinson, I M., Wolfe, H B., and Barringer, R L., "A Simulation Model for Renewal Programming." *J. Amer. Inst. of Planners,* Vol. XXXI (May 1965) pp. 126-134.

60. Bauer, R. A., *Social Indicators* MIT Press (1966).

61 *Toward A Social Report* Dept. of Health, Education and Welfare (1969)

62 *Goals for Americans* President's Commission on National Goals, Prentice-Hall (1960).

63. "Urban Transportation Planning." *Policy and Procedure Memo 50-9,* Bureau of Public Roads (June 21, 1967)

64 Matson, T M , Smith, W. S , and Hurd, F. W , *Traffic Engineering.* McGraw-Hill (1955).

65 Creighton, R L , Hoch, I , and Schneider, M , "The Optimum Spacing of Arterials and Expressways." *Traffic Quarterly* (Oct 1959).

66 Schneider, M , "A Direct Approach to Traffic Assignment *Hwy Res. Record No 6* (1963) pp 71-75

67 *Direct Assignment Trip Tables* Upstate N Y. Trans. Studies (May 1964)

68 Schneider, M , "Direct Traffic Assignment An Antiquarian Addendum." *Tri-State Trans Comm Tech Bull* (Nov. 1965).

69 *Direct Trip Tables Using Schneider's New Assumption,* Upstate N Y Trans Studies, unpub. document (Dec 1965)

70. *HRB Bull 156* (1957)—*HRB Bull 362* (1962).

71 *Hwy Res Record No 1* (1963)—*Hwy. Res Record No. 258* (1968).

72 *Highway Research Board Publications* (Jan 1969)

73 *Reports II-VII* Regional Science Assn , Philadelphia (1959-1968)

74 *Traffic Eng* (1959-1968)

75. *Traffic Quarterly* (Jan 1959—Oct 1968)

76 *An Introduction to Highway Transportation Engineering.* Inst of Highway Eng. (1964).

77 *Transportation Information A Report to the Committee on Appropriations.* U S. House of Representatives, U S. Dept. of Trans (1969)

78 *Cameras Aloft! Project Sky Count Analysis of Transportation Patterns and Land Usage from Aerial Photography* The Port of New York Authority, Operation Services Dept /Operations Standards Div (1968)

79 Zimmerman, J F , ed , *1968 Metropolitan Surveys* Grad School of Pub Affairs, State Univ of N.Y. in Albany

80 *Feasibility Study Automatic Vehicle Identification Systems, Final Report.* Cutler-Hammer/Airborne Inst Lab (June 1969).

81 *Public Urban Locator Service (PULSE) Background and Conference Proceedings* Inst of Public Admin. (Oct 24, 1968)

82 Fischer, R J , and Sosslaw, A B , "Census Data as a Source for Urban Transportation Planning" *Hwy Res Record No 141* (1966) pp 47-72.

83. Hansen, M H , and Voight, R B , "Availability of Census Data for Urban Areas" *Hwy. Res. Record No. 194* (1967) pp 21-31

84 Teyland, G. P., "Implications of the New Haven Census Use Test for Transportation and Land-Use Planning" *Hwy. Res. Record No. 229* (1968) pp 77-98

85. Memmott, F W , III, "Home Interview Survey and Data Collection Procedures." *Hwy Res. Record No 41* (1963) pp 7-12.

86 *Manual of Procedures for Home Interview Traffic Study.* Revised ed , Bureau of Public Roads (Oct 1954)

87. McGrath, W. R , and Guinn, C , "Simulated Home Interview by Television " *Hwy Res Record No 41* (1963) pp 1-6.

88 Mayer, A. J , and Wallace, J. L., "A New Method of Obtaining Origin and Destination Data " *HRB Bull 347* (1962) pp. 34-39

89 *Pinpoint* The Reuben H Donnelly Corporation, Marketing Div , Mount Vernon, N.Y

90 Hanel, R. S., "Handling Small Area Data with Computers " *Computers and Automation* (Dec 1968)

91. *Urban Information System* R L Polk & Co , Urban Statistical Div , Detroit

92. Clawson, M , and Stewart, C L., *Land Use Information A Critical Survey of U S. Statistics Including Possibilities for Greater Uniformity.* Johns Hopkins Press (1966).

93. *Land Use Survey Manual.* Chicago Area Transportation Study, Chicago (1956).

94. TRW Systems Group, *California Regional Land Use Information System Project, Final Report* (Apr. 1968).

95 *Field List and Land Use Check List Manual.* Niagara Frontier Trans Study, Albany (1962).

96. Memmott, F W, III, *Field Verification Manual* Upstate N.Y Trans. Study, Albany (1963).

97 Memmott, F W., III, and Ferguson, G. W., *Land Use Classification Manual,* Rochester Metropolitan Trans. Study, Albany (1963).

98 Memmott, F W , III, and Ferguson, G. W , *Field List Manual,* Upstate N Y. Trans. Study, Albany (1964)

99 Hatfield, S. M , "An Evaluation of Land-Use and Dwelling-Unit Data Derived from Aerial Photography." *HRB Bull 347* (1962) pp 121-132

100. Swanson, R A , *The Land Use and Natural Resource Inventory of New York State* New York State Office of Planning and Coordination, Albany (June 1969)

101 Sharkey, R H , *CATS Land Use Manual—CBD.* Chicago Area Trans Study, Chicago (1957).

102 *Updating Procedures for Metropolitan Area Transportation Studies* La State Highway Dept. (1968)

103 Bradwell, D , "Activating an Assessment Roll for Land Use Planning " *Appraisal Journal*

104. *Manual for the Tri-State Land Area and Floor Space Inventory* Tri-State Trans Comm (May 1968)

105. *Newark Urban Renewal Plan A Demonstration Grant Project* Chap. 2, Newark Central Planning Board, Comm. for Neighborhood Conservation and Rehabilitation (Apr. 1959).

