HIGHWAY RESEARCH BOARD

Bulletin 347

Trip Characteristics and Traffic Assignment

National Academy of Sciences—
National Research Council

publication 1042

HIGHWAY RESEARCH BOARD

Officers and Members of the Executive Committee

1962

OFFICERS

R. R. BARTELSMEYER, *Chairman* C. D. CURTISS, *First Vice Chairman*
WILBUR S. SMITH, *Second Vice Chairman*
FRED BURGGRAF, *Director* WILLIAM N. CAREY, JR., *Assistant Director*

Executive Committee

REX M. WHITTON, *Federal Highway Administrator, Bureau of Public Roads* (ex officio)

A. E. JOHNSON, *Executive Secretary, American Association of State Highway Officials* (ex officio)

LOUIS JORDAN, *Executive Secretary, Division of Engineering and Industrial Research, National Research Council* (ex officio)

PYKE JOHNSON, *Retired* (ex officio, Past Chairman 1960)

W. A. BUGGE, *Director of Highways, Washington Department of Highways* (ex officio, Past Chairman 1961)

R. R. BARTELSMEYER, *Chief Highway Engineer, Illinois Division of Highways*

E. W. BAUMAN, *Director, National Slag Association, Washington, D. C.*

DONALD S. BERRY, *Professor of Civil Engineering, Northwestern University*

MASON A. BUTCHER, *County Manager, Montgomery County, Md.*

J. DOUGLAS CARROLL, JR., *Director, Chicago Area Transportation Study*

C. D. CURTISS, *Special Assistant to the Executive Vice President, American Road Builders' Association*

HARMER E. DAVIS, *Director, Institute of Transportation and Traffic Engineering, University of California*

DUKE W. DUNBAR, *Attorney General of Colorado*

MICHAEL FERENCE, JR., *Executive Director, Scientific Laboratory, Ford Motor Company*

D. C. GREER, *State Highway Engineer, Texas State Highway Department*

JOHN T. HOWARD, *Head, Department of City and Regional Planning, Massachusetts Institute of Technology*

BURTON W. MARSH, *Director, Traffic Engineering and Safety Department, American Automobile Association*

OSCAR T. MARZKE, *Vice President, Fundamental Research, U. S. Steel Corporation*

J. B. MCMORRAN, *Superintendent of Public Works, New York State Department of Public Works*

CLIFFORD F. RASSWEILER, *Vice President for Research and Development, Johns-Manville Corporation*

GLENN C. RICHARDS, *Commissioner, Detroit Department of Public Works*

C. H. SCHOLER, *Applied Mechanics Department, Kansas State University*

WILBUR S. SMITH, *Wilbur Smith and Associates, New Haven, Conn.*

K. B. WOODS, *Head, School of Civil Engineering, and Director, Joint Highway Research Project, Purdue University*

Editorial Staff

FRED BURGGRAF HERBERT P. ORLAND
2101 Constitution Avenue Washington 25, D. C.

The opinions and conclusions expressed in this publication are those of the authors and not necessarily those of the Highway Research Board

ERRATA

In HRB Bulletin 347 the following corrections should be made:

1. Page 269, Eq. 14 should read "$TF = e^{-\beta t}$".
2. Page 273, 5th line after Eq. 23 should read:

   ". . . . convergence criterion (Eq. 26), a second iteration is carried out during which. . . . "
3. Page 278, the heading for Eq. 35 should read:

   "For auto travelers," and the heading for Eq. 36 should read "For transit travelers."
4. Page 298, line 15 should read "Figs. 6 and 7). . . "
5. Page 300 should be page 299, and vice versa. Also, present page 299, line 4 after the second heading should read "are shown in reference (1)."

NRC **HIGHWAY RESEARCH BOARD**

Bulletin 347

Trip Characteristics and Traffic Assignment

Presented at the
41st ANNUAL MEETING
January 8-12, 1962

National Academy of Sciences —
National Research Council
Washington, D.C.
1962

$ 6.00

Department of Traffic and Operations

Fred W. Hurd, Chairman
Director, Bureau of Highway Traffic
Yale University, New Haven, Connecticut

COMMITTEE ON ORIGIN AND DESTINATION STUDIES

Garland E. Marple, Chairman
Chief, Urban Planning Division
Division of Highway Planning, U.S. Bureau of Public Roads
Washington, D.C.

Charles F. Barnes, Jr., Secretary
Traffic Planning Engineer
Automotive Safety Foundation
Washington, D.C.

John E. Baerwald, Professor of Traffic Engineering, University of Illinois, Urbana
Howard W. Bevis, Logistics Department, The Rand Corporation, Santa Monica, California
J. Douglas Carroll, Jr., Director, Chicago Area Transportation Study, Illinois
Nathan Cherniack, Economist, The Port of New York Authority, New York
Donald E. Cleveland, Assistant Research Engineer, Texas Transportation Institute, Texas A & M College, College Station
M.A. Conner, Engineer of Traffic and Planning, Florida State Road Department, Tallahassee
E.C. Cross, Jr., Bureau of Highway Planning and Programming, New York State Department of Public Works, Albany
Thomas J. Fratar, Partner, Tippetts-Abbett-McCarthy-Stratton, New York, New York
Harold W. Hansen, Senior Planning Engineer, Portland Cement Association, Chicago, Illinois
Walter S. Hansen, Alan M. Voorhees & Associates, Washington, D.C.
Joseph Kates, Traffic Research Corporation, Ltd., Toronto, Ontario, Canada
Norman Kennedy, Professor of Transport Engineering, Institute of Transportation and Traffic Engineering, University of California, Berkeley
Warren Lovejoy, The Port of New York Authority, New York, New York
John T. Lynch, McLean, Virginia
William R. McGrath, Director, Department of Traffic and Parking, New Haven, Connecticut
Albert J. Mayer, Director, Detroit Area Traffic Study, Wayne State University, Detroit, Michigan
W.L. Mertz, Technical Director, Regional Highway Planning Committee, Washington, D.C.
Harold L. Michael, Assistant Director, Joint Highway Research Project, Purdue University, Lafayette, Indiana
Frank J. Murray, Engineer of Planning Survey, Ohio Department of Highways, Columbus
R. Parker, Head, Research Section, Planning and Research Division, Arkansas State Highway Department, Little Rock
William S. Pollard, Jr., Partner in Charge, Harland Bartholomew & Associates, Memphis, Tennessee
S.S. Taylor, General Manager, Department of Traffic, Los Angeles, California
Alan M. Voorhees, Alan M. Voorhees and Associates, Washington, D.C.
Lawrence S. Waterbury, Consulting Engineer, New York, New York
George V. Wickstrom, Director, Transportation Division, Penn-Jersey Transportation Study, Philadelphia, Pennsylvania

David K. Witheford, Assistant Study Director, Pittsburgh Area Transportation Study,
Pittsburgh, Pennsylvania
J. E. Wright, Traffic Survey Manager, Texas Highway Department, Austin
F. Houston Wynn, Wilbur Smith and Associates, New Haven, Connecticut

Contents

TRAFFIC PATTERNS AND LAND-USE ALTERNATIVES

Alan M. Voorhees, Charles F. Barnes, Jr., and Francis E. Coleman 1

APPLICATION OF SYSTEMS ENGINEERING METHODS TO TRAFFIC FORECASTING

W. L. Grecco and S. M. Breuning 10

CHARACTERISTICS OF CAPTIVE AND CHOICE TRANSIT TRIPS IN THE PITTSBURGH METROPOLITAN AREA

Louis E. Keefer 24

A NEW METHOD OF OBTAINING ORIGIN AND DESTINATION DATA

Albert J. Mayer and Joanne L. Wallace 34

TRIP GENERATION AND THE HOME

Paul W. Shuldiner 40

AN ITERATIVE ASSIGNMENT APPROACH TO CAPACITY RESTRAINT ON ARTERIAL NETWORKS

Robert Smock 60

EVALUATION OF GRAVITY MODEL TRIP DISTRIBUTION PROCEDURES

Walter G. Hansen 67

A NEW METHOD OF TRIP DISTRIBUTION IN AN URBAN AREA

Anthony R. Tomazinis 77

OCCUPATION, COMMUTING, AND LIMITED-ACCESS HIGHWAY USE

Stanley H. Udy, Jr. 100

A METHOD FOR DETERMINING THE OPTIMAL DIVISION OF EXPRESS AND LOCAL RAIL TRANSIT SERVICE

Alan Black 106

AN EVALUATION OF LAND-USE AND DWELLING-UNIT DATA DERIVED FROM AERIAL PHOTOGRAPHY

Samuel M. Hadfield 121

IMPACT OF INDUSTRIAL DEVELOPMENT ON TRAFFIC GENERATION IN RURAL AREAS OF NORTH CAROLINA

John W. Horn 133

A THREE-DIMENSIONAL CALCULUS MODEL OF URBAN SETTLEMENT

Edgar M. Horwood 143

ELECTRONIC MAPPING RESEARCH AND DEVELOPMENT

Edgar M. Horwood and Clark D. Rogers 147

A THEORETICAL PREDICTION OF WORK TRIPS IN THE MINNEAPOLIS-ST. PAUL AREA

Robert T. Howe 156

DETERMINATION OF O-D ZONES BY MEANS OF LAND-USE DATA

L.W. Kerr 182

USE OF PRE-INTERVIEW TRIP CARDS IN DEVELOPING A TRAFFIC MODEL FOR THE HAMILTON AREA TRANSPORTATION STUDY

Walter Kudlick and Ewen S. Fisher 186

THE DATAPLOTTER—A TOOL FOR TRANSPORTATION PLANNING

Gene Letendre and George V. Wickstrom 203

EVALUATING THE REQUIREMENTS FOR A DOWNTOWN CIRCULATION SYSTEM

Robert L. Morris 211

CORRIDOR ANALYSIS OF TRAVEL DESIRES AS UTILIZED IN MAJOR STREET PLANNING

John W. Guyton and W. S. Pollard, Jr. 222

FORMING A COMPREHENSIVE TRANSPORTATION FLOWS MODEL

Anthony R. Tomazinis and George V. Wickstrom 254

CAPACITY RESTRAINT IN MULTI-TRAVEL MODE ASSIGNMENT PROGRAMS

N.A. Irwin and H.G. von Cube 258

TRAVEL MODE SPLIT IN ASSIGNMENT PROGRAMS

D.M. Hill and Norman Dodd 290

A SURVEY OF THE LITERATURE ON INTER-COMMUNITY TRAFFIC

George T. Marcou 302

Traffic Patterns and Land-Use Alternatives

ALAN M. VOORHEES, Alan M. Voorhees and Associates, Inc;
CHARLES F. BARNES, Jr., Automotive Safety Foundation; and
FRANCIS E. COLEMAN, Connecticut State Highway Department

• FOR SOME TIME it has been recognized that travel in urban areas is related to the land-use activities in these areas. It is logical to expect, then, that transportation requirements are influenced by the way the land-use activities are arrranged in the metropolitan area.

It has also been brought out in the past, particularly by studies made in the Baltimore area, that average trip length increases as transportation service improves. For example, in 1926 the average work trip length in the Baltimore area was 2.6 mi; in 1946 it had increased to about 4 mi; and today it is over 5 mi. This continued increase in trip length is attributable, in a large degree, to the improved transportation service in the Baltimore area (1).

The key point is that the average trip length directly affects the transportation requirements. Given a substantially fixed number of trips, trip length dictates the vehicle-miles of travel on the street system. If the average trip length could be halved, the vehicle-miles of travel and the traffic volume would, in effect, also be cut in half.

From a transportation point of view, to reduce trip length and therefore travel, it is essential to know what factors influence trip length and to understand how these factors work.

Some authorities feel that the reduction of transportation requirements is not the primary objective, believing that the important thing is an increase in mobility, per se. However, if increased mobility does not provide additional service, it holds no advantage. There is no benefit in traveling seven miles to work rather than five unless the job opportunities or choice of residence are increased thereby. On the other hand, if it is possible to reduce the average trip length, while providing similar opportunities, the city in fact has been made more convenient. Here certainly is a worthwhile objective.

This paper therefore attempts to describe (a) what factors influence trip length, and (b) what can be done to minimize trip length and thereby reduce urban transportation requirements.

FACTORS INFLUENCING TRIP LENGTH

Several attempts have been made recently to quantify the relationships between level of service and land-use arrangements on one hand, and average trip length on the other. Because it is practically impossible in an actual field test situation to isolate all the variables present in order to obtain a comparable analysis, most of these studies have been based on the use of mathematical models. In this approach, mathematical formulations are developed to simulate conditions under various assumptions of land use and transportation system arrangements.

The most recent of these attempts is the Hartford Area Transportation Study, conducted cooperatively by the Connecticut Highway Department, the City of Hartford, the Capitol Region Planning Agency, and the U.S. Bureau of Public Roads (2, 3). By use of the gravity model for traffic simulation and an urban growth model to simulate land-use development, projections were made of land use and traffic under several different sets of assumptions.

With additional data from similar analyses made during the Baltimore-Washington Interregional Study (4), it is now possible to state with fairly firm conclusions the interrelationship between land-use arrangements, level of transportation service, and vehicle-miles of travel.

Level of Transportation Service

In the Hartford Area Transportation Study, projections of land use and traffic were made for the years 1965, 1975, 1990, and the horizon year (5). The land-use projections were made under the assumption that the forces presently shaping the urban area (zoning, economic and political factors, etc.) would continue into the future with no substantial change. In effect, it was considered that the growth of the urban area would continue in the future much as it had in the past—the only exception being a greatly expanded freeway system, resulting in a higher level of transportation service. From the traffic analyses for these various land-use patterns it was evident that the growth of traffic was greater than the growth of population, car ownership, or any other factor.

For example, it is estimated that between 1960 and 1975 the population will increase 37 percent, car ownership 61 percent, and vehicle trips 57 percent. However, in this same period, vehicle-miles of travel will increase an estimated 99 percent. It is evident that the major part of the vehicle-mile increase is associated with average trip length, which it is estimated will increase 34 percent during this period. Because this increase is based on a continuation of the existing land-use pattern it must be the result of changes in the transportation system.

Furthermore, by relating the trip-length increase comparatively to desire line and network assignments, it is possible to determine that about 10 points of the 34 percent increase is associated with out-of-direction travel, the other 24 points being due strictly to better transportation service.

Parenthetically, engineers for many years have been adding a factor onto traffic forecasts to reflect unexplained but measurable increases. These increases, generally termed "induced" or "generated" traffic, have ranged from about 25 to 50 percent, depending on the change in level of service, with the usual figure being about 30 percent. This, of course, is very close to the increase observed in the Hartford analyses.

The conclusion that trip length and level of service are interrelated confirms the findings of other work in this field (6). However, by using a model approach it is possible to predict with considerable accuracy the extent of the change in vehicle-miles of travel as the level of service is raised.

Land Use

Various studies have pointed out that, through the proper arrangement of land uses, travel requirements could be materially reduced. For example, the high-density residential development near high-density employment centers should cut the volume of work travel. Two recent investigations, the Baltimore-Washington Interregional Study and the Hartford Area Transportation Study, have undertaken projects to measure, quantitatively, the effect of alternative land-use developments on the regional transportation system requirements.

Regional Approach.—The Baltimore-Washington Interregional Study, in an effort to determine the influence that regional land-use patterns have on urban travel, analyzed four different alternatives and made separate projections of population and employment for each alternative. The land-use projection was made on the basis of an urban growth model, developed in connection with this study; and a traffic model, similar to the one used previously in the Baltimore area was used for estimating travel desires. The alternatives considered were the following:

1. Extension of existing planning policies in the area.
2. Policy revision that would permit a doubling of suburban residential densities while holding constant the densities of existing built-up areas.
3. Establishment of a policy specially designed to encourage high-density development in the central cities and along a theoretical transit system between Baltimore and Washington.
4. Establishment of a regional policy to disperse new employment whenever possible.

The chief conclusion drawn from the traffic analysis of these alternatives is that general changes in land-use patterns in the outer areas will not have a substantial impact on peak-hour highway demands. Peak-hour traffic as projected in the first alternative (the continuation of existing trends) would be reduced only a few percentage points by following the second or fourth alternatives. But by following the third alternative, involving radical changes in density and highway capacity restrictions in the downtown area, really substantial reduction in auto travel could be brought about. However, the bulk of the reduction in auto travel that might be gained with the third alternative is attributable to greater use of transit. The length of the average work trip was about the same for all four alternatives. This means that if a rapid transit system is built in keeping with the third alternative, increases in employment and population densities along these routes will cut auto travel. The remarkable similarity of trip lengths between the various alternatives tested in Baltimore and Washington are especially significant because the plans tested were quite different in nature.

It would appear that this finding stemmed from the fact that large zones were used. Quite often the travel time between zones was in the neighborhood of 10 min. Therefore, the different patterns that were analyzed in Baltimore and Washington were related largely to land-use activities more than 10 min apart. As can be seen by the travel time factors used in the gravity model calculation (Fig. 1), the curves have a moderate slope beyond 10 min, whereas for travel time of less than 10 min the curves are very steep.

It is apparent from these curves that travel time is relatively critical for zones that are located less than 10 min apart whereas travel is comparatively independent of travel time for zones over 10 min apart. For example, a 2-min change in travel time orientation, say in, the 0- to 10-min range, will have a great effect on the number of trips between zones. On the other hand, a 2-min change in the travel time on the flatter portions of the curve, say in the 30- to 40-min range, will have a rather insignificant effect. Hence, the most important relationships in land-use patterns, as they affect travel requirements, are those within 10 min of each other.

The Hartford analysis differed from the Baltimore-Washington study in the method of developing the alternative test plans. Rather than accept the rational restraints imposed by the use of an urban growth model, alternative land-use patterns were simply

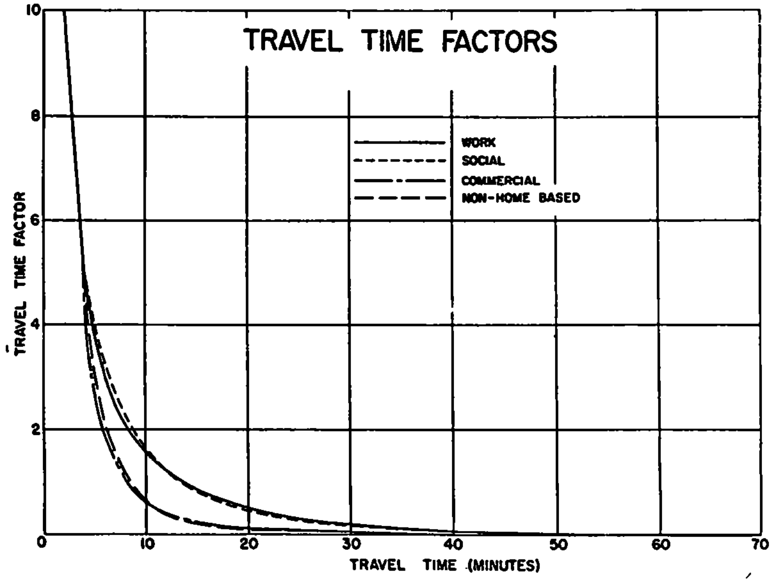
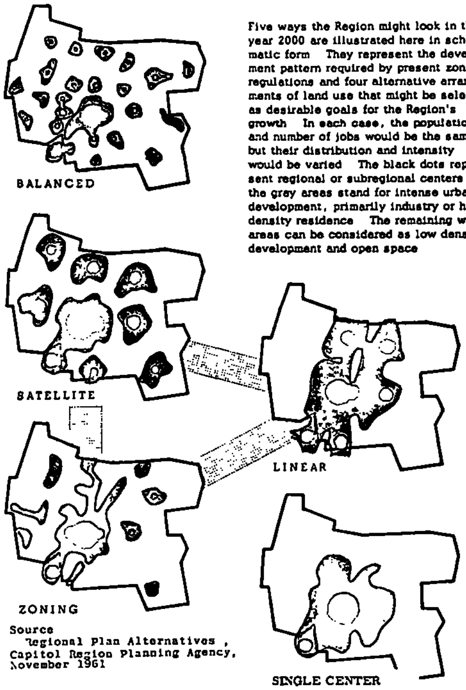


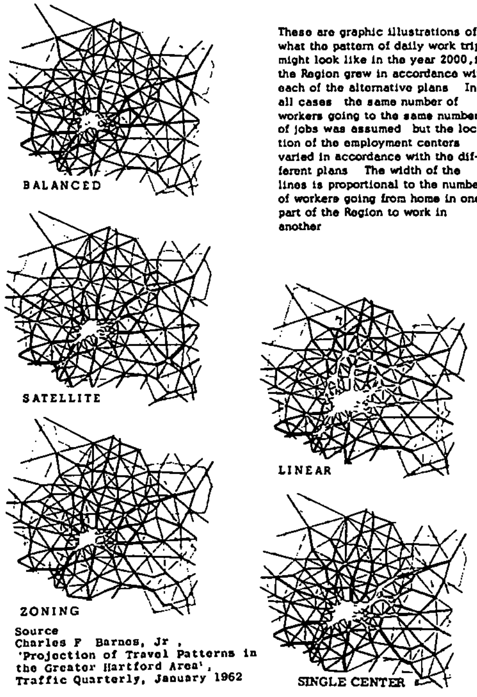
Figure 1. Travel time factors.



Five ways the Region might look in the year 2000 are illustrated here in schematic form They represent the development pattern required by present zoning regulations and four alternative arrangements of land use that might be selected as desirable goals for the Region's growth In each case, the population and number of jobs would be the same but their distribution and intensity would be varied The black dots represent regional or subregional centers and the gray areas stand for intense urban development, primarily industry or high density residence The remaining white areas can be considered as low density development and open space

Source
Regional Plan Alternatives ,
Capitol Region Planning Agency,
November 1961

Figure 2. Alternative land-use plans.



These are graphic illustrations of what the pattern of daily work trips might look like in the year 2000, if the Region grew in accordance with each of the alternative plans In all cases the same number of workers going to the same number of jobs was assumed but the location of the employment centers varied in accordance with the different plans The width of the lines is proportional to the number of workers going from home in one part of the Region to work in another

Source
Charles F Barnes, Jr ,
'Projection of Travel Patterns in the Greater Hartford Area',
Traffic Quarterly, January 1962

Figure 3. Circulation patterns.

assumed to achieve the widest possible difference between the plans. No attempt was made to arrive at realistic plans.

For this phase (Phase I) of the study, special emphasis was placed on new employment and the work trip patterns. The new employment was distributed into five distinct land-use patterns, shown in Figure 2, but the population distribution was the same in all five plans. The plans were developed in sufficient detail to calculate the input necessary for the traffic model computations.

The travel patterns, (Fig. 3) developed by use of the traffic model and assigned to identical desire-line networks, showed a 22 percent difference between the Single Center land-use concept, the most dense plan of development, and the Balanced Community concept, the least dense plan (Table 1).

The fact that the basic difference between the Baltimore-Washington and the Hartford studies was that the former balanced employment and labor force through model techniques and the latter did not (and that the results were different) strongly indicates that the relationship between population and employment has an important impact on traffic demand. In fact, it would appear that in the development of any land-use plan a thorough attempt should be made to coordinate population and employment patterns. This can best be achieved by the use of an urban growth model or some other analytical procedure based on historical analysis.

Subregional Approach. —Because it was apparent that the greatest reduction of travel can be accomplished by the careful distribution of land uses within the subregional structure, both studies undertook careful analyses on this basis.

TABLE 1
AVERAGE TRIP LENGTH RELATIONSHIPS, PHASE I

Study Plan	Trip Length Relative to Existing Zoning
Balanced Community	0.92
Existing Zoning	1 00
Satellite	1 01
Linear	1 11
Single center	1.14

The Baltimore-Washington study explored a series of subregional land-use designs by use of the gravity model. However, instead of developing trip lengths for this series of plans, only the ΣAB's were used (7). The change in ΣAB between plans, when compared with the average trip length for the region and subregion, indicates the change in average trip length that would be brought about by the particular plan. This type of test is quite simple and easy to carry out and provides an effective means of evaluating transportation needs related to many different subregional plans.

This line of analysis revealed that there are several ways to decrease auto travel through sound local planning:

1. By arranging land use so that apartment house development and high-density employment areas are closely tied together, a reduction in auto travel of between 5 and 10 percent is possible.
2. Development of housing for a wide range of income groups within 10 min of large employment centers will further cut auto travel. The greatest impact here comes from reduction of work trip length. It is possible to achieve a 10 percent reduction in work trip lengths by this technique alone.
3. Develop the street patterns in the outlying areas that focus on potential commercial centers where heavy concentrations of employment may be located. This can reduce peak-hour travel nearly 5 percent. This approach, in effect, tends to create communities, and has the advantage of discouraging dispersion of retailing and commerical activities. It will increase the accessibility of certain centers and thereby encourage their growth.

By and large, then, it appears that by proper arrangement of land-use and street patterns into communities having a variety of housing types, it is possible to reduce peak-hour travel about 20 percent.

In light of the Baltimore experience, the Hartford study undertook a more detailed analysis of possible land use alternatives. In this phase (Phase II), further consideration was given the three most promising of the original plans—the Satellite, Linear, and Zoning concepts. The approach differed from the original in two major respects. First, the freeway and arterial street plans were developed for each of the plans. Secondly, actual subregional centers were developed for each plan, with attention given to the following factors found important in the Baltimore-Washington work: (a) the travel time relationship between high-density residential areas and the employment areas; (b) a balance of workers and employment in each subregional center; and (c) the basic arterial street plan to insure that the best possible access was supplied to each center from the surrounding residential areas.

The results of this work showed a substantial reduction in travel over the plans tested in Phase I. For the Linear and Satellite plans this change was quite significant. The trip lengths, reported on a percentage basis, are shown in Table 2.

Of even greater significance in understanding the underlying concepts are (a) the relative changes that resulted and (b) the fact that there was very little difference between the three Phase II test plans. On reflection, this is not surprising.

The small relative difference in average trip length between the Phase II plans can be explained by the fact that the same basic criteria were used in the development of the subregional centers. It could be argued that the Linear concept is actually a satellite plan with the satellites arranged linearly. Because these urban clusters or subregional centers are quite similar in design, yet distinct and more or less isolated, the traffic developed by the individual centers and therefore by the whole region should be quite comparable.

TABLE 2

AVERAGE TRIP LENGTH RELATIONSHIPS, PHASE II

Study Plan	Trip Length Relative to Existing Zoning
Linear	0 96
Satellite	0 97
Existing Zoning	1 00

In Tables 1 and 2, the change in relative position of the Phase I and Phase II plans is likewise logically explained. For Phase I, the Linear concept was based on a more or less continuous pattern of development, with spots of high-density development but no real attempt at discontinuity by the use of low-density land development. By comparison, the Phase II plan was developed as a discontinuous region and therefore it converted a great many of the longer inter-subregional trips into shorter intra-subregional trips. Discontinuous development was present in both phases of the Satellite concept, resulting in a relatively smaller change.

The change in trip length for the two phases of the Existing Zoning concept was less than that for the Satellite and Linear plans because the subregional centers were less well developed.

Analysis of the traffic related to the various alternatives indicates that certain plans create traffic problems in different sections of the region. For example, it is likely that the Existing Zoning concept would create severe traffic problems in the vicinity of the downtown area, whereas the Linear plan would create traffic problems in the area north of Hartford, and the Satellite plan would cause overloading on some sections of the circumferential routes. This merely emphasizes that in using the approaches outlined in this paper for the selection of one land-use alternative over another, the problems involved in handling the traffic related to each alternative must be given careful consideration.

MINIMIZING TRIP LENGTH

The results of the model analyses conducted in the Baltimore-Washington and Hartford regions indicate that substantial reductions in auto travel can be achieved by logical grouping of land-use and street arrangements in selected areas throughout the region. An illustration of how these areas should be planned and designed is shown in Figure 4, which depicts a plan that has been developed for an area southeast of Baltimore. This area is planned to accommodate 200,000 people and applies the criteria outlined in this paper. It has a strong center located at the junction of one freeway and several important arterial streets that focus on this center. Adjacent to this center and closely associated with some of the high density industrial areas are high-density residential areas and the whole area containing a variety of housing types.

Size of Subregions

Another question explored by these studies was how large these urban clusters should be. An analysis was made of urban travel habits to determine the travel patterns of a typical suburb. On the assumption that travel habits reveal people's preferences, this study indicated that the primary field of interest of the adult suburbanite is within 10 min of home. In today's suburban development, a 10-min radius typically includes about 100,000 people. Such an area appears to be adequate to support the stores, shops, and services that are required by most individuals. In other words, it takes at least 100,000 people to support the variety of stores and services that are demanded by the average citizen.

This pattern is revealed by an evaluation of travel patterns for several different sized areas throughout the country (see Fig. 5). For example, in a small community in San Diego containing about 7,000 people, it was found that only 12 percent of the trips made by the residents stayed within the area. This area had all the stores and activities that normally could be supported by 7,000 people. Similarly, for a community of 28,000 people, in the same region, only 27 percent of the trips made by the residents stayed within the area. This community had the full range of stores and community services usually supported by such a population.

On the other hand, in the Bethesda area, just outside the District of Columbia, an area containing about 80,000 persons, it was found that about 60 percent of all auto trips made by residents stayed within the area. Futhermore, if the boundaries of Bethesda are extended to include adjacent jurisdictions, the proportion of trips staying within the area is increased only slightly. Thus, it appears that most people demand the range of stores and services found in a region of 100,000 population. However,

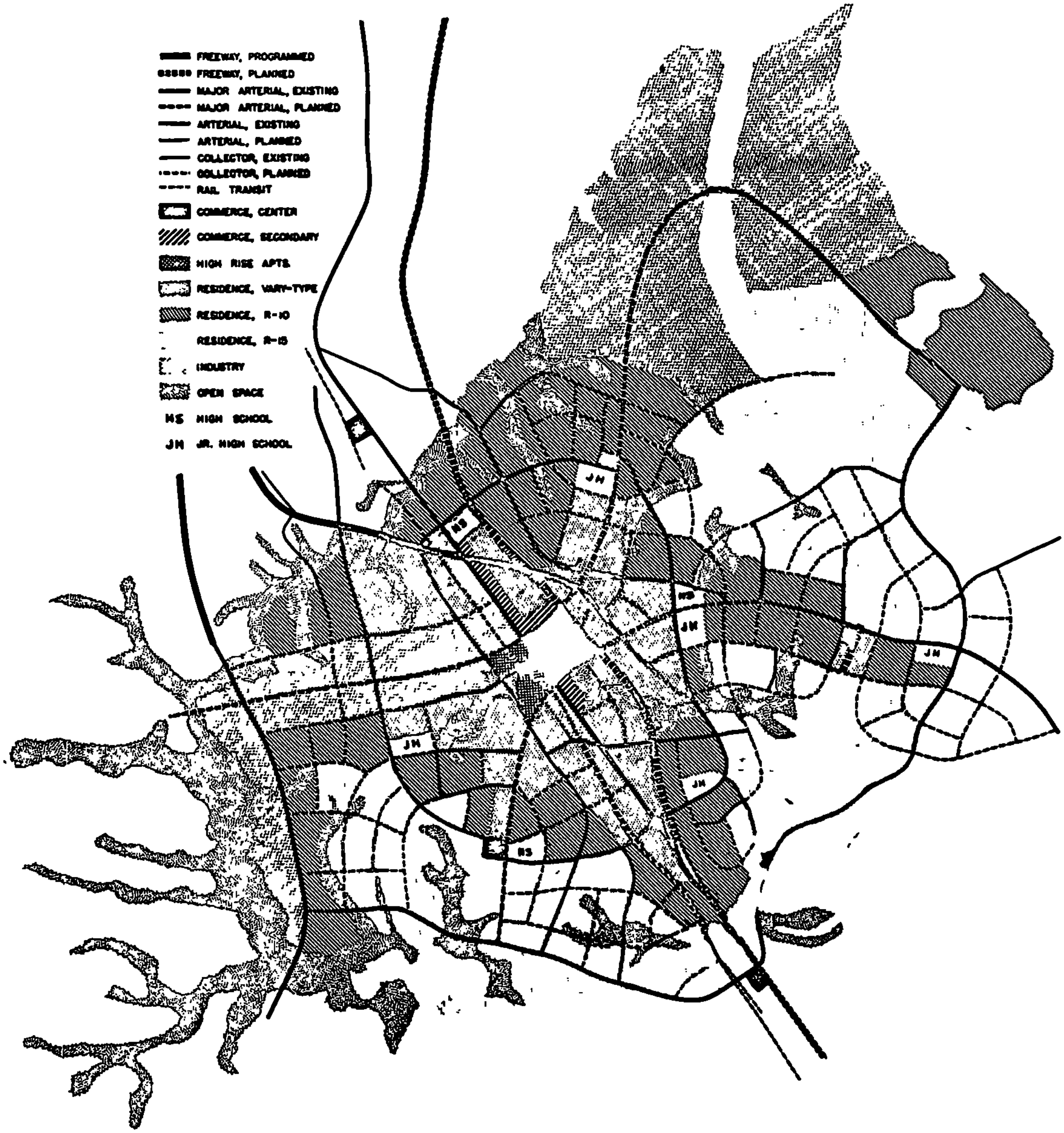


Figure 4. Typical subregional center.

they will go outside of such a region for work purposes and occasional shopping, recreational and social trips.

The curve shown in Figure 6, theorized on the basis of these facts, attempts to point up the interrelationship between community size and transportation cost. Communities below a size of 100,000 persons cannot support the shopping and job opportunities demanded by the majority of the population. This necessitates a large proportion of trips, of all types, outside of the immediate area to satisfy personal needs. As communities grow in size, they can support an increasingly higher percentage of the specialities required for daily living, and a proportionately greater percentage of trips remain within the community.

However, in communities with a single center population exceeding 150,000 or

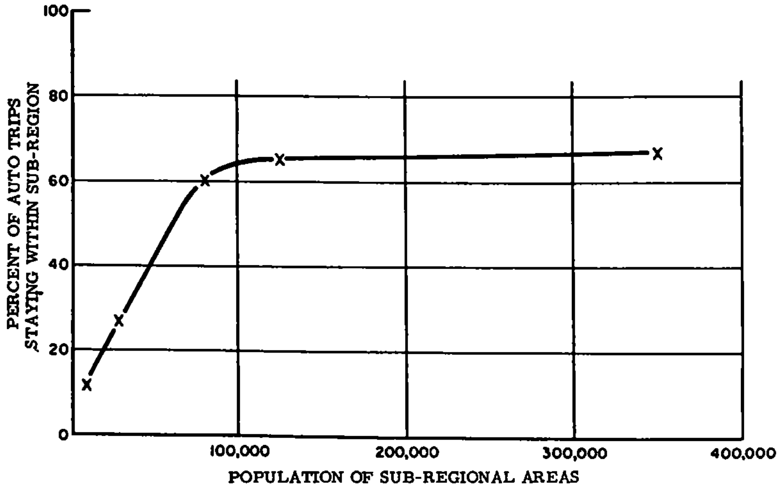


Figure 5. Effect of size of subregional areas on trip length.

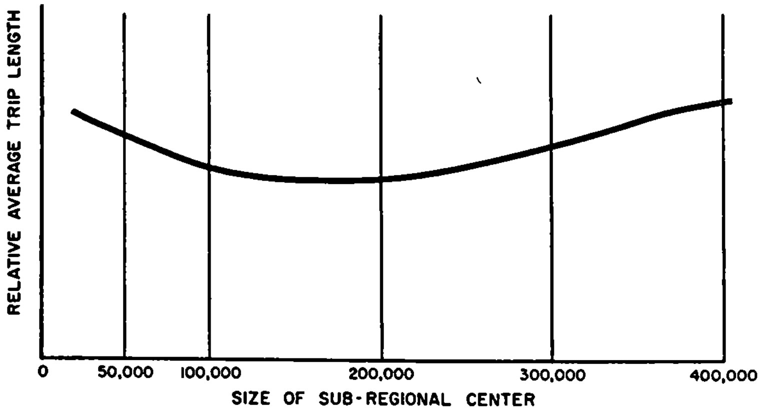


Figure 6. Theoretical relationship between size of subregional center and average trip length, Hartford Area Transportation Study.

200,000, there is a steady drop in the percentage of people who can live within reasonable proximity to their job and shopping opportunities. This forces a general increase in the average trip length, as indicated by the Single Center trip length reported in Table 1.

SUMMARY AND CONCLUSIONS

From these studies it is evident that land use, including transportation, has a marked effect on transportation requirements. This paper has highlighted several, apparently more important factors involved and has indicated the effect that each seems to have on transportation requirements.

It has been shown that vehicle-miles of travel are associated with level of service, and that as level of service rises the vehicle-miles of travel will increase in proportion.

It has also been shown that travel can be minimized by the judicious arrangment of future land use, and that the key factors are as follows: (a) high density residential development must be located within close proximity (10 min or less in travel time) of the high-density commercial and industrial areas; (b) the housing must provide a wide range of types that will attract a diversity of social and economic groups; (c) the street and highway system should be laid out to encourage centralization on the urban center, (d) the development of subregional centers should be encouraged, with populations ranging in the order of 100,000 to 200,000; and (e) the subregional centers should be as distinct and isolated from one another as the natural topography and existing development patterns will permit.

These forces, if utilized to the ultimate, can produce a reduction in travel requirements of 20 percent or more, compared with prevailing patterns of land development. Equally important, this can be accomplished without decreasing the range of job opportunities or the selection of housing types, and hence results in a much more convenient and livable city.

In conclusion, this paper demonstrates that different patterns of land use and transportation have a profound effect on travel. These differences are of a magnitude that can "make or break" the tranportation plan, and it is therefore vital in the development of a regional plan that the interplay between land use and transportation be recognized and given due consideration. Tools are available, today, to measure the impact of various plans quantitatively. It is of the first importance that these tools be employed to aid in the recognition of these differences during the development of the regional plan.

REFERENCES

1. Voorhees, A.M., "Forecasting Peak Hour of Travel." HRB Bull. 203 (1958).
2. "Regional Plan Alternatives." Capitol Region Planning Agency (Nov. 1961).
3. Barnes, C.F., Jr., "Projection of Travel Patterns in the Greater Hartford Area." Traffic Quarterly (Jan. 1962).
4. "Baltimore-Washington Interregional Study—Land Use and Transportation." Baltimore Regional Planning Council; National Capitol Regional Planning Council, (Nov. 1960).
5. Barnes, C.F., Jr., "Integrating Land Use and Traffic Forecasting." HRB Bull. 297 (1961).
6. Schmidt, R.E., and Campbell, M.E., "Highway Traffic Estimation." The Eno Foundation for Highway Traffic Control, Saugatuck, Conn. (1956).
7. Wiant, R.H., "A Simplified Method for Forecasting Urban Traffic." HRB Bull. 297 (1961).

Application of Systems Engineering Methods to Traffic Forecasting

W.L. GRECCO, Professor of Civil Engineering, University of Pittsburgh; and
S.M. BREUNING, Associate Professor of Civil Engineering, Michigan State University

Systems engineering techniques can be used in predicting trip distributions in urban road networks. To deal quantitatively with the interaction of components, each component must be describable mathematically and must be incorporated into the system in accordance with the requirements of linear graph theory. If the traffic system components can be identified, the traffic problem can be solved.

This paper discusses the principles of linear graph theory and the general requirements for using these methods. The most significant contribution comes from applying these techniques to traffic interchange. By using a hypothetical community, the techniques of systems engineering are compared with the gravity model and the electrostatic model for predicting the distribution of work trips.

• THE WORK described in this paper shows the application of systems engineering techniques to a traffic distribution problem. This method is a rigorous technique for computing the system of traffic flow in a road network. Precise and balancing results are obtained in one step by this method. Systems engineering techniques thus offer an extremely powerful tool for the analysis of systems when the system components and their measurements are adequately defined. This technique will be even more powerful when a computer solution for the routine matrix evaluation becomes available. It is excepted that this technique will not only be refined for application to traffic flow computation but will also be used for the analysis of other traffic engineering system problems.

BACKGROUND

The trend in the many studies of traffic engineering is toward a more mathematical and theoretical approach. This fact is evidenced by the writings of Herman, Schneider, Howe, Bevis, and others. One has only to refer to the bibliography of the special report by Haight (1) to conclude that traffic engineering is on the verge of a breakthrough. In spite of the as yet uncontrollable element of human choice or behavior, many phases of the traffic problem will evolve to a scientific level comparable to that of the physical sciences. The traffic engineering profession will probably have to settle for somewhat less replicability than the physical sciences because only two of their ingredients are physical, the vehicle and the facility, whereas the third, the user, presents different and still unsolved problems. This does not imply that the user problem is insurmountable. Although the individual has shown immunity to prediction, groups of many such individuals have shown that patterns can be observed.

Evolution has come to the other sciences by a slow but orderly progression. First, trial and error techniques were used and the effects were noted. The practitioner, who was faced with a series of difficult tasks, slowly added to his store of engineering judgment, and this he utilized on future problems as they developed. This was followed by a concentrated effort to collect and evaluate data. Analysis of data in the field of traffic flow has shown that groups of people are predictable and that mathematical formulas can be developed to express various travel habits and patterns. In the last stage of this evolution, the theory is established. In other fields, new theories have been developed by building on the terminology and theories defined previously and by critically analyzing the work of others in order to find a more direct approach.

So far the traffic theorists have concentrated their work on car-following theory, queuing and waiting line theory, and traffic simulation. Some work dealing with techniques such as the gravity model, the opportunity model and linear programing has been done in the area of theoretical origin and destination studies.

The work reported in this paper deals with development of a methodology for solving traffic flow in a road network by a mathematical model. The necessary preliminary theoretical testing of systems analysis as a technique for theoretical origin and destination studies has been accomplished during the study, but many simplifying assumptions were necessarily made. The theoretical results obtained with this technique are shown to compare encouragingly well with those available with other techniques. In the analysis of systems as a means for achieving a simple systematic procedure for formulating the system equations, the theory of oriented linear graphs, developed as an abstract mathematical topic, is valuable. Because the work with this technique is in its early stages, primary attention in this paper is given to the network description and only secondary consideration to the characteristics of the basic data.

The next step in the continuing research under way at Michigan State University will utilize these established concepts of systems engineering for predicting traffic flow in actual urban road networks.

SYSTEMS ENGINEERING THEORY

The techniques presented here have sometimes been referred to as "linear graph theory" and "network topology." These terms can be used interchangeably (2). A system can be defined as an orderly arrangement of interrelated elements acting together to achieve a specific purpose. Thus a system must have an avowed purpose, be free of extraneous or mathematically redundant parts, and have the elements or components joined in an orderly fashion. Discussion here is limited to systems made up of components having only two terminals, although there is no limit on the number of terminals the component may have in general systems theory.

For the computation of the system characteristics two steps are necessary:

1. To establish a mathematical model of the relevant physical characteristics of the system components expressed in terms of measurements.
2. To establish in mathematical form and in terms of measurements from a knowledge of the component characteristics and their mode of interconnection, the characteristics of the system; i.e., a mathematical model of the system.

Components are described mathematically by relating two measurements of the component in "isolation" from other components. (For a more detailed explanation see Appendix.) These measurements must be such that one is a "through" (or series) measurement called y, which when summed at each vertex must equal zero, and the other is an "across" (or parallel) measurement called x, which when summed around each circuit must equal zero. The relationship between measurements x and y is expressed mathematically and called the terminal equation of the component. The component is represented by an oriented line segment called the component terminal graph. The collection of component terminal graphs obtained by joining the vertices of each terminal graph in a one-to-one correspondence with the union of the physical components is called a system graph.