106 *Dun's Market Identifiers.* Dun & Bradstreet, Marketing Services Div., N.Y. (1969).

107 Sullivan, S W , "Conducting the Truck and Taxi Survey." *Southeastern Wisconsin Regional Planning Comm Tech Record,* Waukesha, Wis. (Feb -Mar 1964) pp 1-9.

108 Fox, W G., "Conducting The Truck and Taxi Postal Questionnaire Survey " *Southeastern Wisconsin Regional Planning Comm. Tech. Record,* Waukesha, Wis (Feb -Mar 1964)

109 Memmott, F. W , III, *Truck and Taxi Survey Manual.* Niagara Frontier Trans Study, Albany (1962).

110. *External Survey Manual* Chicago Area Trans Study (1956)

111 *Roadside Interview Stations* Chicago Area Trans. Study (1956).

112. Edens, H J , "Origin-Destination Survey by Telephone " *Traffic Eng.* (Apr 1963) pp 11-12.

113 Clark, J E., and Morin, D A. "Securing Travel Data by Telephone Interviews " *Traffic Eng* (June 1966) pp 47-49

114. Deen, T B., "Origin-Destination Surveys." Chap. 4, *Manual of Traffic Engineering Studies,* 3d ed , Inst. of Traffic Eng. (1964)

115. Cleveland, D E "Parking Studies." Chap. 6, *Manual of Traffic Engineering Studies,* 3d ed , Inst. of Traffic Eng (1964)

116. Worrall, R D "The Urban Panel as a Longitudinal Data Source " *Hwy Res. Record No. 194* (1967) pp 62-77

117 *Official Census Form—1970 Census* (preliminary copy). Bureau of the Census (1969)

118. Newzil, D R , "Response Characteristics of a Postal Survey " *Traffic Quarterly* (Oct. 1967) pp 585-600

119 Murray, F J , "A Comparative Study of Origin-Destination Data Obtained by Home Interview and Controlled Post Card Methods." *Proc HRB,* Vol. 36 (1957) pp 669-679.

120 *New Haven Census Use Study* Draft, Bureau of the Census (Feb 1967).

121 Ben, C , "Area Travel Survey " *Report No. 11, Census Use Study,* Bureau of the Census (1970).

122 Rainville, W S , Jr , "Transit Studies " Chap. 5, *Manual of Traffic Eng Studies,* 3d ed , Inst. of Traffic Eng (1964).

123. Kochanowski, R , "Design of an Onboard Transit Questionnaire Survey " *Tech. J of Southwestern Penn. Regional Planning Comm* , Pittsburgh (Aug. 1968) pp 4-10.

124 *Transit Survey Procedures* Southwestern Penn. Regional Planning Comm , Pittsburgh (Sept. 1967).

125 "Inventory of the Physical Street System." *Procedural Manual 5A,* National Comm on Urban Trans., Public Admin. Service, Chicago (1958).

126 "Measuring Transit Service " *Procedure Manual 4A,* National Comm on Urban Trans., Public Admin Service, Chicago (1958).

127. Kuemmel, D A , "Rail and Transit Inventory and Design of the Transit Network " *Tech. Record,* Southeastern Wisconsin Regional Planning Comm., Waukesha, Wis (Feb -Mar 1964)

128 Church, D. E , *The 1967 Census of Transportation —Codes, Analyses, and Applications.* Bureau of the Census (May, 1969).

129 Leyland, G P , "Implications of the New Haven Census Use Test for Transportation and Land Use Planning " *Hwy Res Record No 229* (1968).

130. **Farnsworth**, G. L., "A Geographic Base File for Urban Statistical Analysis." *Census Tract Papers,* Series GE-40 No. 5, Bureau of the Census (1968).
131 **Leyland**, G. P., "Computer Mapping—Here and Now." *Census Tract Papers,* Series GE-40 No. 5, Bureau of the Census (1968).
132. **Prince**, M. D., "Computer Graphics: A Look Into the Future." *Census Tract Papers,* Series GE-40 No 5, Bureau of the Census (1968).
133. *Census Use Study Report No. 2—Computer Mapping.* Bureau of the Census (1969).
134. **Daly**, J. F, and **Voight**, R. B., *The 1970 Census Address Coding Guide Improvement Program."* Bureau of the Census (1969).
135. "Special Purpose Traffic Survey Devices." *Traffic Eng.* (Feb. 1966) pp. 29-41
136. **Kicker**, E R., "Monitoring Traffic Speed and Volume." *Traffic Quarterly* (Jan. 1959) pp. 128-140
137. **Thompson**, P. H, and **Huber**, M. J., "Measuring Lateral Placement and Velocity." *Traffic Eng.* (Oct. 1960) pp. 26-28.
138. **Stern**, S, "Traffic Flow Data Acquisition Using Magnetic-Loop Vehicle Detectors." *Hwy. Res. Record No. 154* (1967) pp 38-52.
139. **Campbell**, E. W., "Traffic Counting Studies." Chap. 2, *Manual of Traffic Engineering Studies,* 3d ed, Inst of Traffic Eng. (1964) pp. 10-31.
140 **Wenger**, D. M., "Motor Vehicle Speed Studies." Chap. 3, *Manual of Traffic Engineering Studies,* 3d ed., Inst. of Traffic Eng. (1964) pp. 32-44.
141. *A Survey to Evaluate the Criteria Which Influence the Purchase and Use of a Monthly Transit Pass."* Prepared by W. C. Gilman and Co. for the Bi-State Development Agency (Dec. 11, 1964).
142. **Walker**, W. P., "Speed and Travel Time Measurement in Urban Areas." *HRB Bull. 156* (1957) pp. 27-44.
143. **Herd**, L. O., "An Aerial Photographic Technique for Presenting Displacement Data." *Hwy. Res. Record No. 232* (1968) pp. 64-67.
144. **Freiter**, J., and **Taylor**, J. S., "Traffic Flow Investigations by Photogrammetric Techniques " *Hwy. Res. Record No. 142* (1966).
145. **Wahl**, M., "Vehicle Speeds and Volumes Using Sonne Stereo Continuous Strip Photography." *Traffic Eng.,* Vol. 29, (Jan 1959) pp. 14-19.
146. **Sickle**, S. M., "Continuous Strip Photography—An Approach to Traffic Studies." *Traffic Eng.* (July 1959) pp 11-12.
147 *Parking Study Using Aerial Photography for the Cities of Canton, Massillon, and North Canton, Ohio.* Stark County Area Trans. Study (1968).
148. *Television Traffic Surveillance System.* Research being conducted by the Bureau of Public Roads.

APPENDIX A

MACRO-DIAGRAMS OF FIVE TRANSPORTATION PLANNING PROCESSES

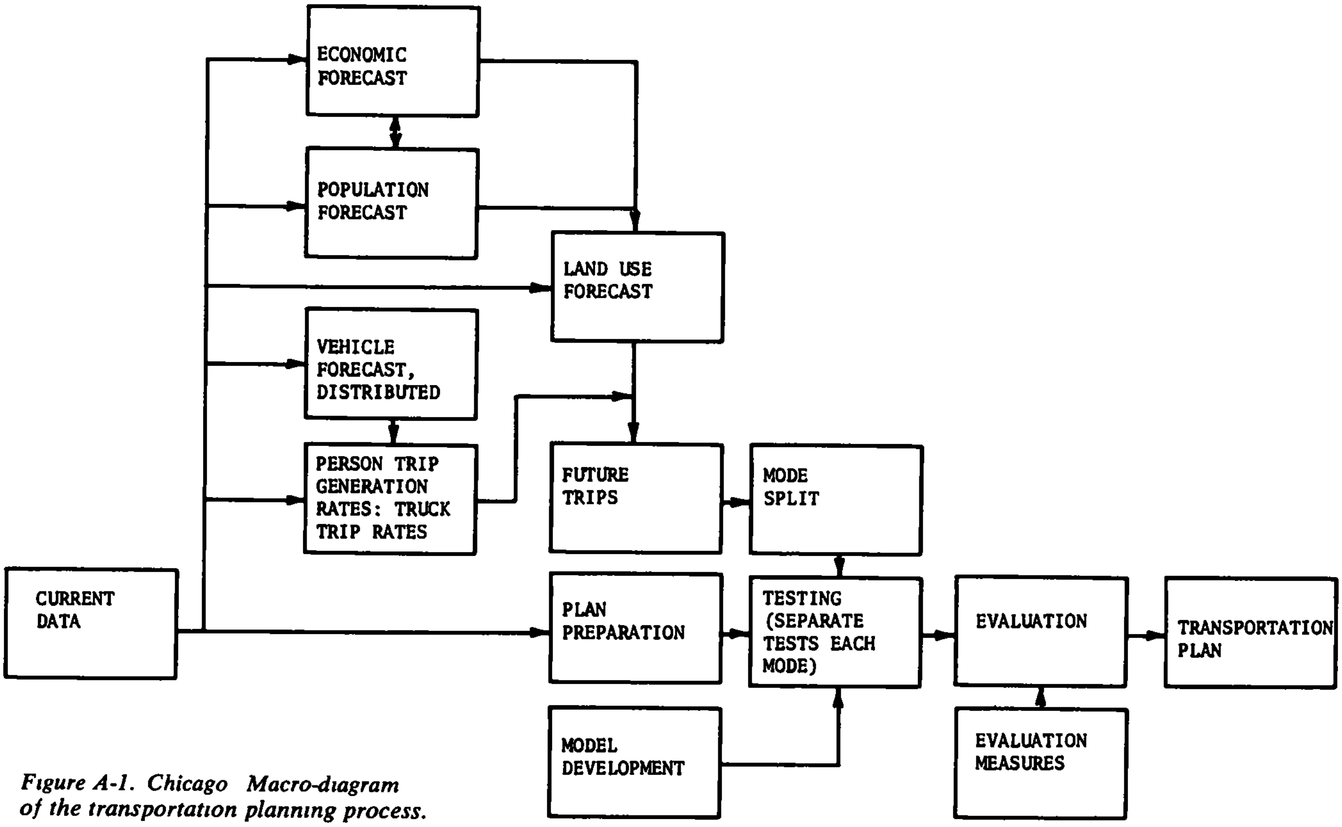

Figure A-1. Chicago Macro-diagram of the transportation planning process.