A "tree" is selected and the elements of the system graph are classified into either branches of the tree or chords. The "vertex postulate" or the "circuit postulate" is then applied to the system graph to establish the graph equations. The graph equations along with the terminal equations of the system components are defined as the system equations. The system equations represent a complete mathematical description of the system. These simultaneous equations are independent and can now be solved.

APPLYING TECHNIQUES TO TRAFFIC FLOW COMPUTATION

Although the techniques of system analysis were developed primarily in electrical network analysis, during the past several years this fundamental discipline of analysis has been applied usefully to many other areas, such as mechanical, hydraulic, and heat-transfer systems. Predicting traffic flow in an urban network also seems amenable to this technique, if the characteristics of the traffic problem can be defined in the form of suitable components and measurements which can be assembled into workable system graphs. The following discussion demonstrates how systems analysis can be applied to the traffic problem.

The selection of the units that will serve as components depends first on what type of system is being analyzed (i.e., transportation, sewage treatment, electrical, etc.), and second, on the specific question to be answered by the analysis of the system. For example, in the study of mass transit, the definition of components and measurements for a study of the system of service areas would probably be different than the definitions for a study of the effect of street capacities on the system.

In selecting the components for the system analysis of traffic flow in a road network it seemed at first feasible to consider the user, the vehicle, and the facility. "User" can be defined as one individual. An individual moves from place to place and this movement could be defined as flow or "through" variable (y). This movement or flow is related to a desire or "pressure" which can serve as the across variable (x). However, analyzing traffic flow on the basis of the individual user would lead to systems far too voluminous and too difficult to evaluate. Considering the vehicle as a basic component, a y measurement could be assigned to flow, but the x variable as desire or pressure is meaningless for a vehicle.

The dwelling unit and the family are the next possible basic components inasmuch as they combine the user and the vehicle. Both will afford the same x and y measurements as suggested for the individual. But even for the smaller urban areas, the number of dwelling units and families involved in the system would still be too large to provide a workable model, so that it will be more desirable to use even larger units, such as zones.

A zone, similar or identical to those used in origin and destination surveys, seems to be the best component evaluated to date. These zones should be defined so that the traffic characteristics within the zones are as homogeneous as possible. It is now assumed that the traffic characteristics of the entire zone can be computed from a limited number of parameters. For example, given a homogeneous residential zone containing a certain number of dwelling units or families and with known parameters such as residential density, income level, and car ownership, one should then be able to establish some value that would express the desire or pressure of that zone to generate a number of trips for a specific purpose. This pressure to make the trips from the given residential area to, say, the central business district (CBD) must be large enough to overcome the resistances against making these trips. The resistance is generated by the previous experience of traveling to the CBD, of parking difficulty and general congestion while in the CBD, and of returning home. If the pressure is not sufficient the trips will not be made. The number of trips that will be made is a function of pressure and resistance.

Research thus far has indicated that in the theoretical computation of traffic flow the classification of trip generation by trip purpose is essential. The percentage of trips assignable to each purpose seems well established. Further studies beyond those cited in the references (3) have proved that there are only very small variations in the percentages within classes of trips according to purpose. Accordingly, if it is assumed that in computing, say, shopping trips from a zone, one of the following three values can be determined from parameters, estimates, or in some other way:

1. Actual flow of shopping trips out of the zone in a given time period: y (t) or
2. Demand or pressure for such shopping trips to be made from the zone: x (t) or
3. Relationship between demand and flow; i.e., the function relating x and y:

$x = f(y(t))$ or $y = f(x(t))$,

then to solve the distribution problem of the trips generated in the zones, parts of the street network also must be defined as components with measurements suitable for systems analysis. In the preliminary stages only major arterials have been considered. Later developments might prove that, between any two zones, each group of streets of a specific type should be defined as a component with certain characteristics. Also, intersections might serve as separate components. The required x and y measurements could reflect such items as posted speed limit, parking, abutting land use, etc.

In the example to be discussed in the next section, simplifications are made. All routes between two zones are represented by two street components, one for each direction. No attempt was made to determine an x or y measurement, but rather an R value is used where $x = Ry$. In this equation R represents a parameter that is the mathematical relationship between x and y. It defines the relationship between flow and desire and might be visualized as a function of resistance or friction. The best physical measurement to be used as a basis for R was determined, at this stage only on an empirical basis, to be travel time. Preliminary work has led to a group of curves where the value R is a function of travel time and dependent on trip purpose (Fig. 1). Each street is assumed to be one-way for proper orientation of the terminal graph. The streets may also be viewed as two-way, but then each direction is represented as a separate component. The curve used has been obtained by substitution of a resistance scale and plotting the "frequency of trips" table as reported by Carroll (4). Further examination of travel time vs trip purpose as indicated in some of the recent comprehensive studies should reveal a stronger correlation than the curves presently used. This point, as well as many others, will require considerable research.

Other possible components of the system are shopping areas, work or employment centers, the CBD, recreational areas, and others. Once again the component must be described mathematically by x or y, or by some relationship between x and y. Early trials have been limited to representing work trips to shopping areas and industrial areas, where a flow y has been estimated on the basis of number of employees. Other measures of an area's attraction will be considered in future research. A possible relationship might come from comparing the specific area with some accepted standard area, just as a resistor is calibrated by comparing it with some standard. This type of approach is similar to McGrath's work in New Haven, where trip attraction based on an effective acre is established as a standard (5). Other possible component measurements will be tried as the research progresses.

SAMPLE PROBLEM

As an example, a small hypothetical community where an origin and destination survey is not available is assumed. The specific problem to be solved here by means of linear graph theory is one of determining the distribution of work trips from each residential zone to each employment zone. Initially, the community is separated into residential zones and zones of employment. The labor force of each nearly homogeneous residential zone might be determined from planning studies or from records of the local Chamber of Commerce. Work trips might be approximated by a correlation equation using driving time to the CBD and an estimate of car ownership. The number of auto driver trips could then be estimated from an average car occupancy value. The number of auto driver work trips arriving at each employment zone could be established by some similar procedure or by a sampling of the known number of employees in that zone. An estimate of auto driving time between every pair of zones in question could be prepared by actual observation or from a travel time map. The validity of this approach is not the concern of this paper.

Regardless of the techniques use, it may be assumed that the following information has been obtained concerning the small hypothetical community. There are four residential zones with a specified number of auto driver work trips as given in Table 1. The number of work trips that arrive at each of the three employment zones is also given in Table 1. The number of trips destined for employment zone 7 (Element 1) is not defined, although it is clear that 3,000 trips must be destined for this zone unless there is an unbalance in the work trip generation vs attraction. The number has been

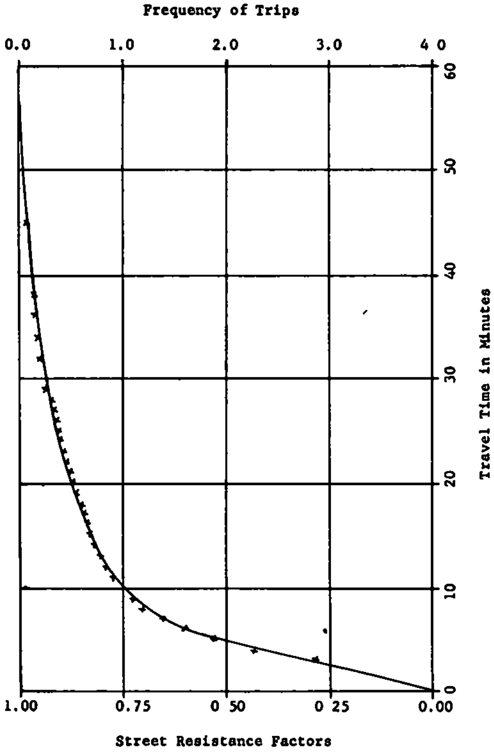


Figure 1. Travel time resistance for work trips.

TABLE 1

AUTO DRIVER WORK TRIPS TO AND FROM ZONES

Element	Zone	From	To
26	Res-1	4,000	--
27	Res-2	3,000	--
28	Emp-4	--	3,000
29	Emp-5	--	5,000
30	Res-3	2,000	--
31	Res-6	2,000	--
1	Emp-7	--	?

TABLE 2

TRAVEL TIMES BETWEEN ZONES IN MINUTES

1	28	29	Zones
10	10	14	26
17	14	10	27
10	17	14	30
14	20	10	31

left open in the table because the method of solution requires that this number be computed. The correct answer serves as a check on the computation.

The estimated travel times between the centroids of each zone are given in Table 2. The element number given for each zone is the number used for identification in the following analysis procedure.

The flow of trips completes a cycle in one day. Thus the time for which this analysis is made is a 24-hr period. Trips to work and trips home are identical in number but occur on different route components during different times of the day. The trips emanating from one zone also return to that zone during the study period.

Component Representation

Each zone is represented as a component part of the urban network and its measurements are shown in Figure 2.

Each residential zone, employment zone, and the system of routes that connect these zones can similarly be illustrated as components. Each component is represented as an oriented line segment which is referred to as the terminal graph of the component. For example, in Figure 2, a residential zone is shown schematically and as a terminal graph.

System Graph

With these components, the system graph can now be drawn in accordance with the following rules:

1. Components are joined in the system graph according to the manner in which the components are combined in the physical system.

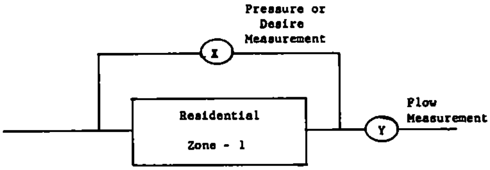
2. The direction of flow is indicated by the direction of the line representing the components.

3. A "tree" is selected. This tree is a subgraph of the system graph containing all vertexes but no circuits. The tree is used in formulating the systems equations.

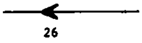
4. Specified desire (x values) are placed in the branches of the tree (B-1) (there are no specified x values here).

5. Specified flow (y values) are placed in the chord set, (C-2).

Figure 3a shows the system graph and how it is built; Figure 3b shows the tree chosen for this example. A tabulation of the values used as given measurements for the establishment and solution of this system is given in Table 3. In the matrix solution shown later, only R and y are used. The other parameters are given only for information. The relation between travel time and R was discussed and shown earlier in Figure 1.



Schematic of Component



Terminal Graph of Component

Figure 2. Component representation.

Circuit Equations

The numerical solution of the system requires the writing of a set of equations (in matrix form) which is done here in accordance with the circuit postulate of linear graph theory.

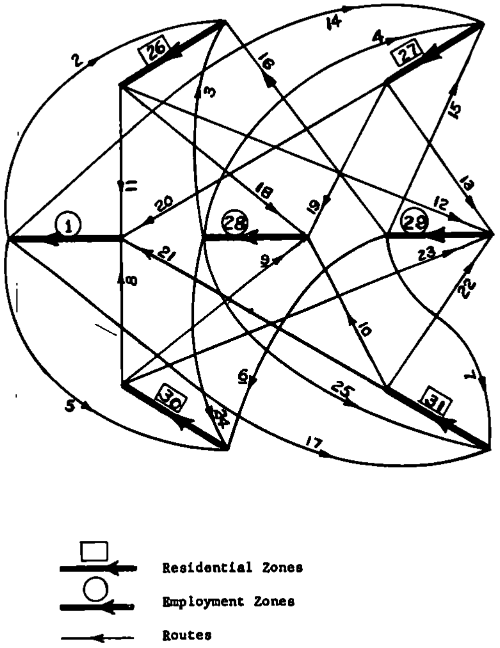


Figure 3a. System graph development.

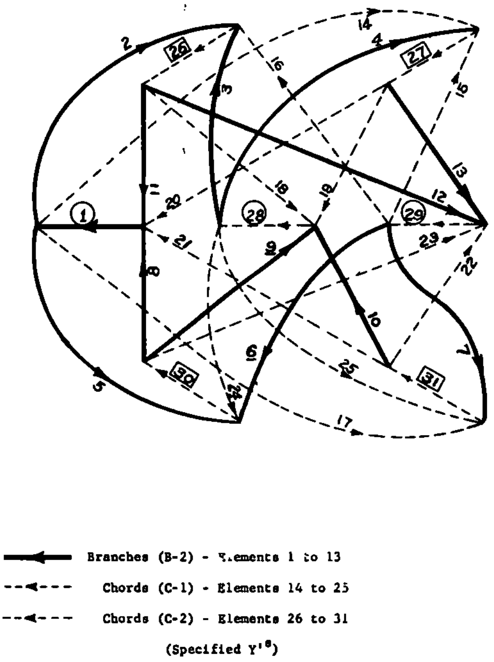


Figure 3b. System graph and tree.

TABLE 3

COMPONENT INFORMATION NECESSARY TO SOLVE THE LINEAR GRAPH

Element No.	Component	Travel Time (min)	Resistance Factor	Y (work trips)
1	Employment (I-7)	--	--	?
2	Street	10	0.7500	
3	Street	10	0 7500	
4	Street	14	0.8125	
5	Street	10	0.7500	
6	Street	14	0.8125	
7	Street	10	0 7500	
8	Street	10	0.7500	
9	Street	17	0.8450	
10	Street	20	0.8675	
11	Street	10	0.7500	
12	Street	14	0.8125	
13	Street	10	0.7500	
14	Street	17	0.8450	
15	Street	10	0.7500	
16	Street	14	0.8125	
17	Street	14	0 8125	
18	Street	10	0.7500	
19	Street	14	0.8125	
20	Street	17	0.8450	
21	Street	14	0.8125	
22	Street	10	0.7500	
23	Street	14	0.8125	
24	Street	17	0.8450	
25	Street	20	0.8675	
26	Residential (R-1)	--	---	4,000
27	Residential (R-2)	--	---	3,000
28	Employment (I-4)	--	---	3,000
29	Employment (I-5)	--	---	5,000
30	Residential (R-3)	--	---	2,000
31	Residential (R-6)	--	---	2,000

1. In accordance with the circuit postulate, the general equation for the k^th^ circuit is:

$$\sum_{j=1}^{e} b_j x_j = 0$$

in which

b_j = 0 if the j^{th} element is not included in the k^{th} circuit;

b_j = 1 if the orientation of the j^{th} element is the same as the orientation for the k^{th} circuit;

b_j = -1 if the orientation of the j^{th} element is opposite to the orientation of the k^{th} circuit.

2. Each circuit will have one and only one chord, and the circuit equations will be written in such sequence that a unit matrix results for the entries C-1 and C-2.

3. Equations using chords (C-1) are written first and chords (C-2) written last.

4. The x's are arranged in the column matrix in the following order X_{B-1}, X_{B-2}, X_{C-1}, and X_{C-2}.

5. The resulting matrix product is

$$\left[\begin{array}{ccccccccccccc|cccccccccccc|cccccc}
0 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -1 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -1 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & -1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & -1 & 0 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
\hline
1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
-1 & -1 & 1 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
-1 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
1 & 0 & 0 & 0 & 1 & -1 & 1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{array}\right]
\begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \\ x5 \\ x6 \\ x7 \\ x8 \\ x9 \\ x10 \\ x11 \\ x12 \\ x13 \\ x14 \\ x15 \\ x16 \\ x17 \\ x24 \\ x25 \\ x18 \\ x19 \\ x20 \\ x21 \\ x22 \\ x23 \\ x26 \\ x27 \\ x28 \\ x29 \\ x30 \\ x31 \end{bmatrix} = 0$$

$$\begin{array}{ccccccccccccc|cccccccccccc|cccccc}
\multicolumn{13}{c|}{\text{B-2}} & \multicolumn{12}{c|}{\text{C-1}} & \multicolumn{6}{c}{\text{C-2}} \\
1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 24 & 25 & 18 & 19 & 20 & 21 & 22 & 23 & 26 & 27 & 28 & 29 & 30 & 31
\end{array}$$

General Solution of Equations in Symbolic Form

$$\begin{bmatrix} B_{11} & B_{12} & U & 0 \\ B_{21} & B_{22} & 0 & U \end{bmatrix} \begin{bmatrix} X_{B-1} \\ X_{B-2} \\ X_{C-1} \\ X_{C-2} \end{bmatrix} = 0$$

$$\begin{bmatrix} B_{11} \\ B_{21} \end{bmatrix} \begin{bmatrix} X_{B-1} \end{bmatrix} + \begin{bmatrix} B_{12} & U \\ B_{22} & 0 \end{bmatrix} \begin{bmatrix} X_{B-2} \\ X_{C-1} \end{bmatrix} + \begin{bmatrix} 0 \\ U \end{bmatrix} \begin{bmatrix} X_{C-2} \end{bmatrix} = 0$$

Substituting $RY = X$ for X_{B-2} and X_{C-1}:

$$\begin{bmatrix} B_{11} \\ B_{21} \end{bmatrix} \begin{bmatrix} X_{B-1} \end{bmatrix} + \begin{bmatrix} B_{12} & U \\ B_{22} & 0 \end{bmatrix} \begin{bmatrix} R_{B-2} & 0 \\ 0 & R_{C-1} \end{bmatrix} \begin{bmatrix} Y_{B-2} \\ Y_{C-1} \end{bmatrix} + \begin{bmatrix} 0 \\ U \end{bmatrix} \begin{bmatrix} X_{C-2} \end{bmatrix} = 0$$

One of the key advantages of this type of analysis is the possibility of replacing certain unknown variables in an equation with a relation of known values. In the next substitution, the unknown Y_{B-2} are replaced by the known values Y_{C-2} (2).

$$\begin{bmatrix} Y_{B-2} \\ Y_{C-1} \end{bmatrix} = \begin{bmatrix} B_{12}^{T} & B_{22}^{T} \\ U & 0 \end{bmatrix} \begin{bmatrix} Y_{C-1} \\ Y_{C-2} \end{bmatrix}$$

which, when inserted, gives the main equation:

$$\begin{bmatrix} B_{11} \\ B_{21} \end{bmatrix} \begin{bmatrix} X_{B-1} \end{bmatrix} + \begin{bmatrix} B_{12} & U \\ B_{22} & 0 \end{bmatrix} \begin{bmatrix} R_{B-2} & 0 \\ 0 & R_{C-1} \end{bmatrix} \begin{bmatrix} B_{12}^{T} & B_{22}^{T} \\ U & 0 \end{bmatrix} \begin{bmatrix} Y_{C-1} \\ Y_{C-2} \end{bmatrix} + \begin{bmatrix} 0 \\ U \end{bmatrix} \begin{bmatrix} X_{C-2} \end{bmatrix} = 0$$

In this main expression, the bottom line of equations, dealing only with known values, does not contribute to the solution. With the top equation from the preceding, the general mesh form or circuit equation can be written:

$$B_{11} \cdot X_{B-1} + \left[B_{12} \cdot R_{B-2} \cdot B_{12}^{T} + U \cdot R_{C-1} \right] \left[Y_{C-1} \right] +$$

$$\left[B_{12} \cdot R_{B-2} \cdot B_{22}^{T} \right] \left[Y_{C-2} \right] + 0 \cdot X_{C-2} = 0$$

The first term is nonexistent in this case, because no X_{B-1} values exist in this problem. Furthermore, because the last term is multiplied by zero, it vanishes. The resulting equation for this problem is therefore

$$\left[B_{12} \cdot R_{B-2} \cdot B_{12}^{T} + R_{C-1} \right] \left[Y_{C-1} \right] + \left[B_{12} \cdot R_{B-2} \cdot B_{22}^{T} \right] \left[Y_{C-2} \right] = 0$$

Arithmetic Solution

Numerical computations with the previous equation will give the desired values for Y_{C-1}, the flow on the streets connecting the zones. Replacing the symbols by the actual matrix and solving the triple matrix product gives the resulting matrix equation in terms of R. Inserting the proper R values and reducing the matrix size where possible, gives the two matrix equations:

$$\begin{bmatrix} +3.1575 & +2.3125 & +0.7500 & +0.0000 & -1.5000 & -1.5000 \\ +2.3125 & +4.6250 & +2.3125 & -1.5625 & -2.2500 & -3.0625 \\ +0.7500 & +2.3125 & +3.1250 & -1.5625 & -1.5000 & -2.3125 \\ +0.0000 & -1.5625 & -1.5625 & +3.1250 & +0.7500 & +2.3125 \\ -1.5000 & -2.2500 & -1.5000 & +0.7500 & +3.0950 & +2.2500 \\ -1.5000 & -3.0625 & -2.3125 & +2.3125 & +2.2500 & +4.6800 \end{bmatrix} \begin{bmatrix} Y14 \\ Y15 \\ Y16 \\ Y17 \\ Y24 \\ Y25 \end{bmatrix} + 0 \cdot \begin{bmatrix} Y18 \\ Y19 \\ Y20 \\ Y21 \\ Y22 \\ Y23 \end{bmatrix} + \begin{bmatrix} -5437.50 \\ -8625.00 \\ -6187.50 \\ +1687.50 \\ +3750.00 \\ +4687.50 \end{bmatrix} = 0$$

$$0 \cdot \begin{bmatrix} Y14 \\ Y15 \\ Y16 \\ Y17 \\ Y24 \\ Y25 \end{bmatrix} + \begin{bmatrix} +3.0950 & +2.3450 & -0.7500 & -1.5950 & -2.3450 & -1.5000 \\ +2.3450 & +4.7200 & +2.3125 & -1.5950 & -3.1575 & -2.3125 \\ -0.7500 & -2.3125 & +3.1575 & +0.0000 & -1.5625 & -1.5625 \\ -1.5950 & -1.5950 & +0.0000 & +3.2750 & -2.4625 & +0.7500 \\ -2.3450 & -3.1575 & -1.5625 & -2.4625 & +4.7750 & +2.3125 \\ -1.5000 & -2.3125 & -1.5625 & +0.7500 & +2.3125 & +3.1250 \end{bmatrix} \begin{bmatrix} Y18 \\ Y19 \\ Y20 \\ Y21 \\ Y22 \\ Y23 \end{bmatrix} + \begin{bmatrix} -1595.00 \\ -2220.00 \\ -2125.00 \\ -1640.00 \\ -1765.00 \\ -0875.00 \end{bmatrix} = 0$$

These equations can now be solved directly by solving first for Y_{14} to Y_{25} and then for Y_{18} to Y_{23}. The solutions are given in Table 4.