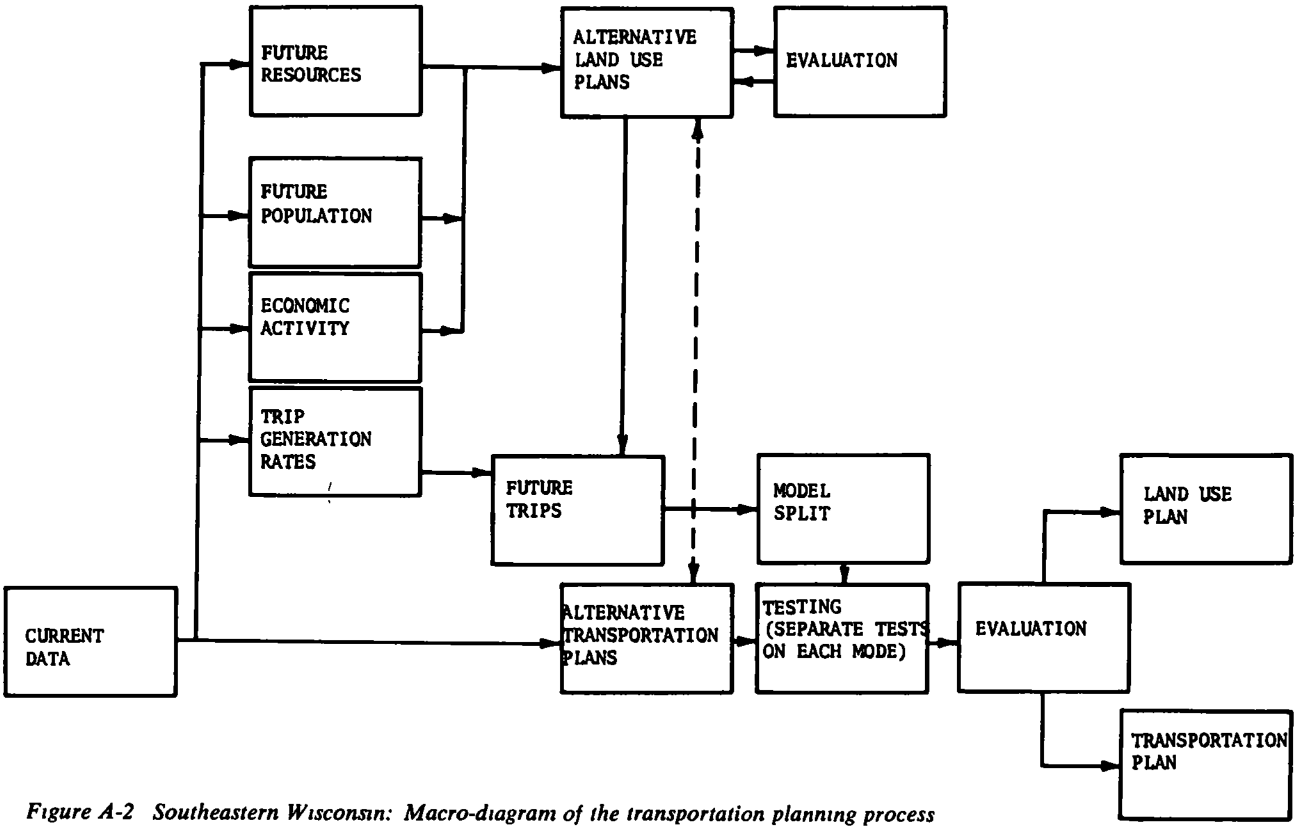

Figure A-2 Southeastern Wisconsin: Macro-diagram of the transportation planning process