Discussion of Systems Solution

The matrix manipulations and the arithmetic solution have only been sketched. A more detailed discussion of the steps taken and of the validity of the computation would have been too extensive for this paper, but these matters are explained in detail in the texts on this subject (2).

It might be argued at this point that a rather cumbersome algebraic procedure was used to solve a relatively trivial problem and that systems analysis for larger and more complex systems would be impossible to do manually. This is correct, but the extensive algebraic manipulations are an easy task for an electronic computer. The only reason for manually computing such a small example here is to demonstrate how such a problem can be worked. Michigan State University is presently developing a computer program which will solve these steps and produce the final answers directly from the given terminal and system equations.

A flow diagram of the solution showing the flow of trips to work only is given in Figure 4.

Comparison with Gravity Model

In this and the following sections the same sample problem is worked using the iterative processes called "gravity model" (6) and "electrostatic model" (7), respectively. Only the principal formulas used and the correction factors are repeated here.

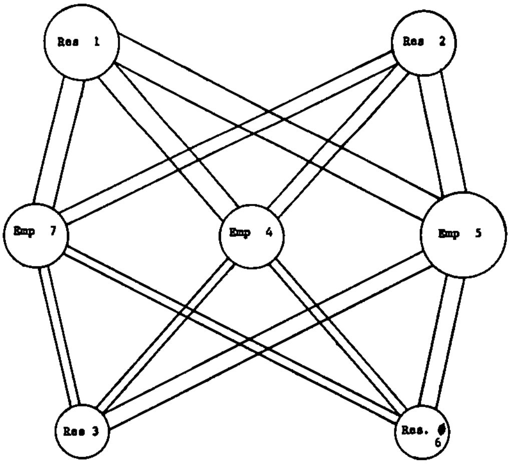
The results of the second estimate of the gravity model and of the fourth assignment of the electrostatic model are compared with the results obtained with systems engineering methods in Table 5. The difference of each flow line computation by the three methods is shown and expressed in percentages, assuming the systems solution as a basis.

$$T_{ij} = \frac{T_i \times T_j / (D_{ij})^x}{\sum_{1}^{j} T_j / (D_{ij})^x}$$

TABLE 4

WORK TRIPS OR FLOW THROUGH EACH ELEMENT

Element No.	Work Trips
1	3,000.00
2	1,199.10
3	1,215.40
4	825.08
5	536.13
6	973.54
7	1,044.91
8	536.13
9	490.33
10	469.19
11	1,199.10
12	1,585.50
13	1,396.05
14	778.87
15	1,396.05
16	1,585.50
17	485.90
18	1,215.40
19	825.08
20	778.87
21	485.90
22	1,044.91
23	973.53
24	490.33
25	469.19



Scale 1 inch = 5000 work trips

Figure 4. Flow diagram of work trips from four residential zones to three employment zones.

in which

T_i = number of auto driver work trips made from each residential area (i);

T_j = size of attractor represented by number of auto driver trips made to each industrial area (j);

D_{ij} = distance factor expressed in terms of travel time;

x = empirically determined exponent, assumed as 0.5.

Corrections in the first computation are made as follows:

1. A correction factor is computed for each value of j which equals

$$\frac{T_j}{\sum_{1}^{i} T_{ij}}$$

2. The first estimate is multiplied by the appropriate correction factors.

Comparison with Electrostatic Model

$$V_{P_iQ_j} = \frac{\frac{Q_j}{R_{ij}} \times P_i}{\sum_{j=1}^{m} \frac{Q_j}{R_{ij}}} \qquad (i = 1, 2, \ldots., n)$$

in which

$V_{P_iQ_j}$ = probability of movement from i to j;

P_i = number of workers living in Zone i;

Q_j = number of jobs available at Zone j;

R_{ij} = straight-line distance from i to j if the field contains no physical barriers. Where such barriers exist, R would have to be the straight-line distance from i to the point of passage across the barrier plus that from the point of passage to j.

TABLE 5

COMPARISON OF FLOW COMPUTATIONS

To Zone	Model[a]	From Zone 26			From Zone 27			From Zone 30			From Zone 31			Total to Zones
		Flow	Δ	%	Flow	Δ	%	Flow	Δ	%	Flow	Δ	%	
1	S	1,199 1			778 9			536 1			485 9			3,000.0
	G	1,161 5	- 37 6	- 3 1	695 0	- 83 9	-10 8	623 5	+ 87 4	+16 3	519 9	+34.0	+7 0	2,999 9
	E	1,217 6	+ 18 5	+ 1 5	583 7	-195.2	-25 0	707 8	+171 7	+32 0	490.9	+ 5.0	+1.0	3,000 0
28	S	1,215 4			825 1			490 3			469.2			3,000.0
	G	1,231 9	+ 16 5	+ 1.4	812 1	- 13 0	- 1 6	507 2	+ 16.9	+ 3.5	461.4	- 7 8	- 1 6	3,012 6
	E	1,359.8	+144.4	+11 9	791 6	- 33.5	- 4 1	464.9	- 25 4	- 5 2	383 7	-85 5	-18 2	3,000 0
29	S	1,585.5			1,396 1			973 5			1,044.9			5,000.0
	G	1,620 5	+ 35 0	+ 2 2	1,494.1	+ 98 0	+ 7 0	869 5	-104.0	-10 7	1,014.7	-30 2	- 2 9	4,998 8
	E	1,423.5	-162 0	-10 2	1,624.2	+228 1	+16 3	827.4	-146 1	-15 0	1,124.8	+79 9	+ 7.6	4,999 9
Total	S	4,000 0			3,000.1			1,999 9			2,000 0			11,000.0
	G	4,013 9			3,001 2			2,000.2			1,996 0			11,011 3
	E	4,000.9			2,999 5			2,000.1			1,999 7			11,000 1

[a] S = systems engineering, G = gravity model, E = electrostatic model

Corrections in this computation are based on the following equation:

1. First assignment is multiplied by the appropriate correction factor C_j for $j = 1, 2, \ldots\ldots, m$

$$C_j = \frac{Q_j}{\sum_{i=1}^{n} V_{P_iQ_j}}$$

2. The second assignment is multiplied by the appropriate correction factor C_i for $i = 1, 2, \ldots\ldots, n$

$$C_i = \frac{P_i}{\sum_{j=1}^{m} V_{P_iQ_j}}$$

3. The first and second steps are repeated for each successive assignment.

COMMENTS

The example problem, although extremely small, should have served to demonstrate the great potential of systems analysis by linear graph techniques for theoretical traffic flow problems. Many simplifying assumptions have been made. Further research is required to establish the technique to the point where it can be used to its full potential. The next step in the research will be a test of the theory against actual origin and destination surveys.

Future work on establishing other system components must be tried to evolve finally the best possible components or component systems, with proper x and y measurements and terminal representation. It is possible that a heterogeneous zone might be separated into distinct parts, each of which may be defined by a component and described mathematically.

The components used to date require a more complete study. For example, the curves used to predict the resistance factor on the street components must be studied more completely.

Although only a hypothetical case has been presented here, the results, when compared with the gravity model or the electrostatic model, show promise for eventual acceptance of this method.

It must be recognized, too, that changes in parameters in the given system can be made easily without disturbing the principles of the technique. Thus, any refinements in component definition can be entered as they become available without need for development of a new technique. Eventually this technique will permit research into the parameters.

Appendix

DETAILS OF LINEAR GRAPH

Measurements

In the mathematical analysis of any given type of physical system (electrical, mechanical, thermal, etc.) the tie between the mathematics and the system is generally accomplished through the use of two basic measurements; the across (or x) and the through (or y) measurements. The x and y measurements used to date are

1. Electrical.—x is voltage and y is current flow.
2. Mechanical translation.—x is displacement and y is force.
3. Thermal systems.—x is temperature and y is heat flow.
4. Hydraulics.—x is pressure and y is flow.

Definitions

Terminal Graph.—The terminal graph of an n-terminal component is defined as a collection of (n - 1) oriented line segments which forms a connected graph with no circuits and includes exactly one vertex for each terminal of the component.

In general, the terminal graph serves to identify the variables in the terminal equations with a unique set of measurements and establishes a vital link between the physical component and its mathematical description. The graph or terminal equation are each incomplete in themselves.

Terminal Equations.—The mathematical equations relating the measurements represented by the through and across variables of the terminal graph are called the terminal equations of the component.

Terminal Representation.—The terminal graph plus the terminal equations are called the terminal representation of a system component.

System Graph.—A system graph is a collection of component terminal graphs obtained by uniting the vertices of the terminal graphs in a one-to-one correspondence with the union of the physical components. When the fundamental operational concept of the linear graph is adopted, the system graph follows directly from the prescribed manner in which the components of the system are connected. If the characteristics of the system components can be determined—and they must be if the system is to be analyzed—there is never any question as to the form of the system graph.

System Equations.—The graph equations along with the terminal equations of the system components are defined as the system equations. The fundamental cut-set equations, stating that the sum of all through measurements at the vertices equal zero, and fundamental circuit equations, hereafter referred to as the graph equations, serve to establish a set of independent equations among the through and among the across variables used in presenting the characteristics of the system components.

The system equations represent a complete mathematical description of the system. When the terminal equations of the system components are linear, a partial solution to these simultaneous equations can be effected without the necessity of calculating an inverse. The partial solutions obtainable depend on the given forms of component terminal equations.

Tree.—If a connected graph G contains v vertices, connected subgraph of G containing all v vertices and no circuits is defined as a tree.

Branches.—The elements in the tree are appropriately called branches. Although there may be many different trees in any graph, a tree is easily identified by simply allowing one and only one element to join any pair of the v vertices. The tree which has all elements incident at one vertex is called a Lagrangian tree.

Chords.—The elements of a connected graph G which form the complement of a tree are defined as chords.

Specified Values.—The tree will then be further subdivided into those elements for which one has specified x or across variables, symbolically referred to as (B-1), and those for which no variable is known (B-2). The chords are also subdivided into (C-1) which are the unknowns and (C-2) for which the y or through variable has been specified.

Postulates

The graph equations can be established when the vertex and circuit equations are satisfied. The system must be such that the x or across variables will sum to zero around the circuits of the systems graph and further that the y or through variables sum to zero at the vertices of the linear graph. The fundamental across and through variables used to represent measurements in the various types of physical systems all have these important and fundamental properties. The mathematical formulation of these properties (the vertex and circuit equations, together with the component terminal equations) forms the basis for the analysis of physical systems. If the through and across variables of the system graph are defined so that they sum to zero at the vertices and around the circuits, then these techniques of formulation will apply to that physical system. These criteria can be formally stated as postulates.

Vertex Postulate. —If the system graph of a physical system contains e-oriented elements and if y_j represents the fundamental through variable of the jth element, then at the kth vertex of the graph

$$\sum_{j=1}^{e} a_j y_j = 0$$

in which

a_j = 0 if the jth element is not incident at the kth vertex;

a_j = 1 if the jth element is oriented away from the kth vertex;

a_j = -1 if the jth element is oriented toward the kth vertex.

Circuit Postulate. —If the linear graph of a physical system contains e-oriented elements and if x_j represents the fundamental across variable of the jth element, then for the kth circuit

$$\sum_{j=1}^{e} b_j x_j = 0$$

in which

b_j = 0 if the jth element is not included in the kth circuit;

b_j = 1 if the orientation of the jth element is the same as the orientation chosen for the kth circuit;

b_j = -1 if the orientation of the jth element is opposite to that of the kth circuit.

When the circuits used in writing the independent equations are chosen so as to include the branches first and chords last, a general and convenient form can be obtained. This is also applicable when writing the vertex or segregate equations except that one and only one branch is included when summing around the vertices.

REFERENCES

1. Haight, F.A., "Mathematical Theories of Road Traffic." Institute of Transportation and Traffic Engineering, Special Report, University of California (March 1956).
2. Koenig, H.E., and Blackwell, W.A., "Electromechanical System Theory." McGraw-Hill (1961).
3. Curran, F.B., and Stegmaier, J.T., "Travel Patterns in 50 Cities." HRB Bull. 203, 99-130 (1958).
4. Carroll, J.D., Jr., and Bevis, N.W., "Predicting Local Travel in Urban Areas." Papers and Proc., Regional Science Association (1955).
5. McGrath, W.R., "Land Use Planning Related to Traffic Generation and Estimation." Proc., Inst. Traffic Engineers (1958).
6. Voorhees, A.M., "A General Theory of Traffic Movement." Proc., Inst. Traffic Engineers (1955).
7. Howe, R.T., "A Theoretical Prediction of Work-Trip Patterns." HRB Bull. 253, 155-165 (1960).

Characteristics of Captive and Choice Transit Trips In the Pittsburgh Metropolitan Area

LOUIS E. KEEFER, Director, Pittsburgh Area Transportation Study

• THIS PAPER is an exploration of the characteristics of two general classes of transit tripmakers: those who comprise a "captive" audience because they are unlicensed to drive or lack access to a car and those who could have driven but "chose" transit instead.

The explored characteristics are limited to the data available from the Pittsburgh Area Transportation Study home interview survey (1958). These cover the rider and his background—where he lives, his sex, race, age, and occupation—and the nature of the trips he makes—when and where they start, their trip purpose and land use linkages, and their length and speed. The examination does not cover comparative family incomes, out-of-pocket travel costs, comfort and convenience factors, or similar items not reported in the survey. The examination does not derive from any kind of attitude survey; people were not asked what travel mode they preferred and why. This, then, is phenomenological research. It describes what people do, not what they think they do.

Defining captive and choice trips was comparatively simple. About 283,000 transit trips by nondrivers and by persons from non-car-owning households were mechanically separated from the grand total of 474,000 transit trips (see Table 1). The remaining 191,000 trips (representing about 7,000 unexpanded trip records) were individually examined to determine whether a car was available to each transit tripmaker between the time his trip started and ended. The principal determinant was its availability at or near the time the transit trip started—once committed to start a trip by transit, the return or subsequent trip will usually be by transit. In cases of doubt, it was ruled that a car was available; this eliminated the chances of understating the number of choice trips.

It is surprising, perhaps, that only 15 percent of all transit riders could have chosen to drive. The great bulk (85 percent) were captives. It has been well established that transit riders generally have characteristics different from automobile drivers and passengers (e.g., 1, 2). However, there is still a further difference between choice and captive transit riders.

It is fair to add that there is also a captive audience of auto drivers and passengers who do not have access to transit service when and where they need it. This study would be more meaningful if both captive transit and automobile tripmakers could be defined and removed from the total trip file, and comparisons could be made between the remaining tripmakers who had a relatively equal choice as between the auto and transit. This, however, is beyond the scope of the present investigation. Hopefully, more can be done later.

RIDER BACKGROUND

Residence

The highest proportion of choice trips is reported by residents of households at middle distances from the Golden Triangle, that is in rings 3 through 5 (See Fig. 1). Conversely, the proportion of captive trips is highest near the Golden Triangle, where car ownership is lowest, and near the cordon line, where car ownership is highest but where low residential density makes transit service difficult to provide (see Table 2). But the differences are very slight. In itself, knowing where the transit rider lives is no criterion to whether he has chosen transit or is a captive rider.

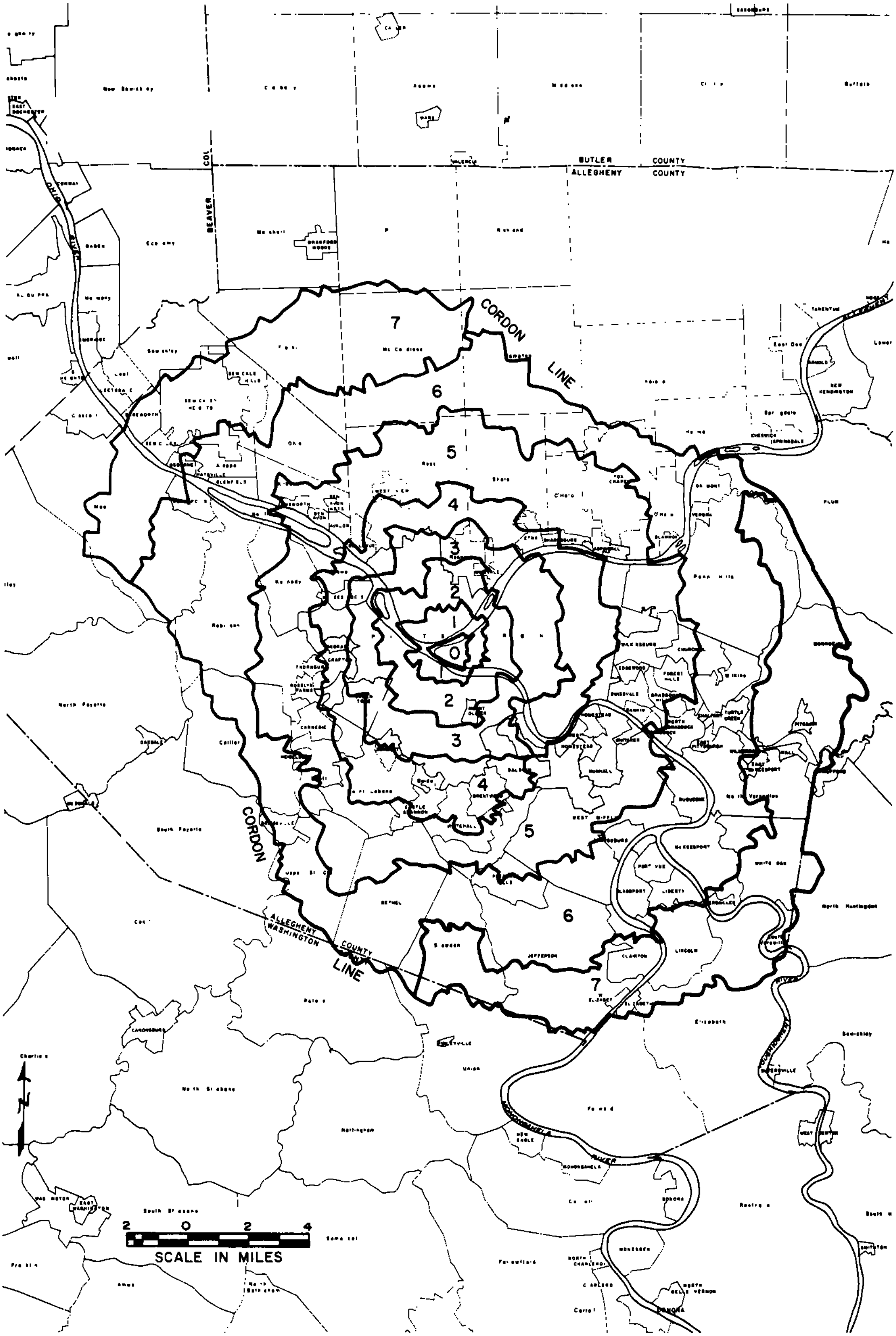


Figure 1. PATS study area with analysis zones.

Sex, Race, and Age

Choice tripmakers are predominantly male; captive tripmakers are predominantly female (see Fig. 2), which suggests that the principal family wage earner, usually the husband, takes driving priority in the single-car household; the housewife and children must take transit, solicit a ride with friends, or walk. At the same time, there is more likelihood that captive trips will be made by nonwhites and that choice trips will be by whites. These probabilities reflect comparative incomes and, hence, rates of car ownership and driver licensing.

Among choice tripmakers, there is a much smaller proportion of younger and older riders (see Fig. 3). Obviously, all transit trips by the age groups under 15 years old are captive. The proportion of choice trips builds up from age 15 to age 35, then decreases again. The age group 30 to 34 years old makes more choice trips than any other (37 percent). It would appear that many older residents prefer not to drive and either sell their car or let their driver's license lapse.

TABLE 1

CAPTIVE AND CHOICE TRANSIT TRIPS IN THE PITTSBURGH METROPOLITAN AREA

Type of Trip	No. of Trips
Total Transit	473,750
Less trips from non-car-owning households	141,354
Less trips by nondrivers from car-owning households	142,132
Less trips by drivers from car-owning households with no car available	120,321
Total Captive	403,807
Total Choice	69,943

TABLE 2

CAPTIVE AND CHOICE TRANSIT TRIPS AS REPORTED AT RESIDENCES, BY RING

Ring of Residence	Captive Trips		Choice Trips		Total Transit Trips
	Number	Percent of Total	Number	Percent of Total	
0 and 1	17,533	87.8	2,434	12.2	19,967
2	45,824	87.0	6,871	13.0	52,695
3	68,494	84.3	12,722	15.7	81,216
4	76,743	81.9	16,929	18.1	93,672
5	89,294	84.1	16,900	15.9	106,194
6	78,625	88.3	10,408	11.7	89,033
7	27,294	88.1	3,679	11.9	30,973
Total	403,807	85.2	69,943	14.8	473,750

Occupation

Differences in age, sex, and race between captive and choice tripmakers can be related to differences in occupation. Judging from first work trips only, there is a strong tendency for choice trips to be made by professionals, managers, and skilled craftsmen (see Fig. 4). Sales workers, operatives, domestics, and laborers are more likely to be captive riders. Clerical workers make over one-third of all first work trips by transit, about equally as between choice and captive trips. Clearly, the two universes of tripmakers have different occupational backgrounds.