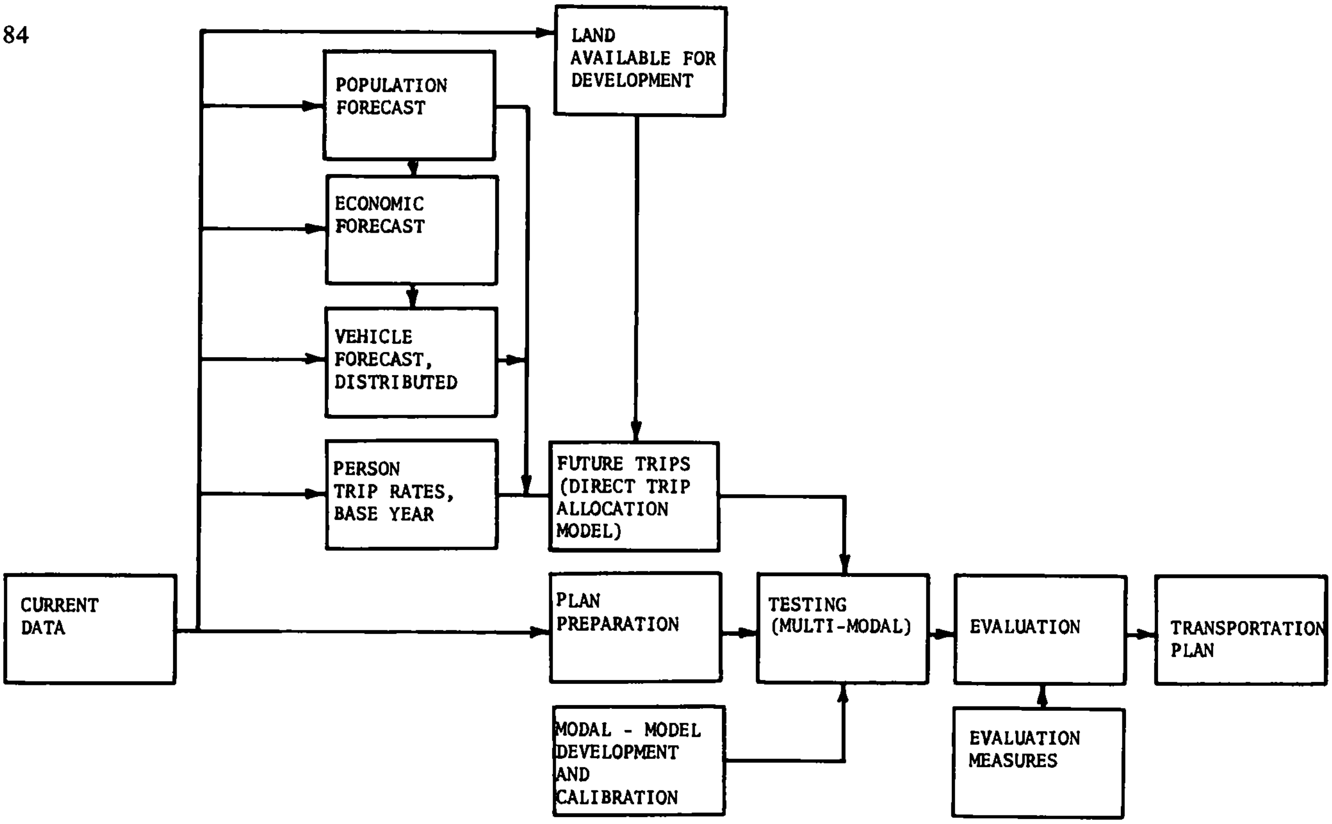

Figure A-3 Niagara Frontier Macro-diagram of the transportation planning process.

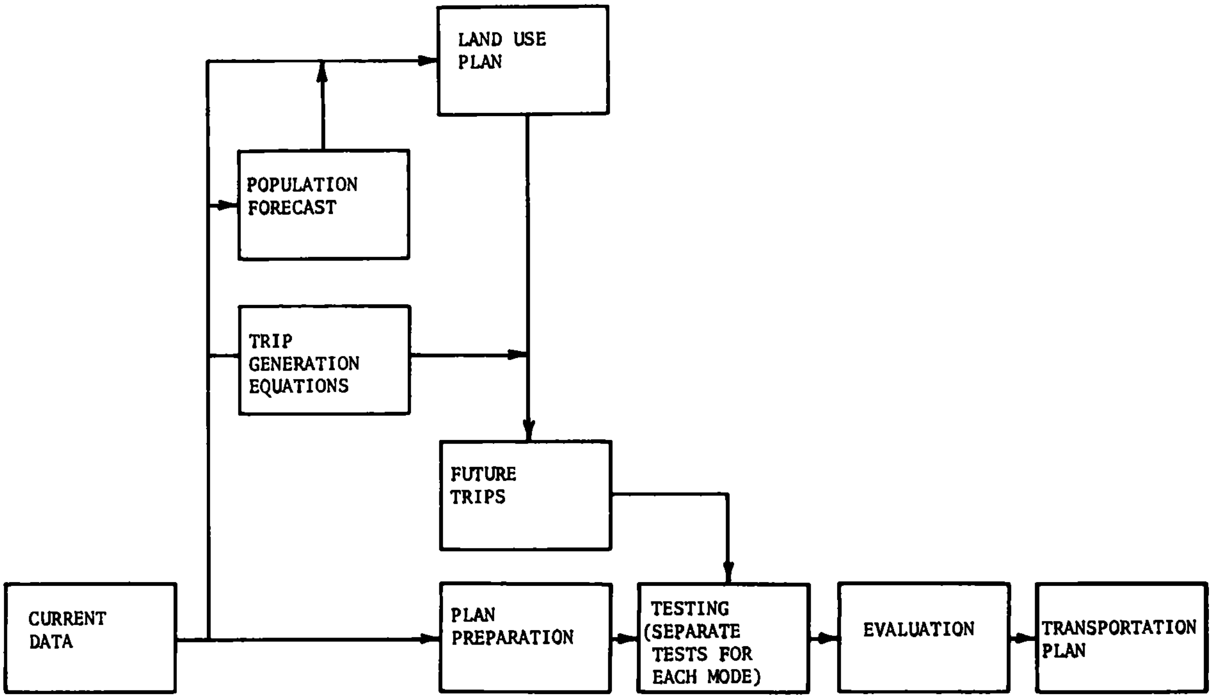

Figure A-4 Wilmington Macro-diagram of the transportation planning process

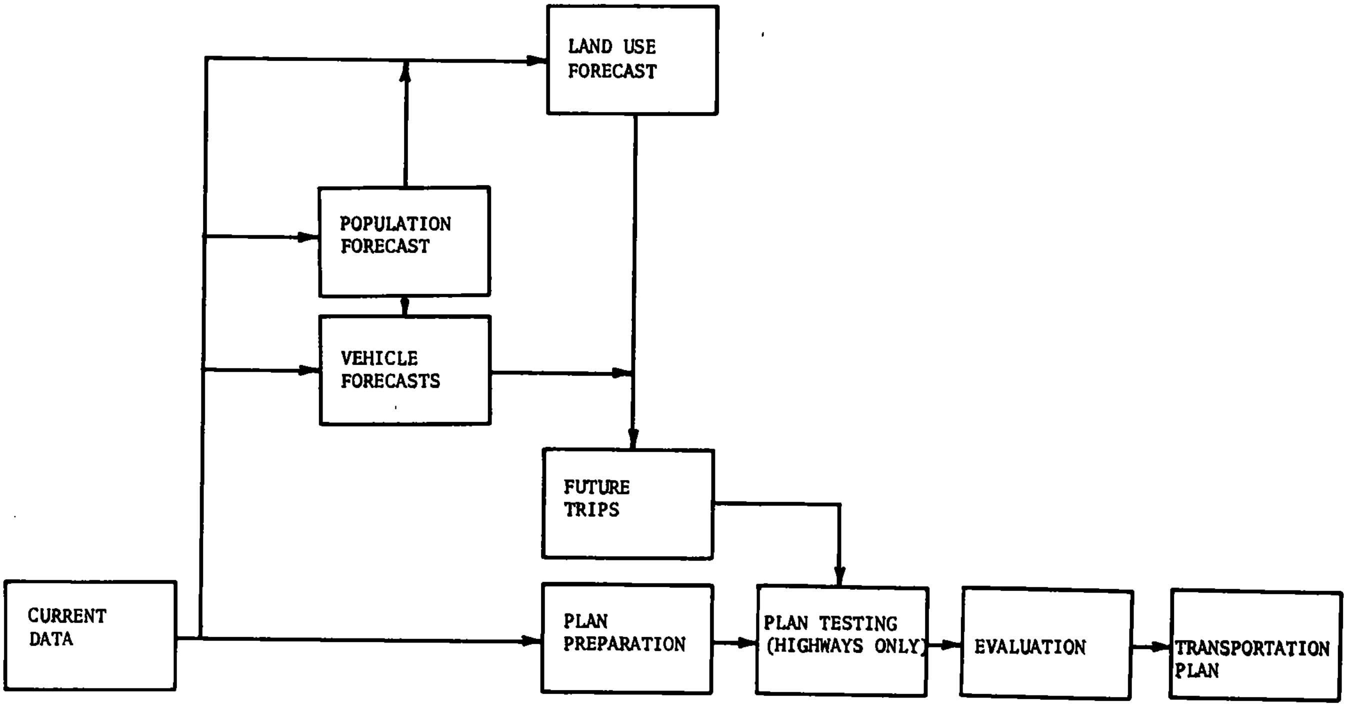

Figure A-5 Tucson Macro-diagram of the transportation planning process

APPENDIX B

THE BASIC TRANSPORTATION PLANNING PROCESS AND ITS DATA REQUIREMENTS

By superimposing the macro-diagrams of five transportation studies (see Appendix A) it was possible to generate a "basic" (or minimum) transportation planning process (TPP). This process is shown in Figure 3. Each of the steps in the basic TPP is described in this appendix, and the data requirements of these steps are listed. These data requirements constitute, in the judgment of the researchers, the minimum set of data needed for strategic transportation planning.

STEP	TITLE AND BRIEF DESCRIPTION OF STEP	DATA REQUIREMENTS	SOURCE [a]
N	*Employment Forecast.* Estimate target-year employment by major industry type (i e., manufacturing, wholesale, retail). This forecast must be coordinated with the population forecast.	1. Employment data by major industry type for central city, counties, and metropolitan area, present and historical	S
		2. Population data, as specified in Step O.	—
O	*Population Forecast.* Estimate target-year population, coordinated with employment forecast.		
	1. Ratio method	1 Present population of study area, by analysis zone.	P or S
		2. Present and historical population of study area, state, and nation.	S

STEP	TITLE AND BRIEF DESCRIPTION OF STEP	DATA REQUIREMENTS	SOURCE [a]
		3. National population forecasts prepared by Bureau of the Census.	S
	2. Cohort survival method.	1. Birth and death rates for the metropolitan area, state, and nation.	S
		2. National projections of birth and death rates.	S
P	*Automobile Forecast.* The minimum forecast technique will include an aggregate forecast based on trend data plus a geographic allocation based on present distribution of automobiles owned per capita or per dwelling unit.	1. Historical registration data for automobiles for the state, metropolitan area, and (if available) minor civil division.	S
		2. Automobiles available, by geographic location of residents	P
		3. Population data, as specified in Step O.	—
R	*Land Use Forecast.* There are too many land use forecasting models to permit description of each, but certain basic data are required for all. If a long-range plan is available, it may be substituted for this forecast. If an accessibility-sensitive model is used, network data will be needed.	1. Land use (and vacant land) by type (at least ten categories), by analysis zone.	P
		2. Population, by location of residence, as specified in Step O.	—
		3. Employment (first work trips) by land use at destination, by location.	P
		4. Available public and institutional plans for "controlled" land uses such as major airports, parks, colleges, watershed areas.	S
		5. Zoning maps and ordinances, mainly for industrial land uses.	S
		6. Topographic and floodplain data.	—
		7. Network data as specified in Step W.	—
S	*Trip Forecast* Resident trips are estimated by applying trip production rates to a future population, but with variations in the rates as functions of density and auto ownership. When the gravity or opportunity model is used, person trips must be estimated by type, which requires breakdowns by purpose, land use, and trip length. Various methods of forecasting can relate truck trips to person trips, to population, to land use, or to employment. Taxi trips can be estimated on a flat expansion basis, based on population growth or CBD growth. Present external trips can be expanded on the basis of population growth in the areas surrounding the study area.	1. *Resident Trips*	
		a. Present person trip destinations by analysis zone, related to	P
		b. dwelling places, and	P
		c. auto ownership, and as broken down by	P
		d. mode of travel	P
		2. *Gravity or Opportunity Model*	
		a Present person trips in each analysis zone by trip purpose at destination,	P
		b by land use at destination, and	P
		c. by length, as calculated from X, Y origin and X, Y destination.	P
		3. *Truck Trips*	
		a. Present truck trip destinations, by analysis zone, related to	P
		b population,	—
		c. resident trip destinations,	—
		d. land use at destination, and	P
		e. employment (first work trips).	—
		4. *Taxi Trips*	
		a. Taxi trip destinations by analysis zone.	P
		5. *External Trips*	
		a Present external vehicle trips, by location of destination, or by external station of exit,	P
		b. by vehicle type.	P
		c. Present population of external zones.	S
		d. Forecast of external zones' population.	S