TRIPS

Origin

Choice trip origins tend to be a higher proportion of the total transit trip origins in the inner rings than in the outer rings (see Table 3). The proportion decreases rather regularly with increasing distance from the Golden Triangle. It would appear that a number of the choice trips propagated by households in the outer rings actually start in the inner rings. This is a reflection of trip "linking"; that is, where trips from outer ring households begin at home as auto driver or auto passenger trips and subsequently transfer to a transit mode at a station or stop closer to the center. This is borne out by the data—only 3 percent of all captive trips are linked; 9 percent of all choice trips are linked. Thus, a transit tripmaker who has been dropped off at his bus stop is somewhat more likely to have passed up an opportunity to drive than the tripmaker who has walked to his bus stop.

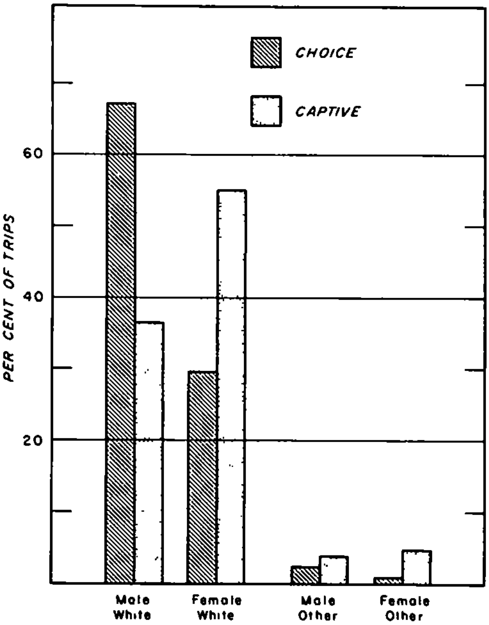


Figure 2. Choice vs captive transit trips by sex and race of tripmaker.

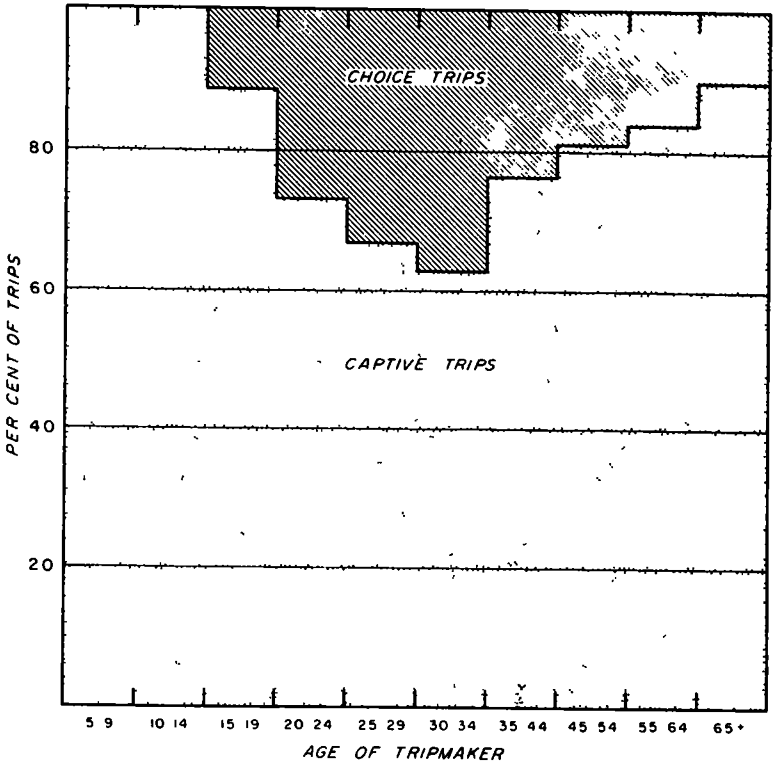


Figure 3. Choice vs captive transit trips by age of tripmaker.

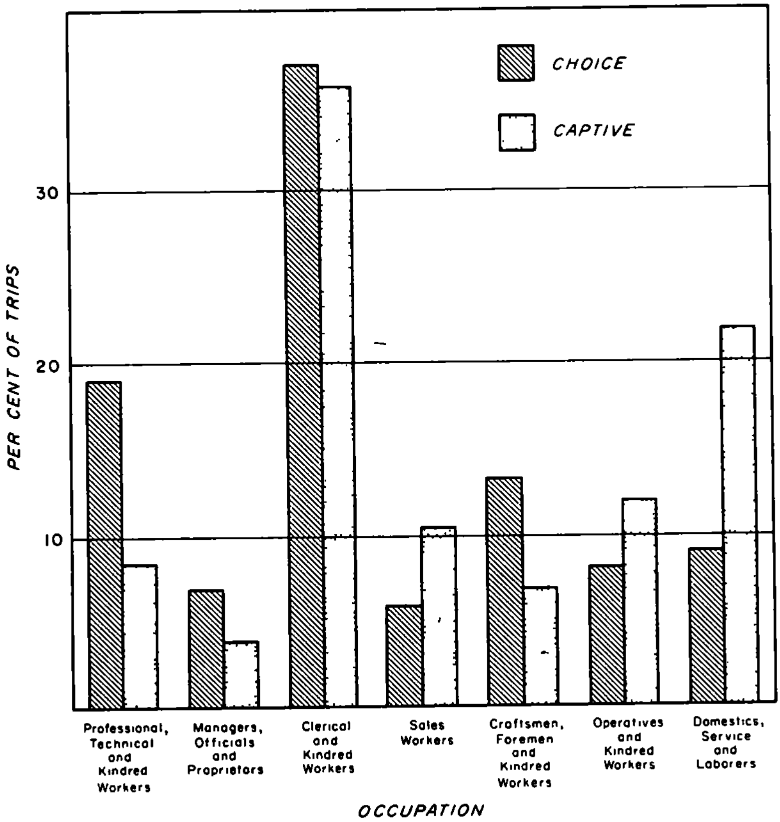


Figure 4. Choice vs captive transit trips first work trips by occupation of tripmaker.

More importantly, Table 3 shows that over one-fourth of all transit trips beginning or ending in the Golden Triangle are choice trips. This is the most important single focus for choice trips—almost 60 percent of the total choice trips themselves begin or end in the Golden Triangle. Over 80 percent of the total choice trips are oriented to

TABLE 3

CAPTIVE AND CHOICE TRANSIT TRIPS BY RING OF ORIGIN

Ring of Origin	Captive Trips		Choice Trips		Total Transit Trips
	Number	Percent of Total	Number	Percent of Total	
0	57,580	73.5	20,719	26.4	78,299
1	22,475	84.4	4,166	15.6	26,641
2	34,575	87.6	4,907	12.4	39,482
3	58,732	87.0	8.737	13.0	67,469
4	60,702	86.3	9,612	13.7	70,314
5	72,360	87.5	10,367	12.5	82,727
6	75,847	89.2	9,175	10.8	85,022
7	21,536	91.5	2,260	9.5	23,796
Total	403,807	85.2	69,943	14.8	473,750

to the Golden Triangle plus eight other analysis zones. All of the latter contain secondary business districts or important commercial concentrations. It would appear then that driving and parking frictions and costs have an important bearing on the traveler's decision to use transit to reach these areas. By comparison, only 4 percent of all transit trips to or from school are choice trips, and about 13 percent of all other transit trips are by choice (see Fig. 5).

Starting Time

Except for the afternoon peak hour, choice trips have about the same hourly distribution as captive trips (see Fig. 6). The difference is in the trips to school, because these are almost all captive trips and because school lets out earlier than the usual quitting time for work, the captive trips peak much earlier than the choice trips.

Trip Purpose

The choice trip is predominantly a work- and home-connected trip. Figure 7 shows that over 37 percent of the choice trips are to work; by contrast, only 20 percent of the captive trips are to work. As expected, the biggest difference is in the trips to school—about 18 percent of all captive trips are to school and only 4 percent of the choice trips. With the exception of trips to home and work, in fact, there are proportionately more captive trips for all purposes.

The weighting effect of school trips also shows up in the comparison of captive vs choice trips by destination land use. Although about 23 percent of all captive trips are to public buildings, only 10 percent of the choice trips are destined to that kind of activity (see Fig. 8). At the same time, there is a considerably higher proportion of choice trips than captive trips to commercial and manufacturing activities. (The latter are larger office buildings in the Golden Triangle.) Figure 8 reflects both the kind of areas these trips seek and the occupation of the tripmaker.

Trip Length

The average length of captive trips is 2.7 airline miles; the average length of choice trips is 4.0 airline miles (see Table 4). Choice trips are longer for every trip purpose with the exception of social recreation. This makes sense—for pleasure, a short transit trip may be tolerable, a longer trip intolerable. It might be speculated that anyone can use transit acceptably for business purposes, but to use transit to go to the theater, to a dance, or to a party is not only inconvenient but would involve loss of social status. But then, too, because generally more than one member of a household is involved in the typical social-recreation trip, the car becomes a cheaper mode of transportation, at least in terms of out-of-pocket expenses.

There are two reasons why choice trips are longer than captive trips. First,

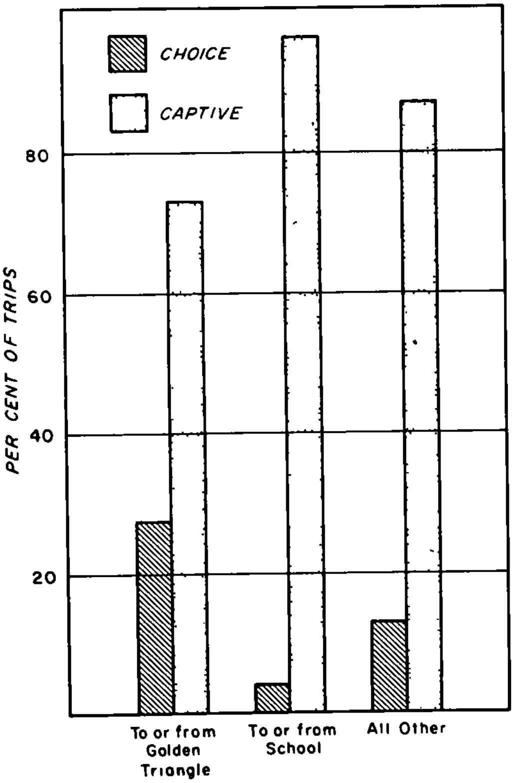


Figure 5. Choice vs captive transit trips by major trip category.

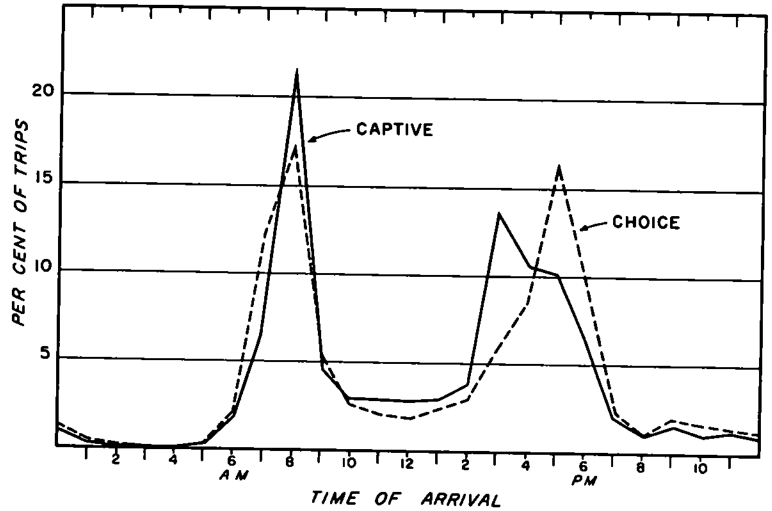


Figure 6 Choice vs captive transit trips by time of arrival.

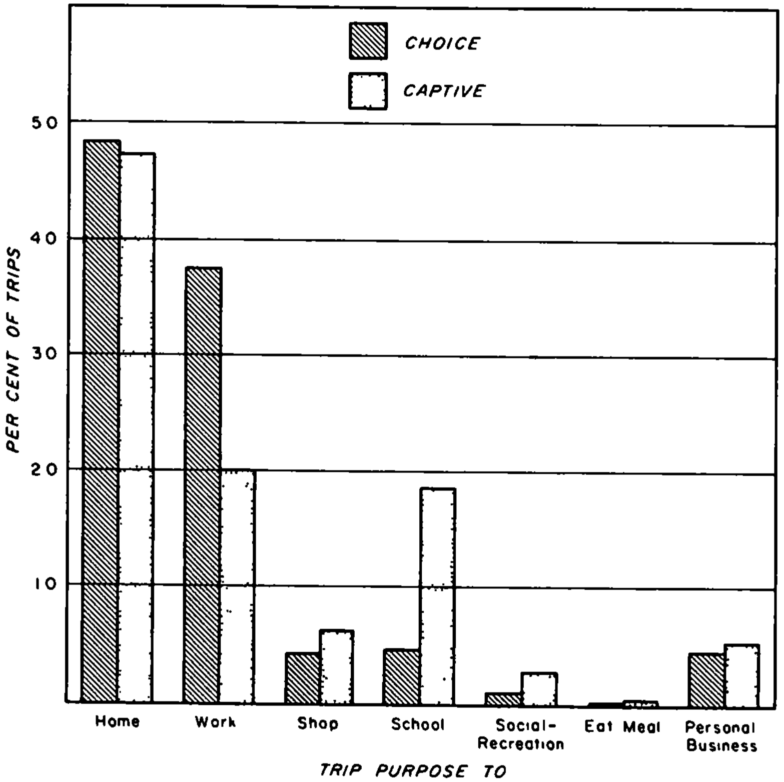


Figure 7. Choice vs captive transit trips by trip purpose.

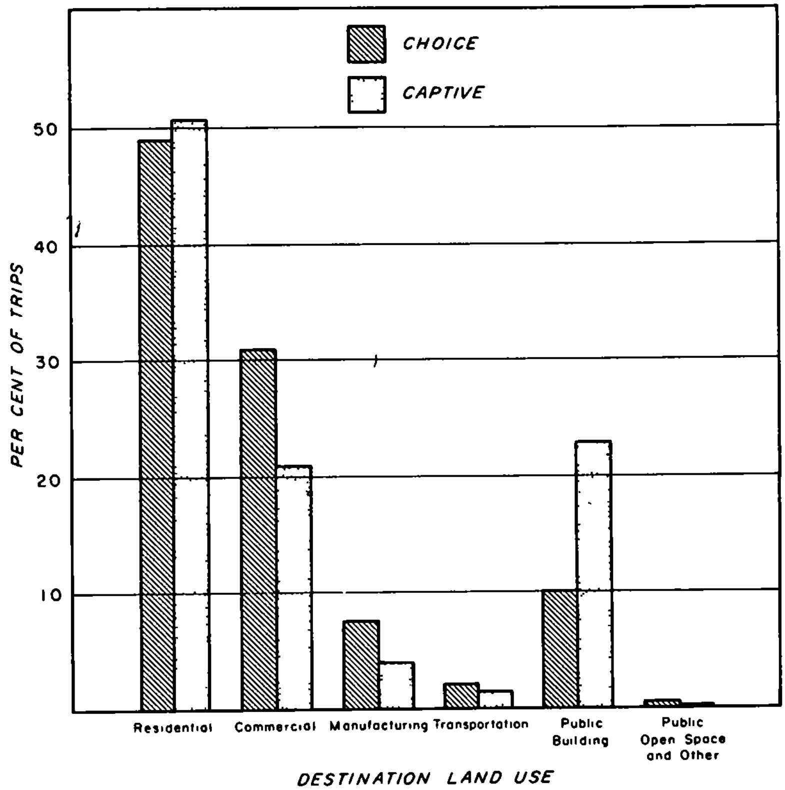


Figure 8. Choice vs captive transit trips by destination land use.

TABLE 4

CAPTIVE AND CHOICE TRANSIT TRIPS BY AIRLINE TRIP LENGTHS AND AIRLINE DOOR-TO-DOOR SPEEDS BY TRIP PURPOSE

Trip Purpose	Captive Trips		Choice Trips	
	Trip Length (airline mi)	Speed (mph)	Trip Length (airline mi)	Speed (mph)
Home	2. 6	4. 9	4. 1	6. 5
Work	3. 3	5. 9	4. 1	7. 3
Shop	3. 1	6. 6	4. 4	8. 3
School	1. 8	4. 6	3. 6	6. 8
Social recreation	3. 0	5. 7	2 7	5. 9
Eat meal	1. 5	5. 0	4. 8	10. 1
Personal business	2. 8	5. 5	3. 3	6. 6
Average	2. 7	5 3	4. 0	6. 8

school trips are very short and more heavily weight the latter than the former. Second, trips to the Golden Triangle and to other important commercial centers are generally longer than trips to other areas; choice trips include a higher proportion of these. Figure 9 compares the trip length distribution of captive and choice trips as a percent of all person trips in the Pittsburgh area. Generally, as all trips get longer, transit

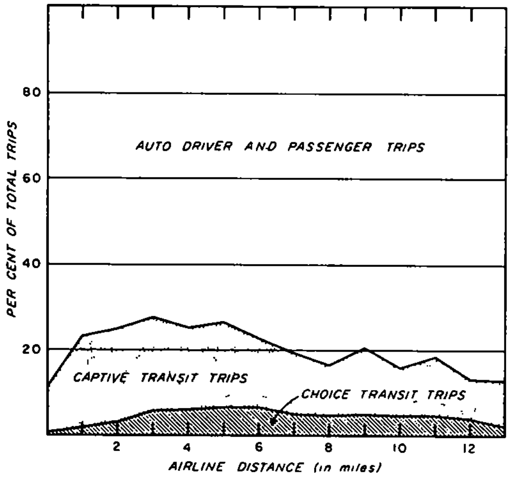


Figure 9. Choice and captive transit trips as a proportion of all internal person trips, by trip length.

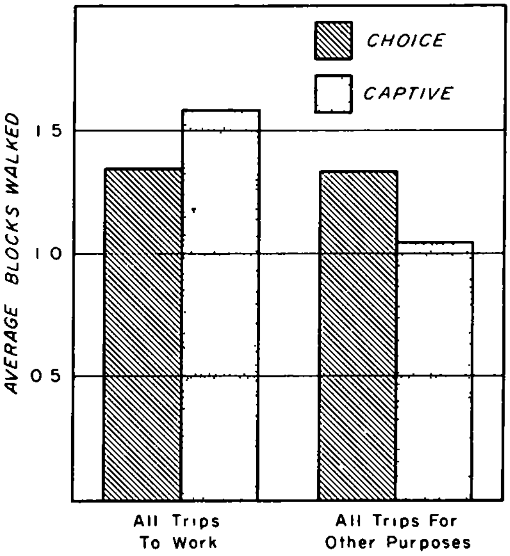


Figure 10. Choice vs captive transit trips by blocks walked at origin.

takes a smaller share of the total, ranging from about 28 percent of all trips between 3 and 4 airline miles long to about 14 percent of those more than 13 airline miles long. With increasing trip length, however, a larger and larger share of the total transit tripmaking is represented by choice trips.

<u>Trip Speed</u>

The longer average trip lengths of choice trips insure that door-to-door speeds will be higher than those reported for all captive trips. All transit trips combined increase regularly from about 2 mph for trips under 1 airline mile to about 15 mph for trips of 14 airline miles. The increasing average speeds of longer trips are due to the time constants involved (walking and waiting time) being a relatively smaller part of the total elapsed time as the trip length increases.

Choice trips are not on faster transit routes per se. Most of the surface transit routes in the Pittsburgh region provide comparable scheduled speeds (there is no rapid transit). There appears to be no clustering of choice trips around the few surface routes that offer somewhat faster speeds than others. Although a large proportion of all commuter railroad transit trips are choice trips (2,307 out of 5,670), the weighting effect is insignificant. These trips, however, are longer than bus and streetcar choice trips (6.9 airline miles) and are somewhat faster per se (10.2 mph, airline door-to-door speed).

Nor is there a significant difference in the average number of blocks walked by captive vs choice tripmakers. Figure 10 shows that choice trips average about 1.3 blocks whether to work or for some other purpose. By contrast, captive trips walk a little farther for trips to work, but do not walk as far for other purposes. Again, it is the large number of captive trips to school that keeps the latter average low. As remarked previously, the choice trips have a greater probability of being linked; particularly the trips to work; this would account for the difference in that category.

SUMMARY

The facts do not necessarily disclose the conscious (or subconscious) reasons why certain travelers choose transit when they could have driven. If questioned, their reasons might have been expressed in terms of personal comfort, convenience, safety, cost, etc. However, because their personal attributes and the nature of their trips differ significantly from those of captive transit tripmakers, it is certainly possible to suggest their reasons for choosing transit.

From the evidence at hand, it would appear that the most persuasive argument for leaving the family car at home is the difficulty and expense of driving and parking in highly built-up downtown areas. This, in turn, is closely related to other personal attributes—choice tripmakers are most apt to be men of income-earning age, in professional and white-collar jobs. The trips they make are most apt to be work-oriented, to commerical and service establishments in downtown areas, and to be relatively long. For the most part, the differences between captive and choice tripmaking show up sharp and clear. Hopefully, they will prove useful in estimating the future potential market for public transit.

REFERENCES

1. "Survey Findings." Chicago Area Transportation Study, Final Report, Vol. 1 (1959).
2. "Study Findings." Pittsburgh Area Transportation Study, Final Report, Vol. 1 (1961).

A New Method of Obtaining Origin And Destination Data

ALBERT J. MAYER and JOANNE L. WALLACE, Detroit Area Traffic Study, Wayne State University

• THE PURPOSE of this paper is to compare household trip behavior obtained in the convential manner, by means of a household survey based on an area probability sample, with similar data obtained by interviewing persons as they renewed their driver's licenses in the police station. This experiment was made in Battle Creek, Mich., in the summer of 1961. The Michigan State Highway Department conducted the conventional O-D survey, and the Detroit Area Traffic Study of Wayne State University carried out the driver's license type of interviewing.

Inasmuch as the conventional O-D survey procedure is both familiar and time-tested, its features need not be redescribed here. However, the driver's license procedure is new; therefore, a brief description of its theoretical basis and practical procedure is in order.