STEP	TITLE AND BRIEF DESCRIPTION OF STEP	DATA REQUIREMENTS	SOURCE [a]
T	*Estimate Mode Split.* Mode can be estimated by a simple projection of transit trips, as in a CBD-type forecast. Or, mode may be estimated as a function of car ownership and/or density. More elaborately, mode may be estimated based on car availability, trip purpose and trip length. In keeping with idea of basic TPP, forecasts are for AADT, not for peak hour. If an accessibility-sensitive model is used, network data will be needed, including fares and parking costs. For various purposes, trends in transit use need to be examined. For checking modal model assignments, PMT data are needed.	1. *Simple Projection*	
		a Person trip destinations and origins, by mode of travel, and by location.	P
		b A population or CBD trip forecast	—
		2 *Auto Ownership Method*	
		a. Automobile ownership forecast.	—
		b. Land use forecast.	—
		c. Person trip destinations by mode and location related to automobile ownership, and	P
		d Density.	—
		3. *System-Sensitive Method*	
		a Car availability data, based on time of trip origins and destinations for all members of a family, by mode.	P
		b Trip purpose by mode.	—
		c. Trip length.	—
		d. Network data as specified in Step W.	—
		e. Fares	S
		f. Parking costs.	S
		4. *Historical Data*	
		a. Historical transit use or revenue passengers by bus and (separately) by rail rapid transit.	S
		5. *PMT Data*	
		a. PMT by transit link (sampled over entire network or for selected links).	P
V	*Plan Preparation.*		
	1. Obtain existing land use plans.	1. *Land Use Plans*	
		a. Plans for redevelopment, public open space, airports, parks, colleges, institutions, and other land uses over which there exists some kind of control Such plans must be measured and mapped with precise boundaries.	S
	2. Obtain plans for transportation facilities	2 *Transportation Plans*	
		a. Committed facilities and historic plans in mapped form.	S
	3. Calculate efficient spacings (optional; for large metropolitan areas only).	3. *Efficient Spacing*	
		a. Future vehicle trip destination densities by analysis zone. (See Step S.)	—
		b. Expressway construction costs. (See Step X-1.)	—
		c. Expressway and arterial speeds. (See Step W.)	—
		d. Trip length frequency distribution (calculated from trip origin and destination data).	—
		e. Value of time, etc. (See Step X-1.)	—
	4. Apply system and land use planning principles.	4. *Planning Principles*	
		a. No data needed.	—
	5. Review plans against large-scale maps or air photos.	5. *Review Plans*	
		a. Maps (1" = 400' or larger).	S
		b. Aerial photographs (1" = 400' or larger.)	S

STEP	TITLE AND BRIEF DESCRIPTION OF STEP	DATA REQUIREMENTS	SOURCE [a]
	6 Prepare "barriers" map showing land use constraints	6 *Barriers Map*	
		a. Precise locations of cemeteries, institutional lands, major transportation facilities of all kinds, ports, airports, etc	S
W	*Plan Testing*		
	1. Code highway network for assignment purposes	1 *Highway Network*	
		a Link length	P
		b Link width	P
		c Link type	P
		d. Area type	P
		e Link "initial speed "	P
		f Other capacity data required by any "restrained assignment" model (signalization, turn controls, bus stop locations, etc)	P
	2 Code transit network for assignment purposes.	2 *Transit Network*	
		a Transit link length	P
		b. Transit link speed.	P
		c. Transit link type.	P
		d. Transit link headway	P
		e. Mean walking distance to transit line, by analysis zone	P
	3. Develop speed-volume relationships by street type for restrained assignment	3 *Speed-Volume Function*	
		a. Traffic speeds related to volumes for a sample of links, by link type.	P
	4. Obtain future vehicle and person trips.	4 *Trips*	
		a See Step S.	—
	5. Obtain assignment computer program; assume preliminary probability or exponential values.	5 *Assignment Program*	
		a No data required	—
	6. Calibrate vehicular and transit assignments to base year	6. *Calibration (Base Year)*	
		a VMT by district and for entire study area.	—
		b Screen line volume counts.	P
		c. PMT Data (See Step T-5.)	—
	7 Calibrate to target year, based on estimate of future VMT and PMT.	7. *Calibration (Target Year)*	
		a Estimated future vehicles times mean VMT/vehicle/day. (See Step S)	—
		b Estimated future vehicle trips times mean trip length. (See Step S)	—
		c Estimated future PMT, based on estimated transit trips and mean transit trip length. (See Step T.)	—
X	*Plan Evaluation* Apply economic and social criteria	1. *Economic Criteria*	
		a. Value of time for persons and vehicles	S
		b. Travel cost data as a function of road type and volume.	S
		c. Travel cost data for transit passengers, by type of service	S
		d Accident cost data for roads as a function of volume and road type.	S
		e Accident cost data for transit systems, by type	S
		f Road construction costs, including R.O.W , by type	S