The procedure substitutes a sample based on a universe of licensed drivers for a sample based on a universe of households. Every licensed driver in the State of Michigan must apply in person for license renewal on or about his or her birthday every third year. Because birthdays are randomly distributed in the population, this means that each day 1/1,095 (365 days a year for 3 years) of all drivers must report to the nearest licensing office (the police station or sheriff's office) to have their licenses renewed. Pursuing this relationship it is seen that every week 0.64 percent of all drivers experience birthdays and must report for license renewals during the five to six days the office is open. The number of interviews obtained each week is related to the size of the total population of drivers.

Does the sample obtained in this manner meet the criterion of randomness? If the universe is considered to be all drivers, it does. First, the list is totally inclusive, inasmuch as all drivers must have a license. Second, calling in renewals by birthday is either so close to random that small differences can be ignored, or controlled if that is desired because the universe parameters are known. The small deviation from pure chance arises from the possibility that birth patterns by month may vary in population groups whose driving habits vary. These differences, if they exist, are likely to be small. A recent study of racial and economic differentials in birth by season has indicated differences of between 3 and 7 percent, depending on the time of year (1).

Even at a maximum, this chance of error becomes insignificant compared with the error inherent in a household survey, when the "not-at-homes" and refusals are considered. Furthermore, if the period of interviewing renewal applicants is of sufficient length (say, twenty weeks) any differences related to month of birth would tend to disappear. A third point is that, at least for drivers born after 1920, adequate birth records exist, and the sample can be stratified accordingly if desired. The differential month-of-birth patterns can be calculated if necessary.

If it is granted for the moment that the theory is sound, the question then arises as to whether the driver's license procedure has any advantages over the area probability sample which would justify its general or even occassional use. Conversely, does it have disadvantages that preclude its use in any or all situations? These contentions were tested by making the two types of surveys at the same time and in the same place.

RESULTS

The principle question is whether the two survey techniques yielded similar results in the Battle Creek experiment, or put another way, whether the driver's license renewal method is an adequate substitute for the household survey. The answer to this question is summarized in Table 1.

This brief resume′ contains two essential findings. First, the driver's license survey did not obtain as many trips as the household survey. The difference was about 5 percent less for the license survey. In the strict interpretations of sampling error inherent in both surveys, this is not necessarily a real difference. That is, if both surveys were to be repeated the results might be diametrically opposite, and still might be equally correct or incorrect, as the case might be. However, because the license renewal survey is, in a sense, the "challenger," and the household interview survey the "champion," a defensive posture, will be assumed and an attempt made to explain why the driver's license survey found fewer trips per household.

Before attempting a detailed analysis as to specifically why the driver's license survey failed to get as many trips as the household survey, it should be pointed out that the distributions by trip mode, trip purpose, and trip distribution make it clear that the pattern of trip behavior as obtained in the two surveys is essentially the same. This is the major point to be made in this paper. If the origins and destinations of trips as obtained in each survey are compared, as they are in detail in Table 2, an extremely

TABLE 1

COMPARATIVE TRIP DATA—DETROIT AREA TRAFFIC STUDY, DRIVER'S LICENSE RENEWAL O-D SURVEY, AND MICHIGAN STATE HIGHWAY DEPARTMENT AREA PROBABILITY SAMPLE O-D SURVEY

Item	Detroit Area Traffic Study	Michigan State Highway Department
Total number of interviews	1,147	1,147
Number of completed interviews	1,138	1,062
Refusals	9	85
Average trips per household	6.76	7.17
Mode (%):		
Auto drivers	65.3	62.8
Auto passengers	33.0	33.8
Other	1.7	3.4
Total	100.0	100.0
Purpose (%):		
Home	40.7	37.5
Work	18.1	14.5
Shopping	7.5	10.0
Social recreation	17.6	18.7
Serve passenger	9.5	8.8
Other	6.6	10.5
Total	100.0	100.0
Summary trip distribution (destination):		
In city	82.1	84.1
Outside city	17.9	15.9
Outside MSHD study area	(7.5)	(5.5)
Total	100.0	100.0

TABLE 2

PERCENT TRIP DISTRIBUTION BY TRAFFIC ANALYSIS TRACT, DETROIT AREA TRAFFIC STUDY AND MICHIGAN STATE HIGHWAY DEPARTMENT SURVEYS, BATTLE CREEK, MICHIGAN, 1961

Tract	Distribution of Trips							
	By Tract of Origin				By Tract of Destination			
	MSHD		DATS		MSHD		DATS	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
City:								
1	347	4 2	354	4 6	351	4.3	348	4.5
2	663	8.1	618	8.0	648	7.9	615	7.9
3	314	3.8	331	4.3	319	3 9	334	4.3
4	421	5.1	448	5 8	416	5.1	457	5.9
11	552	6 7	429	5 5	521	6.3	432	5.6
12	1,472	17.9	1,194	15.4	1,514	18.4	1,222	15.8
13	948	11 5	792	10.2	945	11.5	803	10.4
14	1,109	13.5	768	9.9	1,108	13.5	783	10.1
15	424	5.2	509	6.6	421	5 1	505	6.5
16	179	2.2	203	2.6	176	2.1	203	2 6
17	489	5.9	661	8.5	499	6.1	656	8.5
In remainder of MSHD Study area:								
21	15	0.2	7	0.1	15	0.2	7	0.1
22	52	0 6	100	1.3	51	0.6	98	1.3
23	29	0.4	7	0.1	35	0 4	7	0.1
24	32	0.4	22	0.3	32	0.4	23	0.3
25	17	0.2	7	0.1	16	0.2	7	0.1
26	102	1 2	77	1.0	101	1.2	77	1.0
27	8	0 1	13	0.2	7	0 1	13	0.2
31	33	0 4	34	0.4	35	0.4	35	0.4
32	33	0.4	36	0.5	33	0.4	37	0.5
33	35	0 4	17	0.2	35	0.4	16	0.2
34	269	3.4	313	4.0	268	3.4	315	4.0
35	72	0.9	77	1.0	72	0.9	79	1.0
36	132	1.6	89	1.1	131	1.5	88	1.1
37	19	0 2	7	0.1	19	0.2	7	0.1
Outside study area	455	5.5	635	8.2	453	5.5	581	7.5
Total	8,221	100.0	7,748	100 0	8,221	100.0	7,748	100.0

close correspondence is found; that is, the trip pattern obtained in the two surveys is similar. In fact, it is just as close as if two conventional household O-D surveys were done simultaneously and then compared. In general, the driver's license technique can be employed as an instrument to obtain origin-and-destination data. This is a necessary but not sufficient condition for recommending the use of a driver's license O-D procedure. It is necessary to know further what its actual limitations are as they worked out in practice; also, what its advantages are. Unless it has particular advantages, there is no reason to employ it instead of the time-tried home interview.

LIMITATION OF DRIVER'S LICENSE METHOD

Theoretically, there were at least five limitations to this procedure. The actual experience proved the following with regard to these limitations:

1. A problem in using this technique is the fact that it does not cover all travel behavior. The inability to include the travel behavior of families without a licensed driver might prove a serious disadvantage in a larger city, but in Battle Creek it was a minimal disadvantage as shown in Table 1, where distribution by mode of travel was given. Because in the MSHD survey only 3.4 percent of all trips were in buses or taxis, and this includes public transportation trips of persons and households with driver's licenses, it is apparent that this factor had little or no effect in assessing travel behavior in Battle Creek. Nevertheless, it remains as a possible disadvantage in larger cities.

2. The second problem of the licensing procedure can be called the "Monday problem." In the customary O-D survey, interviews are randomized over the days of the week with Monday excluded. Because in the licensing procedure the interviewees come to the interviewer, not only do they come in on Monday, but Monday is by far the busiest day. However, it is necessary to know their weekday travel, not their travel on the preceeding day (Sunday). The question is whether the travel characteristics of people who come in on Monday differs in their weekday travel behavior from those who come in during the remainder of the week.

Persons reporting on Monday were listed and then interviewed at home, with the travel day being randomized over the days of the week in the usual manner. Their travel behavior proved much like that of persons reporting during the remaining days of the week. The average number of trips of the Monday people was 7.1 compared with 6.8 for the regular sample. (As explained later, these persons were interviewed at home, and consequently their average number of trips was higher.) They reported 61 percent combined home and work purposes compared with 61 percent for the other group. Fifty-nine percent of them were auto drivers compared with 65 percent in the regular sample. The Monday sample yielded 76 of all trips made within the City of Battle Creek compared with 82 percent in the regular sample. These differentials are all within the range of sampling error. Thus, evidence so far indicates that either the Monday persons can be interviewed at home, or that the study can be done on a Tuesday to Saturday basis and the people reporting on Monday can be dropped, because Monday persons are no different from persons reporting for renewal on the other days of the week.

3. The third problem was whether second, third, and fourth members of the same household would appear to have their licenses renewed causing duplications of households. According to sampling theory, duplication would occur in 5 percent of the cases. In Battle Creek it actually occurred in approximately 4 percent of the cases bearing out the theoretical calculation. This simply means that only 4 percent of the interviews had to be discarded because they duplicated households. This amount of wastage is not significant.

4. A fourth possible complicating factor is that persons are legally required to renew their driver's license in their birthday month. Some neglect to do this. The question then becomes whether persons who are late have different trip characteristics than those who renew their licenses within the stipulated time period. It was found that 14 percent of all renewals were late renewals. Using mean trips as a rough index of travel behavior, it was found that the mean number of trips for the late group was 6.5 as compared with 6.8 for the total sample. This difference was well within the range of sampling error. A further breakdown by month of birth revealed a distribution ot mean trips greatly similar to those found in the total sample. At this point there is no reason to believe that lateness in renewing a driver's license is necessarily associated with a differing pattern of trip behavior.

5. The final problem concerned the possibility of some persons living in Battle Creek obtaining their license renewal elsewhere in the State; something they legally can do. No quantitative information on this subject was obtainable because of the nature of the State's filing system. However, the Secretary of State's Office was confident that this favor was negligible and could be disregarded. In additon, the number of out-of-area licenses issued in the Battle Creek offices was checked. Less than 1 percent of the licenses were issued to people from outside the area. There is no reason to suspect that residents of Battle Creek would behave any differently and hence there is no residence-occurrence problem.

This concludes the listing of theoretical questions concerning the capability of the driver's license survey. All questions were answered to the authors' satisfaction. The most severe problem was none of these, but arose out of the practical problem of interviewing in the police station. In the beginning, it was assumed that this procedure would be more efficient. Because a higher percentage of principal tripmakers (working males) was being interviewed it was assumed that a larger total number of trips would be obtained than in the conventional O-D procedure. As has already been mentioned 473 (or five percent) fewer trips were actually obtained. The details of the analysis are too complex to present in this brief space, but in essence it was found that the DATS study overreported work and home trips, and the MSHD overreported all other trip purposes. This means that the police station interview did not capture, as well as it should, the trips of the other household members. The average number of trips made with the licensee at his home, was then examined and an average of 8.4 trips per household, compared with the 7.7 trip average obtained in the MSHD home interview, and an average of 6.6 in the police station was found.

Each of the two interviewers who interviewed both in the police station and at home obtained a higher trip average in the home interview situation; therefore, it was evidently a function of the interviewing situation, not of the interviewer. When the police station interviewing procedure, was re-examined it was decided that one factor could have been improved. The interviewers were too hurried, taking on the average about 18 minutes per interview. The presence of more interviewers would have improved this. There was no problem of cooperation; the respondents would have stayed longer but there was no interview time to give them.

The major difficulty is that fewer housewives are interviewed in a license-renewal procedure. Thus fewer shopping, social recreation, and other non-work trips are reported. This is an inherent disadvantage. On the other hand, the home interview procedure results in fewer work trips being reported, and this is its inherent disadvantage. Because facilities are planned with the work trip principally in mind, the driver's license procedure may very well be the most valid of the two techniques for some traffic planning purposes.

SPECIFIC ADVANTAGES OF DRIVER'S LICENSE RENEWAL PROCEDURE

The principal advantage of the driver's license procedure over the household interview can be summarized in a single phrase—it saves money (Table 3). It was found that in the Battle Creek field operations, the costs ran about $2.00 less per interview

TABLE 3

COMPARATIVE COSTS OF DETROIT AREA TRAFFIC STUDY, DRIVER'S LICENSE RENEWAL PROCEDURE, O-D AND MICHIGAN STATE HIGHWAY DEPARTMENT HOUSEHOLD INTERVIEW O-D, BATTLE CREEK, MICHIGAN, 1961

Phase	No. of Interviews		Cost per Interview ($)		Battle Creek Survey Total Cost ($)	
	MSHD	DATS	MSHD	DATS	MSHD	DATS
Sample Selection	1,147	1,147	0.82	none	940.54	none
Interviewing, coding, and check-coding (wages)	1,147	1,147	4.62	3.62	5,299.14	4,152.14
Interview-collection cost (mileage)	1,147	1,147/135 H.I.	0.24	0.05	275.28	57.35
Total	1,147	1,147	5.68	3.67	6,514.96	4,209.49
Difference in cost		Same		2.01 less		2,305.47 less

or about 35 percent less for the entire survey. These differentials cannot be linearly extrapolated, because the relationship of the various cost elements is dependent on the geographic size and population of an area. A table of estimated costs based on population and geographic considerations has been prepared. Estimated comparative costs of collection of data by household interview O-D and driver's license O-D, for three levels of population size are given in Table 4.

Other advantages of the driver's license procedure are the following:

TABLE 4

Population of Area	Cost (dollars)		Percent Saving
	Household Interview O-D	Driver's License O-D	
40,000	6,500	4,000	38
400,000	60,000	28,000	53
4,000,000	300,000	130,000	57

1. The sample selects itself, there are no errors in judgment or sampling techniques possible.
2. This method of obtaining the interviews is highly flexible as to time and place. The entire population is covered by interview stations; the respondent is obliged to report to the station with no effort on the interviewers' part; and no preliminary work is necessary because the sample is automatic. Thus, one can, make an O-D survey on very short notice and at any time of the year.
3. Because the interviews are established at a desk in the licensing office, and because only rarely will they be interviewing continuously throughout the day, the time remaining between interviews can be used to do practically all of the necessary coding. Thus, they are much more efficient than the home interviewer who wastes time on unproductive travel. A system of transporting finished interviews from busier to less busy interviewing stations for the purpose of coding can be worked out in the process of the survey, with a corresponding increase in efficiency.

SUMMARY

This single experience in comparing a conventional household interview O-D survey with obtaining similar information from licensed drivers at the time of license renewal has shown that the two types of surveys produce essentially the same distribution and behavioral pattern information. The driver's license O-D survey is deficient in that it produces somewhat fewer total trips, but at the same time work trips are better reported by the driver's license technique. Although there are some additional minor advantages of the driver's license technique, its principal advantage is that it costs from 38 percent to 57 percent less than the household interview O-D survey.

This paper is a brief abstract of a lengthy report now being prepared for the Michigan State Highway Department. Copies of the complete report giving full explanatory details will be available in the spring of 1962.

ACKNOWLEDGMENT

This study was financed by the Michigan State Highway Department, in cooperation with the U.S. Bureau of Public Roads.

REFERENCE

1. Pasamanick, B., Dinitz, S., and Knoblock, H., "Socio-Economic and Seasonal Variations in Birth Rates." Milbank Memorial Fund Quar., 38: 248-254 (July 1960).

Trip Generation and the Home

PAUL W. SHULDINER, Department of Civil Engineering, Northwestern University, Evanston, Ill.

The relationship between a number of household and neighborhood characteristics and the frequency of person-trips associated with individual dwelling units is analyzed. Family size and vehicle ownership are found to have the greatest effect on trip production. Other dwelling unit variables affect trip generation only slightly when the impact of associated variations in family size and vehicle ownership are accounted for.

A fuller understanding of observed variations in trip generation is derived from consideration of certain social characteristics of the generating area. Two indexes obtained from Census data—social rank and degree of urbanization—are found to be particularly useful in this regard.

The paper closes with a brief discussion of the apparent gain in precision which results from grouping data before regression analysis. Examples of the bias that such aggregation produces are considered.

•THIS REPORT is a study of the effect of variations in several household and neighborhood characteristics on urban trip generation. Neighborhood characteristics are described in terms of a social area typology developed by E. Shevky and W. Bell from data published in the U.S. Decenial Census of Population. The typology is composed of three indexes representing the social rank, degree of urbanization, and extent of segregation of a census tract or other limited geographic area. This phase of the analysis is limited to a sample of census tracts in the City of Chicago.

The variables relating directly to individual households (such as family size and vehicle ownership) were derived from standard O-D data. The source of individual household data was a home interview origin-and-destination study of 5,039 homes conducted in 1956 by the California Division of Highways in the Modesto, Calif., area. The survey area encompassed about 60 square miles and included the City of Modesto, the county seat and marketing center of Stanislaus County, and the neighboring town of Ceres. The population of the entire study area was 77,355 persons, of which 29,155 lived in Modesto and 3,870 in Ceres. A more complete description of the Modesto study is found elsewhere (1).

For most of this study, the basic unit of analysis is the individual household. The use of single households differs significantly from the customary practice of working only with geographic aggregations of dwelling units such as traffic or analysis zones. Single-unit analysis permits investigation of the effects of non-numeric and, therefore, non-averageable characteristics (such as occupation or dwelling unit type) on trip generation. Even where family size, vehicles ownership, or other numeric variables are employed, the use of individual dwelling units provides a much more sensitive and unbiased measure of existing relationships. A comparison of the results obtained using grouped and ungrouped data is presented, showing the extent of the aggregation bias and the apparent gain in precision obtained through grouping.

The analysis is concerned first with data from the Modesto survey. Considered here are the effects of five household characteristics: family size, vehicle ownership, occupation of the head of the household, distance to the CBD, and type of dwelling unit, on frequency and kinds of trips made from the home. (Unless otherwise specified, for the Modesto data, "trips" include all person-trips made from the home by members of the household either as auto drivers or as auto or transit passengers. Walking trips, including walking trips to work, are not considered.)

FAMILY SIZE

If travel is a function of human activity, a relationship should exist between the frequency of trips made from the home and the size of the family making such trips. To test this hypothesis, the dwelling units in the Modesto study were grouped according to the number of persons in each household. Separate mean trip generation rates were then computed for each family size category. These data, summarized as marginal subtotals in Table 1, are shown in Figure 1. Average trip frequency increases with increasing persons per household—rapidly at first, then more slowly in the upper range of family size. The sharp dip at the 7 person-per-household level is probably due more to random variations caused by the small cell size in this category than to any inherent relationship between the variables.

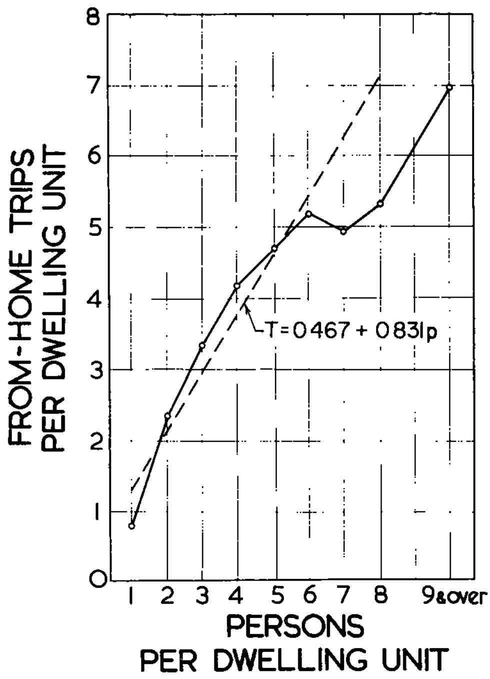


Figure 1. Frequency of from-home trips per dwelling unit at various levels of family size.

The general concavity of the curve reflects the changing age composition of the family as the household grows. Table 2 shows that the percentage of persons 14 years of age and older in the family falls from 99 percent in two-person families, to 45 percent where there are 7 persons in the household. Because children do not make as many vehicle trips as adults, a smaller and smaller portion of each increment of family size is available to affect trip generation. Reduction in the rate of increase is also a result of the restriction in trip making imposed by lower car/person ratios in larger familes (see Table 2).