STEP	TITLE AND BRIEF DESCRIPTION OF STEP	DATA REQUIREMENTS	SOURCE [a]
		g Transit construction and equipment costs, by type.	S
		2 *Social Criteria*	
		a. Number of dwellings and non-residential establishments affected.	P
		b Historical buildings	S
		c Other data on social values, such as	
		1. Stability and security of an area (neighborhood preservation).	
		2 Pollution (noise, air, water).	
		3. Compatibility of land uses (provision of safety and security, especially for children).	
		4 Aesthetic considerations.	
		5 Access to employment center, facilities, and services (mobility, opportunity, and variety).	
		6 Preservation of community tax base	S
Z	*Staging* Technically, methods for establishing priorities use the same data as used in the evaluation stage But priorities, except in very broad categories, are generally adopted on a judgmental-political basis Careful evaluation of arterial needs is essential.	1. *Establish Priorities*	
		a Same data as in Step X	—

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[a] Primary (P) and Secondary (S) data are defined in Chapter Two

APPENDIX C

PRIMARY DATA NOT NEEDING TO BE COLLECTED

The following list represents data items not used, or having extremely limited use, in the five transportation studies examined It does not seem necessary, therefore, to collect these data items. It is recommended that transportation planning study staffs consider the following discussion describing data limitations before undertaking their own surveys.

TRIP SURVEYS

1 *Tripmaker Occupation and Industry* —These data are rarely used First work trips by destination land use serve as a better employment indicator.

2 *Tripmaker Sex, Race, and Age* —So far, these variables have not been extensively used for trip generation or modal choice analyses. If such analyses continue to emphasize household characteristics on an aggregated area basis, these variables will remain ineffectual.

3. *Car Pool* —This is difficult to define (every day, or occasional?) and difficult to apply This data item has not been used in the STPP

4 *Blocks Walked.*—This is difficult to define (a "block" may vary from 100 ft to 600 ft) and is virtually useless in the context of any kind of parking study; more than 90 percent of all trips are reported as walking zero blocks, meaning anything less than one block.

5 *Number of Persons in Car* —Car loading factors are generally derived by summing auto driver plus auto passenger trips and dividing by auto driver trips. This item is more commonly used as a means for interviewers to pick up trips "forgotten" by home interview respondents (This item, however, has other uses in roadside interview analyses)

6 *Kind of Parking.*—This has some utility for CBD parking analyses, but is rarely used in the STPP.

7. *Major Route of Travel or Checkpoints.*—This item has some utility for accuracy checks, but is virtually useless for recreating trip paths, which require a different kind of survey. It is difficult to define and to use.

8. *Intermediate Stops.*—This is an element of through trips in the roadside surveys, but information is extremely difficult to collect. Through trips are a minute fraction of all urban area trip making The item is meaningless for analysis.

9. *Commodity Carried.*—This is difficult to define, unless only one commodity is carried. It is difficult to use because points of loading and unloading cannot be identified. These data are no substitute for specially designed goods movement surveys.

10. *Empty or Loaded.*—This is difficult to define and is no substitute for loadometer surveys. (See also previous comments.)

11 *Vehicle Weight.*—Truck type is better identified by body type and number of axles than by weight.

12. *Business-Industry of Truck Owner* —Although data are sometimes used for forecasting trip generation by industrial category (related to employment forecasts), this variable has, probably, only a poor correlation with the variety of industries served, and with the type of goods carried.

13. *Miles Traveled* —This item is inconsistently reported in typical truck-taxi trips and is not directly used in STPP application.

14. *Number of Stops.*—This item is used by some studies solely for the purpose of defining truck-taxi trips (origins and destinations must be in separate blocks).

15. *Auto Available.*—This question has been asked of transit trip makers only. This variable is difficult to define, and its application in modal choice analysis is uncertain.

TRANSPORTATION FACILITY SURVEYS

1. *Speed-Delay Runs* —The present level of service on highway networks can be inferred from volume/capacity ratios by link. Assignment travel speeds can be established by judgmental methods.

2. *Turning Movements, Counts, and Other Intersection Capacity Variables.*—For systems analysis of link capacities, turn percentages, signal timing, percentage of commercial vehicles, bus stops, pedestrian counts, type area, and so forth, can generally be assumed, street widths and intersection design should be factual, however. Because the STPP normally focused on the system capacity in the target year, present control barriers—signalization and signs (e.g , speed limits, stop signs, turn restrictions)—have little bearing. These variables generally have been collected and used only by studies with greater interest in short-term planning.

3 *Accident Records.*—These records are more useful in short-term planning. They are only useful in the STPP if research work is undertaken to develop unit costs for benefit-cost analyses.

4. *Parking Records.*—Except for obtaining CBD parking space data, these records are usually available from secondary sources Parking surveys are not required for long-range planning; they are more useful for short-term planning

5 *Terminal Facility Records.*—Activity at truck, bus, rail, and air terminal facilities should be measurable from origin-destination data. Where such facilities are large, and therefore may influence systems planning, special attention may be given them, but detailed planning is not part of the STPP.

LAND USE SURVEYS

1. *Floor Area Measurements* —Present data are not useful unless target-year data are furnished in comparable detail. Barring dramatic physical changes in the CBD, CBD tripmaking is better forecasted by other types of analyses.

SOCIOECONOMIC SURVEYS

1. *Personal Opinion or "Attitudinal" Surveys.*—Direct methods of bringing such data to bear on the STPP have not been found.

2. *Household History or Population Mobility Surveys* —These data are difficult to apply and are used mainly in developing urban growth models. Such data might better be collected and used in separate research projects, outside the STPP.

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2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
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