Although the shape of Figure 1 is clearly curvilinear, most of the observations are concentrated in the middle range. For this reason, the relationship among the data

TABLE 1

EFFECT OF FAMILY SIZE AND VEHICLE OWNERSHIP ON FROM-HOME TRIP FREQUENCY

No of Persons per DU	0 Veh per DU		1 Veh per DU		2 Veh per DU		3 Veh per DU		4 Veh per DU		5 Veh per DU	
	Trips per DU	No of DU	Trips per DU	No of DU	Trips per DU	No of DU	Trips per DU	No of DU	Trips per DU	No of DU	Trips per DU	No of DU
1	0 37	403	1 21	330	1 73	15	--	--	--	--	0 77	748
2	0 79	193	2 49	947	2 64	352	3 17	23	--	--	2 31	1,515
3	1 66	56	3 16	452	3 80	333	3 96	57	--	--	3 35	898
4	2 16	25	3 88	462	4 48	337	5 46	60	6 27	11	4 19	895
5	2 11	18	4 03	274	5 39	229	6 31	39	--	--	4 68	560
6	3 50	12	4 29	100	5 98	90	6 81	16	--	--	5 12	218
7	--	--	4 03	34	4 83	41	7 64	14	--	--	4 96	89
8	--	--	5 14	14	--	--	--	--	--	--	5 14	14
Total	0 75	707	2 95	2,613	4 08	1,397	5 20	209	6 27	11	3 05	4,937

TABLE 2

FAMILY COMPOSITION AND AVERAGE VEHICLE OWNERSHIP FOR DIFFERENT HOUSEHOLD SIZES

Persons per DU	Percent Family 14 Years and Older	Avg. No. of Wage Earners per Family	Percent of Family Wage Earners	Avg. No. of Veh. per Dwelling Unit	Avg. No. of Veh. per Person
1	100	0.82	82.0	0.48	0.48
2	99	1.33	66.5	1.13	0.57
3	80	1.66	55.4	1.44	0.48
4	62	1.47	36.8	1.52	0.38
5	64	1.55	31.0	1.51	0.30
6	47	1.39	23.2	1.50	0.25
7	45	2.01	27.7	1.78	0.25

may be described by a linear regression equation as a first approximation. The least squares regression equation relating family size and from-home trip frequency was computed to be

$$T = 0.467 + 0.831p \tag{1}$$

in which

T = average number of person trips made from the home per day;

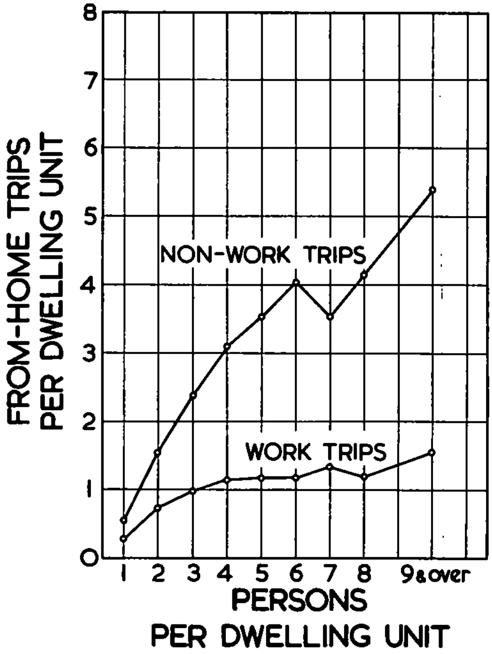


Figure 2. Frequency of from-home work and non-work trips per dwelling unit at various levels of family size.

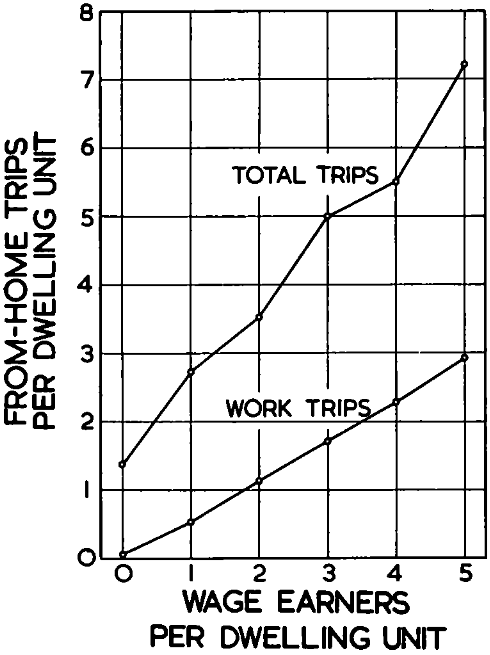


Figure 3. Frequency of from-home work and non-work trips per dwelling unit for various numbers of wage earners per dwelling unit.

p = number of persons living in the dwelling unit.

The coefficient, 0.831, indicates that the addition of each family member increases from-home trip production by about 0.8 trips per day. Comparison of the slope of the regression line with the curve in Figure 1 shows that the coefficient, 0.8, approximates the true increase only in the middle range of household size. It underestimates the effect of family size at the lower end and exaggerates it for the larger families. Over the entire range, the standard error of estimate, σ_e, is ±0.76 trips per day and the coefficient of variation is 24.5 percent. (The inclusion of non-linear terms in this and subsequent equations increases the precision of the estimate only a negligible amount due to lumping of the data in the middle and lower range of the independent variable. The gain is much too slight to justify the additional computations involved.)

The increase in trip production accompanying increased family size is mainly in the non-work category. Figure 2 shows work trips level off at the 4-person-per-dwelling-unit level, whereas non-work trips continue to rise beyond this point. Because work trips vary almost linearly with number of workers (see Fig. 3), limitation of the number of wage earners in even the largest families results in the leveling off in the frequency of work trips which is observed.

VEHICLE OWNERSHIP

Although it is the activities of persons which produce the demand for trips, it is chiefly the presence of the automobile and an adequate system of streets and highways which makes the satisfaction of these demands possible. Assuming that in any one community the relative adequacy of the road system is more or less uniform throughout that community, the opportunity to travel will be principally a function of the number of motor vehicles available for use by the members of the household. By separating the households in the Modesto area according to the number of vehicles owned, this hypothesis could be tested. These data, summarized along the lower margin in Table 1, are shown in Figure 4. As noted in the case of family size, the curve is concave downward, indicating that the intensity of vehicular use in terms of trips per vehicle is lower for multi- than for single-car households. The relationship beyond three vehicles per dwelling unit is based on only 54 observations and therefore, should not be given as much weight as the other points.

Most of the observations fall in the one- and two-car-per-dwelling-unit range, and, as before, the data may be summarized by a linear regression equation. The least squares equation is

$$T = 1.229 + 1.379v \qquad (2)$$

in which

T = average number of person trips made from the home per day;
v = number of vehicles per dwelling unit.

The graph of this expression is superimposed on the curve of the tabulated data in Figure 4, which shows that the coefficient, 1.379, understates the effect of vehicle ownership in the lower range of the independent variable and overstates it in the upper portion of the curve. This will always be the case where a straight line is fitted to data that are concave downward. The standard error of estimate, σ_e, is ±0.78 trips per day and the coefficient of variation is 25.2 percent.

In addition to summarizing the relationship between vehicle ownership and from-home trip frequency for Modesto, Figure 4 includes similar data prepared for 36 cities by Schmidt and Campbell (2). The agreement between these data and the curve derived from tabulated Modesto information is quite good in the lower range of vehicle ownership. However, linear extrapolation beyond the one-vehicle-per-dwelling-unit limit would grossly overestimate the frequency of generated trips.

The effect of auto ownership on travel mode is shown in Figure 5. As car ownership increases from zero- to four-vehicles-per-person, auto-driver trips rise, both numerically and as a proportion of total trips. Auto-passenger trips decline proportionately, although their absolute numbers generally increase. The frequency of transit trips, though consistently low at all levels of vehicle ownership, represents a significant mode of travel for families owning no vehicles. This would indicate a definite and continuing need for transit service even in areas of high auto ownership such as those characterized by Modesto and cities of similar size.

JOINT EFFECTS OF FAMILY SIZE AND VEHICLE OWNERSHIP

Because high vehicle ownership is usually associated with large family size, the effect of either of these variables on trip frequency tends to be exaggerated by the contributory effects of the other. Interference of this type can be eliminated by cross-tabulating the two independent variables. Table 1 shows such a cross-tabulation permits analysis of the relation between family size, for example, and trip frequency at any level of vehicle ownership. Conversely, it allows the study of effects of variations in vehicle ownership at any level of family size.

The data of Table 1 are shown graphically in Figures 6 and 7. Figure 6 illustrates the effect of family size on trip production at four different levels of vehicle ownership. This set of curves shows that not only do trips per dwelling unit increase with increasing family size, but also that the rate of increase is least at the zero-vehicle level and greatest for families owning two or three cars. It would appear that the greater trip potential inherent in larger families is fully realized only where a sufficient number of automobiles is available for use by the family members. (It is also likely that multi-car families contain a greater number of adults than single-car families of the same size and, therefore, would produce more trips, all other things being equal.) A similar effect is noted in Figure 7, where the rate of increase in trip frequency with increasing vehicle ownership is greatest for large families and least for small ones.

Figures 6 and 7 have been combined into Figure 8, an isometric block diagram, to illustrate the joint relationship between family size, vehicle ownership, and frequency of from-home trips. In this diagram, as in the previous two, only data for those classes containing ten or more dwelling units have been shown in order to exclude erratic values resulting from very small class sizes.

The surface of relationship in Figure 8 may be estimated by

$$T = -0.137 + 0.632p + 0.950v \tag{3}$$

in which T, p and v are defined as before. The standard error of estimate is ± 0.72 trips per day and the coefficient of variation is 23.2 percent.

Comparison of Eq. 3 with the two equations discussed previously indicates the extent to which consideration of either one of the variables, person or vehicles, by itself, overestimates the effect of that variable on trip generation. In Eq. 1, the addition of one person to the household resulted in an increase of 0.8 trips per dwelling unit per day. Because family size and vehicle ownership are, themselves, related in a positive manner, inclusion of the effect of vehicle ownership in the regression equation reduces the impact of family size from 0.8 to 0.6 trips per day, a reduction of 25 percent. A comparable reduction in the effect of vehicle ownership on trips is noted when family size is also considered. In this instance, the coefficient drops from 1.4 to 0.95 trips per dwelling unit per day.

DISTANCE TO CENTRAL BUSINESS DISTRICT

An increase in the average frequency of motor vehicle trips with increasing distance of the dwelling unit from the CBD is a well-observed phenomenon in most urban traffic studies. CBD distance, however, is also associated with household size and level of vehicle ownership—variables which, themselves, are closely related to trip production.

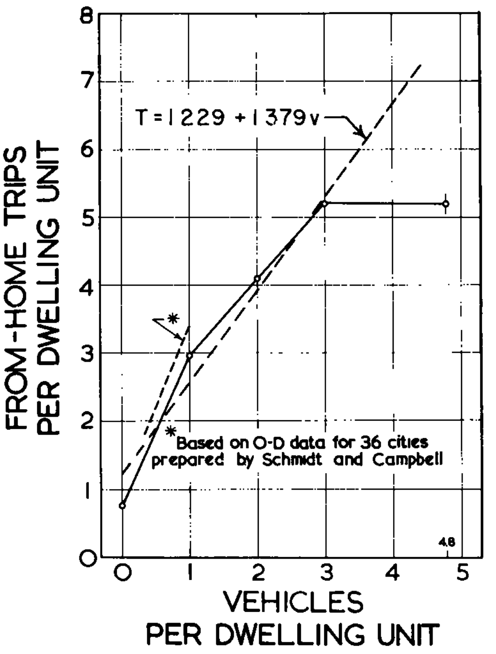


Figure 4. Frequency of from-home trips per dwelling unit at various levels of vehicle ownership.

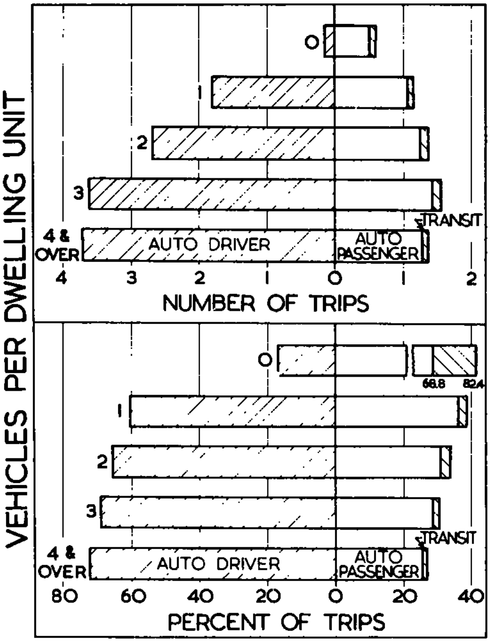


Figure 5. Number and percent of from-home trips per dwelling unit by mode of travel at various levels of vehicle ownership.

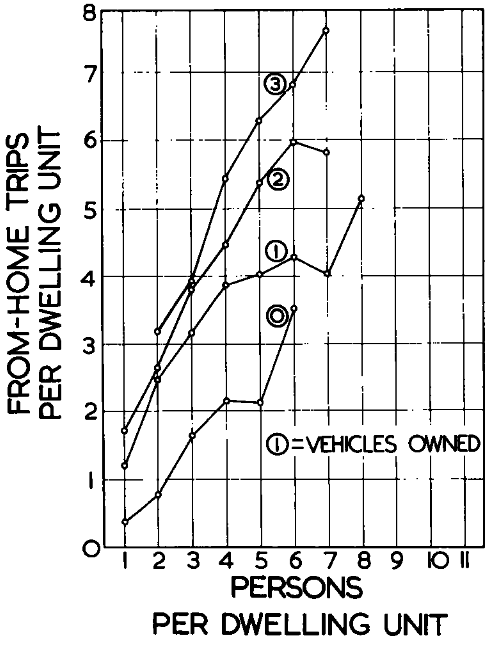


Figure 6. Frequency of from-home trips per dwelling unit at various levels of family size and vehicle ownership.

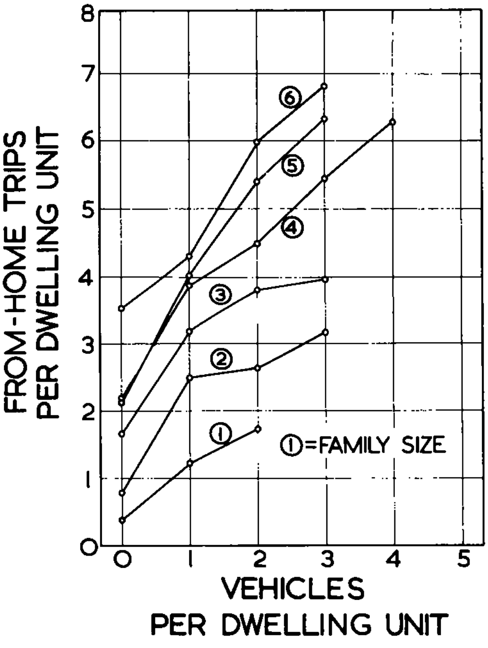


Figure 7. Frequency of from-home trips per dwelling unit at various levels of vehicle ownership and family size.

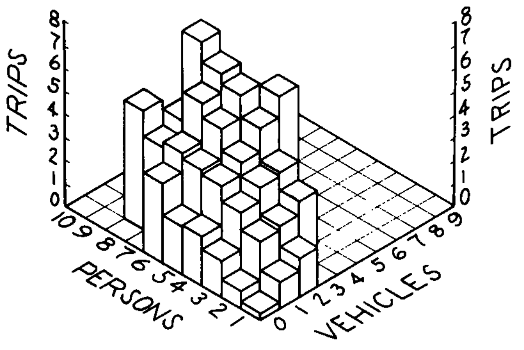


Figure 8. Frequency of from-home trips per dwelling unit at various levels of family size and vehicle ownership.

Average trip frequency, family size, and vehicle ownership have been summarized in Table 3 according to distance of the dwelling unit from the CBD. The resulting relationships are shown in Figure 9. Vehicle ownership and family size rise parallel with trip frequency as distance from the city center increases.

To test the effect of distance on trips, independent of variations in the other two variables, the Modesto households were cross-tabulated according to each of the three independent variables. In this manner, each of the nine distance categories was subdivided into 20 subclassifications depending on dwelling unit size and number of vehicles owned. Average trip frequencies for the resulting 180 cells are given in Table 4. Mean trip frequencies for two- and four-person households owning one vehicle are shown in Figure 10. A very slight upward trend is still discernible (almost obliterated by sampling variability due to small cell frequencies), but the strong relationship between distance and trips which is apparent in Figure 9 is no longer evident. The association between trip frequency and distance from the city center is seen mainly to reflect concurrent variations in family size and vehicle ownership.

DWELLING UNIT TYPE

A number of alternative hypotheses may be appropriate in explaining the association of different trip generation rates with different types of dwelling units. Perhaps the most interesting and fruitful of these considers dwelling unit type to be a reflection of the degree of integration of the family into the community. Families residing in single family dwelling units are assumed to be the most highly integrated, whereas those living in hotels are considered to be the least integrated. Associated with higher degrees of integration should be greater participation in social and community activities which, on the average, may result in a great number of trips from these types of dwelling units as compared to less settled households.

To test this hypothesis, the dwelling units in the Modesto area were classified

TABLE 3

AVERAGE NUMBER OF FROM-HOME TRIPS, PERSONS, AND VEHICLES PER DWELLING UNIT AT VARIOUS DISTANCES FROM THE CITY CENTER

Distance to CBD (mi)	From-Home Trips per DU	Avg. No. of Persons per DU	Avg. No. of Veh. per DU	No. of Cases
0.0 - 0.3	1.19	1.72	0.52	155
0.4 - 0.6	2.00	2.26	0.94	508
0.7 - 0.9	2.66	2.65	1.19	432
1.0 - 1.4	3.26	2.99	1.32	861
1.5 - 1.9	3.21	3.26	1.27	1,086
2.0 - 2.4	3.44	3.46	1.35	806
2.5 - 2.9	3.50	3.32	1.39	476
3.0 - 3.9	3.56	3.42	1.50	350
4.0 and over	3.50	3.49	1.40	364

TABLE 4

FREQUENCY OF FROM-HOME TRIPS PER DWELLING UNIT AT VARIOUS DISTANCES FROM CBD FOR DIFFERENT COMBINATIONS OF FAMILY SIZE AND VEHICLE OWNERSHIP

0 VEHICLES PER DWELLING UNIT

DISTANCE TO CBD, miles	FROM-HOME TRIPS PER DWELLING UNIT					
	PERSONS PER DWELLING UNIT					TOTAL
	1	2	3	4	5 & MORE	
0.0-0.3	0.21 70	0.43 14	1.00 4	—	1.00 1	0.29 89
0.4-0.6	0.29 99	0.58 40	1.00 8	1.00 3	2.00 2	0.44 152
0.7-0.9	0.53 43	0.50 20	0.33 3	1.00 1	3.00 1	0.56 68
1.0-1.4	0.44 50	0.95 22	1.00 10	3.67 3	6.75 4	1.02 89
1.5-1.9	0.52 60	0.92 39	2.13 15	2.30 10	2.09 11	1.07 135
2.0-2.4	0.34 32	0.96 28	2.54 13	1.40 5	2.78 14	1.27 92
2.5-2.9	0.35 17	1.50 12	0.00 1	0.00 1	1.00 2	0.79 23
3.0-3.9	0.27 15	0.50 4	2.00 1	6.00 1	1.00 2	0.70 23
4.0 & OVER	0.41 17	0.71 14	3.00 1	3.00 1	2.00 2	0.77 35
TOTAL	0.37 403	0.79 193	1.66 56	2.16 25	2.69 39	0.77 716

1 VEHICLE PER DWELLING UNIT

DISTANCE TO CBD, miles	FROM-HOME TRIPS PER DWELLING UNIT					
	PERSONS PER DWELLING UNIT					TOTAL
	1	2	3	4	5 & MORE	
0.0-0.3	0.81 21	2.25 16	1.86 7	7.67 6	1.00 1	2.28 51
0.4-0.6	1.12 60	2.26 113	3.00 43	2.88 26	5.06 19	2.39 261
0.7-0.9	1.02 41	2.42 112	2.97 39	2.91 24	4.00 23	2.45 239
1.0-1.4	1.41 66	2.57 200	3.97 63	4.19 79	3.95 61	3.05 469
1.5-1.9	1.36 56	2.66 179	3.20 112	3.68 118	3.73 117	3.06 582
2.0-2.4	1.50 24	2.34 123	3.46 91	3.71 96	3.71 85	3.12 419
2.5-2.9	1.15 27	2.76 98	2.57 35	4.15 46	4.69 54	3.21 260
3.0-3.9	1.21 19	2.10 40	2.54 33	3.56 36	5.12 34	3.04 162
4.0 & OVER	0.88 16	2.44 66	2.58 29	5.22 31	5.96 41	3.58 183
TOTAL	1.21 330	2.49 947	3.16 452	3.88 462	4.26 435	2.98 2626

2 VEHICLES PER DWELLING UNIT

DISTANCE TO CBD, miles	FROM-HOME TRIPS PER DWELLING UNIT					
	PERSONS PER DWELLING UNIT					TOTAL
	1	2	3	4	5 & MORE	
0.0-0.3	—	1.60 5	2.00 3	2.67 3	15.00 1	3.08 12
0.4-0.6	1.00 1	2.75 28	3.61 31	2.60 10	4.78 9	3.28 79
0.7-0.9	2.50 2	2.87 38	3.52 29	4.71 17	4.93 15	3.66 101
1.0-1.4	2.00 2	2.68 62	4.10 60	4.76 69	5.16 66	4.18 259
1.5-1.9	1.50 2	2.83 74	3.95 64	4.37 86	5.46 82	4.18 308
2.0-2.4	2.00 3	2.74 51	4.09 56	4.58 60	5.66 68	4.35 238
2.5-2.9	1.00 2	2.20 35	3.50 32	5.03 38	6.26 50	4.42 157
3.0-3.9	1.00 2	2.11 35	3.47 34	4.64 28	5.92 38	4.01 137
4.0 & OVER	3.00 1	2.87 24	3.66 24	3.73 26	4.63 41	3.85 116
TOTAL	1.53 15	2.64 352	3.80 333	4.48 337	5.49 370	4.09 1407

3 & MORE VEHICLES PER DWELLING UNIT

DISTANCE TO CBD, miles	FROM-HOME TRIPS PER DWELLING UNIT					
	PERSONS PER DWELLING UNIT					TOTAL
	1	2	3	4	5 & MORE	
0.0-0.3	—	2.00 1	—	3.00 1	—	2.50 2
0.4-0.6	—	4.00 4	3.33 6	9.00 1	4.75 4	4.27 15
0.7-0.9	2.00 1	4.00 1	5.17 6	6.50 4	8.00 11	6.56 23
1.0-1.4	—	4.50 4	4.24 12	5.50 12	4.69 16	4.78 44
1.5-1.9	2.00 3	1.67 6	3.83 12	5.94 19	7.14 14	5.09 54
2.0-2.4	1.00 1	2.00 2	3.94 18	4.86 14	7.31 22	5.35 57
2.5-2.9	—	3.00 4	3.74 4	4.14 7	5.10 10	4.52 25
3.0-3.9	—	2.75 4	4.00 5	5.63 8	8.19 11	5.93 28
4.0 & OVER	3.00 1	3.60 5	3.50 6	7.14 7	6.38 8	5.29 27
TOTAL	2.50 6	3.13 31	3.98 69	5.61 73	6.61 96	5.21 275

0.21 = FREQUENCY OF FROM-HOME TRIPS PER DWELLING UNIT
70 = NUMBER OF DWELLING UNITS IN SAMPLE

according to type. Mean trip frequency, family size, and vehicle ownership were then computed for each type. This information is summarized in Table 5, where the five dwelling unit types are arranged in increasing order of permanency. In keeping with the hypothesis, average trip frequencies increase with increasing degree of permanency—but so do family size and vehicle ownership. To account crudely for these concurrent variations, the mean trip frequencies were adjusted for differences in vehicle ownership and family size according to the multiple regression equation developed earlier. Adjustment in this manner greatly reduces the differences in average trip frequency between each type, although the ranking of the various types is unchanged. (The more rigorous approach would have been to compute separate regression equations for ve-

TABLE 5

EFFECT OF FAMILY SIZE AND VEHICLE OWNERSHIP ON FROM-HOME TRIP FREQUENCY BY DWELLING UNIT TYPE

DU Type	Avg No. of Persons per DU (p)	Avg No. of Veh. per DU (v)	Avg. No. of From-Home Trips per DU (T)	Adjusted No. of From-Home Trips per DU (Ta)[1]	No. of DU
Hotel, motel, Rooming house, etc.	1.99	0.67	1.50	2.95	206
House trailer	2.15	0.82	1.91	3.10	112
Apartment	1 74	0 64	1.57	3.19	149
Duplex and flat	2 37	0 94	2.31	3.26	334
Single-family	3.25	1 35	3.32	3.32	4,237

[1] Average trip frequencies for each dwelling unit type were adjusted by moving T up regression line, $T = -0.137 + 0.632p + 0.950v$, to point where levels of family size and vehicle ownership were all equal to those of single-family group. For example, in apartment category:

$$\begin{aligned} T_a &= 1.57 + (3.25 - 1.74)\ (0\ 632) + (1.35 - 0.64)\ (0.950) \\ &= 1.57 + 0.95 + 0\ 67 \\ &= 3.19. \end{aligned}$$

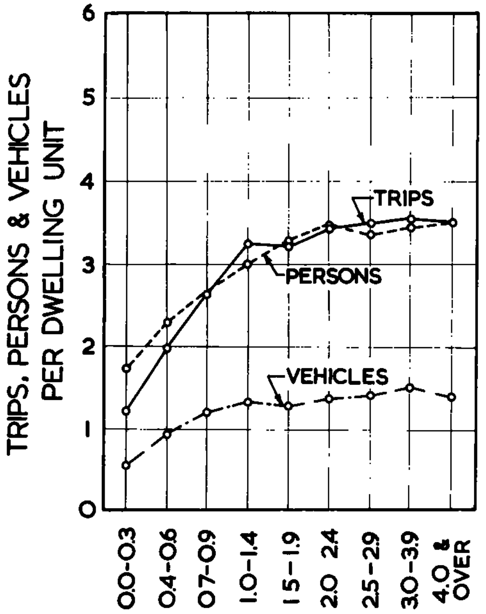


Figure 9. Frequency of from-home trips per dwelling unit, family size and vehicle ownership at different distances from CBD

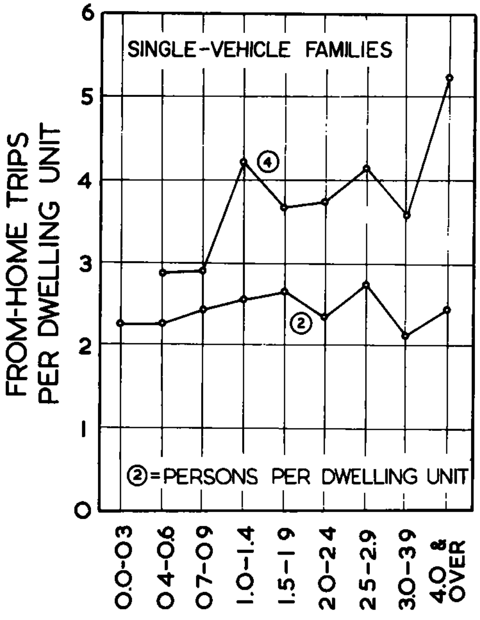


Figure 10. Frequency of from-home trips per dwelling unit for various family sizes at different distances from CBD.

TABLE 6

COMPOSITION OF THE FOUR OCCUPATION STATUS GROUPS

Status Group	Occupation
High	Professional and semi-professional; proprieters; managers, and officials; farmers and farm managers
Medium	Clerks and salesmen (including traveling salesmen), protective services, military personnel
Low	Operators, semiskilled laborers, farm laborers; personal service; truck and taxi drivers; deliverymen
Non-gainful	Retired, housewives, students, looking for work, employment status unknown

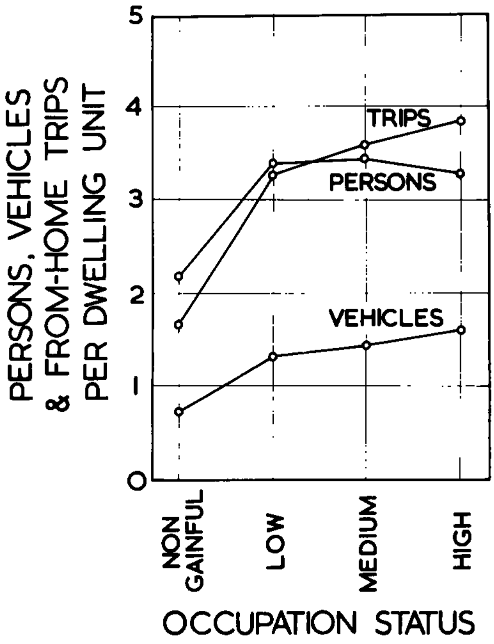


Figure 11. Variations in from-home trips, persons and vehicles per dwelling unit for different occupation status groups.

TABLE 7

EFFECT OF FAMILY SIZE AND VEHICLE OWNERSHIP ON FROM-HOME TRIP FREQUENCIES BY OCCUPATION STATUS

Occupation Status of Head of Household	Avg No. of Persons per DU (p)	Avg No. of Veh per DU (v)	Unadjusted No of From-Home Trips per DU (T)	Adjusted No. of From-Home Trips per DU (Ta)[1]	No. of DU
Non-gainful	2.17	0 74	1.68	2.97	1,202
Low	3.37	1.30	3.24	3.24	1,381
Medium	3 41	1.42	3.58	3 44	1,263
High	3.26	1.58	3.83	3.63	1,192

[1] Trips adjusted to level of low group on basis of regression equation: $T = -0.137 + 0.632p + 0\ 950v$.

hicles and persons within each class of dwelling unit. The average number of trips per dwelling unit for each type would then have been adjusted according to the equation for that particular type.)

OCCUPATION OF HEAD OF HOUSEHOLD

The occupation of the head of the household is one of the major determinants of the level of living a family enjoys. As such, occupation should be associated with trip frequency, as well as with other household characteristics (such as family size and vehicle ownership) which have been shown to affect trip production.

To test the relation between occupation and trip generation, the 14 occupation groups reported in the Modesto study were combined into four categories roughly indicative of the status of the several occupations included within each category. The composition of each category is shown in Table 6. The dwelling units in the Modesto area were then identified with one of the four status groups according to the reported occupation of the head of the household. Average trip frequency, vehicle ownership, and family size were computed for each of these four groups and are reported in Table 7. Figure 11 shows all three variables exhibit approximately parallel changes in moving between the four occupation groups. Adjusting trip frequencies for differences in the other two variables according to the approximate technique previously discussed decreases the differences between the mean trip frequencies considerably. A very crude analysis of the resulting variances indicates that this adjustment reduces the variance ratio from approximately 40 to 4.5, a value that is significant at the 0.005 level.

To study further the effects of occupation status on trip generation, each of the four occupation groups was subdivided into 16 classes depending on level of family size and vehicle ownership. Mean trip generation rates for each of the 64 resulting categories are given in Table 8. These data are summarized in Figure 12, which shows the manner in which trip generation varies with changing occupation for each combination of vehicle ownership and family size. A slight increase in trip frequency is noticeable with changing occupation, but most of the variation apparent in Figure 11 is seen to be a result of associated variations in household size and vehicle ownership.

Table 9 and Figure 13 show the distribution of from-home trips by purpose for the different status groups. With the exceptions of an understandably small proportion of

TABLE 8

FREQUENCY OF FROM-HOME TRIPS PER DWELLING UNIT AT VARIOUS LEVELS OF FAMILY SIZE AND VEHICLE OWNERSHIP WITHIN FOUR OCCUPATION STATUS GROUPS

NON GAINFUL

PERSONS PER DWELLING UNIT	FROM-HOME TRIPS PER DWELLING UNIT				
	NUMBER OF VEHICLES OWNED				TOTAL
	0	1	2	3	
1	0.30 276	1 24 106	2.00 2	0.00 1	0 57 385
2	0 70 138	2 02 327	2.32 47	1 33 3	1 69 515
3	1 30 30	2 33 70	3 13 38	4.75 4	2.40 142
4	1.64 11	3 22 36	4 83 18	4 60 5	3 49 70
TOTAL	0.52 455	1 99 539	3 04 105	3 54 13	1.51 1112

LOW STATUS

PERSONS PER DWELLING UNIT	FROM-HOME TRIPS PER DWELLING UNIT				
	NUMBER OF VEHICLES OWNED				TOTAL
	0	1	2	3	
1	0.47 78	0 99 84	1 50 4	1 67 3	0 78 169
2	0 92 38	2 70 221	2 46 79	3 33 6	2 46 344
3	2.06 17	3 28 144	3.53 96	4 16 13	3.33 270
4	1 50 8	3.94 138	4 33 86	4 50 16	4.03 248
TOTAL	0 84 141	2 89 587	3 43 265	3 97 38	2 79 1031

MEDIUM STATUS

PERSONS PER DWELLING UNIT	FROM-HOME TRIPS PER DWELLING UNIT				
	NUMBER OF VEHICLES OWNED				TOTAL
	0	1	2	3	
1	0 67 27	1.20 64	1.50 4	2 00 2	1 08 97
2	0.86 7	2.72 212	2.66 97	3.33 3	2.67 319
3	—	2.98 132	3.92 102	3.61 18	3 40 252
4	—	3.81 167	4.54 122	5.33 15	4.21 304
TOTAL	0.71 34	2.93 575	3.75 325	4.39 38	3.18 972

0.30 = FREQUENCY OF FROM-HOME TRIPS PER DWELLING UNIT

HIGH STATUS

PERSONS PER DWELLING UNIT	FROM-HOME TRIPS PER DWELLING UNIT				
	NUMBER OF VEHICLES OWNED				TOTAL
	0	1	2	3	
1	0.50 22	1.41 76	2.00 5	3.00 1	1.26 104
2	1.50 10	2.79 187	2 85 129	3 55 11	2.80 337
3	1.25 4	3.74 111	4.21 97	4.00 22	3.91 234
4	6.33 3	4.05 124	4.48 111	6.04 24	4.44 262
TOTAL	1.28 39	3.10 498	3.76 342	4.74 58	3.37 937

276 = NUMBER OF DWELLING UNITS IN SAMPLE

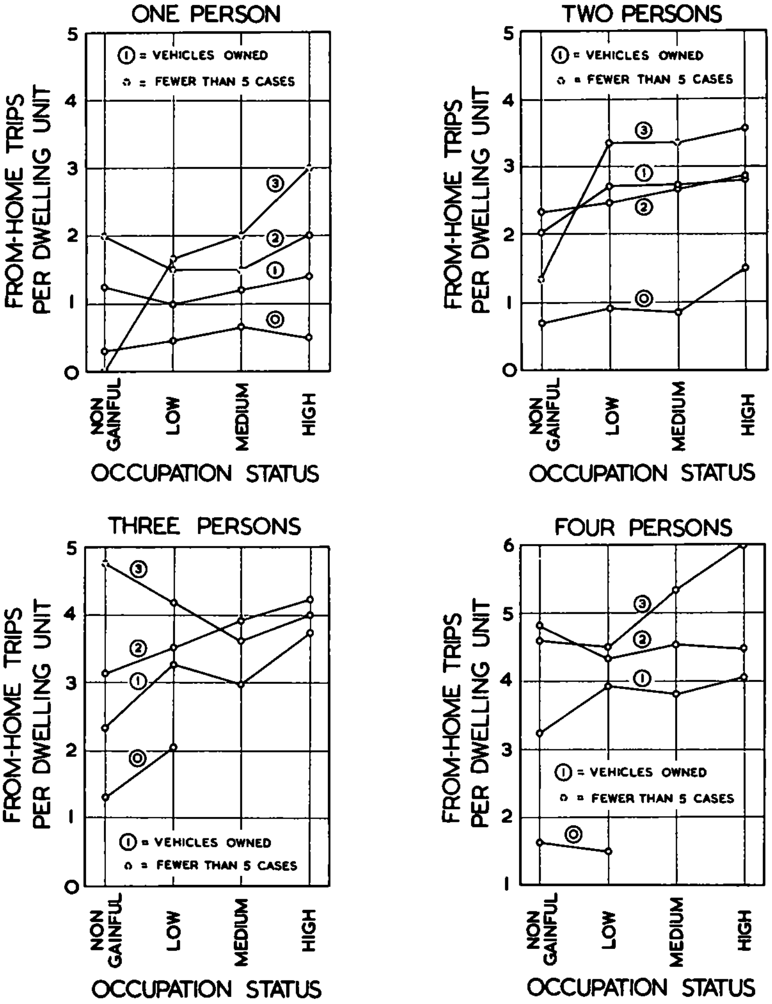


Figure 12. Frequency of from-home trips per dwelling unit for different occupation status groups at various levels of family size and vehicle ownership.

work trips in the non-gainfully employed group and a relatively large percentage of related business trips in the high group, a remarkable similarity in travel habits is evidenced. But for these two exceptions, occupation status apparently has little effect on the relative proportions of trips that families make for various purposes.

To facilitate comparison of the non-work trips, Table 10 gives the percent distribution of the five non-work categories alone. In this way, the effect of the very low proportion of work trips in the non-gainful group is eliminated, permitting a more realistic comparison to be made between the remaining non-work portions. As a result, the percentages for the non-gainful group fall more clearly into line with the other three classes and the similarities in the distributions becomes even more marked.

The lack of appreciable variations between the travel habits of families in the four status groups may be examined from diverse points of view. On one hand, the observed similarities may reflect a real lack of social differentiation between the various groups, at least insofar as travel habits are concerned. It may be that society is less rigid in western cities than in the older settled areas of the country. Perhaps the activities of lawyers and bricklayers in Modesto do not vary nearly so much as they do in Phila-

TABLE 9

DISTRIBUTION OF FROM-HOME TRIPS BY PURPOSE FOR VARIOUS OCCUPATION STATUS GROUPS

Occupation Status of Head of Household	Work (%)	Related Business (%)	Shopping (%)	Social Recreational (%)	Medical Dental (%)	Education Religion Civic (%)	Other[1] (%)	Total (%)
Non-gainful	11.0	0.5	22.9	29.3	2.2	7.5	26.6	100.0
Low	31.8	1.5	14.3	23.2	1.4	6.8	21.1	100.0
Medium	26.4	3.1	13.2	25.4	1.8	6.7	23.4	100.0
High	22.3	6.0	13.8	22.9	1.7	7.6	25.7	100.0
All groups	24.7	3.2	15.0	24.6	1.7	7.0	23.8	100.0

[1] Includes eat meal, serve passenger, change mode, and others.

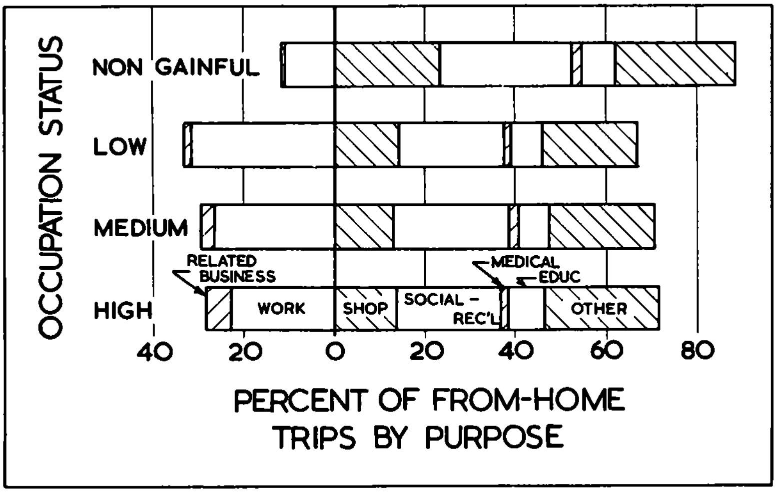


Figure 13. Percent distribution of from-home trips for four occupation status groups.

delphia or Boston, or even in smaller eastern communities. Studies of possible variations in relationships between status and trip characteristics in cities of differing types and in different parts of the country might provide a test of this premise.

On the other hand, failure to observe appreciable variations in travel habits may result from lack of a valid operational classification of occupational status and from the aggregation of dissimilar status classes into the same group. The status level of each occupation, as used in Table 6, is based on the classification scheme developed by Alba M. Edwards for use with the United States Census of 1930 (3). Changes in the status of certain occupations since that time, principally the economic and social gains made by semi-skilled laborers during and since World War II, tend to reduce the usefulness of this system of occupational ranking. The applicability of the Edwards ranking was further reduced by the combination in this study of such diverse classes as farmers and farm managers within the same status group.

TABLE 10

DISTRIBUTION OF NON-WORK FROM-HOME TRIPS BY PURPOSE FOR VARIOUS OCCUPATION STATUS GROUPS

Occupation Status of Head of Household	Shopping (%)	Social Recreational (%)	Medical Dental (%)	Education Religion Civic (%)	Other[1] (%)	Total (%)
Non-gainful	25.9	33.1	2.5	8.5	30.0	100.0
Low	21.4	34.8	2 1	10.1	31.6	100.0
Medium	18.7	36.0	2.6	9 5	33.2	100.0
High	14.3	31.9	2.4	10.6	35.8	100.0
All groups	20.8	34.1	2.4	9 7	33.0	100.0

[1] Includes eat meal, serve passenger, change mode, and others.

It is most important that future studies of this kind be based on a system of occupational ranking that is more in keeping with the current status of the various occupations. Also, every effort should be made to maintain the identity of each occupation throughout the analysis, rather than to combine occupations prematurely into larger status groups.

To test the generality of the relationships between occupation and trip generation developed for Modesto, data from another, quite different, community were examined.

TABLE 11

DISTRIBUTION OF TRIPS BY PURPOSE OF TRAVEL FOR VARIOUS OCCUPATION GROUPS (Chicago)

Status Group and Occupation		All Trips Other Than To-Home						No. of DU
		Avg. No. per DU	Percent by Purpose					
			Work	Shop	Social-Recreation	Other	Total	
High:	Managers and proprietors	4 36	43.6	12.2	15.8	28.4	100.0	643
	Professional	4 05	38.0	13.8	17.3	30.9	100.0	526
	Total	4 22	41.1	12.9	16.5	29.5	100.0	1,169
Medium:	Sales workers	4 74	54.9	9.3	11.4	24.4	100.0	324
	Craftsmen and foremen	3.10	46.2	14.2	14.8	24 8	100.0	896
	Clerical	2 64	51.1	11.4	13.6	23.9	100.0	469
	Total	3 29	49.2	12.5	13.8	24.5	100.0	1,689
Low:	Operatives	2 66	53.7	12.4	13.2	20.7	100.0	663
	Service Workers	2 71	50.9	10.0	15.1	24.0	100.0	340
	Laborers	2.43	57.6	7.0	13.6	21.8	100.0	270
	Total	2 62	53.8	10.6	13.8	21.8	100.0	1,273
Unemployed		2 45	13.5	24.9	25.7	35.9	100 0	293
Total		3 29	46.0	12.9	15.3	25.8	100.0	4,424

A sample of 4,455 dwelling units in the Chicago area were obtained from the Chicago Area Transportation Study and subdivided into twelve occupation categories. For each category, mean trip generation rates by trip purpose were computed. Table 11 summarizes these data for the major occupation categories, grouped into four classes roughly comparable to the four occupation status groups used in the Modesto study. Because Table 11 is based on all trips (except trips to home), it is not strictly comparable to Tables 9 and 10 for which only those trips originating at the home were used. There is enough in common, however, between the two studies to permit the following observations to be made.

Average daily trip frequencies vary with occupation, being greatest for the high group and lowest for the non-gainfully employed. The one occupation that is markedly different from the other occupations in its group is sales workers. The trip frequency for the sales group reflects the disproportionate number of job trip characteristic of this occupation. Because the Modesto data included only from-home trips, work trips made as part of the day's activities were not considered. With this one exception, the ranking of occupation groups according to average trip frequency agrees very well between the two studies. Further agreement is noted for the ranking of trips to work. As before, the proportion of work trips for the gainfully employed groups decreases as occupation status increases; the major exception once again being the sales group. Because trips to work represent the largest percentage of trips in Table 11, the relative proportions of trips for other purposes more or less reflect the variations previously discussed. The percentage for non-work purposes varies little between the several occupations (with the exception of the unemployed category).

Variations in family size and vehicle ownership between the different occupations are currently being analyzed. Pending completion of this analysis, further discussion of these data do not appear to be warranted at this time.

SOCIAL AREA INDEXES

The discussion heretofore has dealt with characteristics that were applicable to individual dwelling units. Differentiations between households in terms of family size, vehicle ownership, or some other attributes of a single dwelling unit, have been attempted which would help to explain why one household differs from other households in terms of the number of trips it produces. Yet, a family does not live in isolation; it affects and is affected by its environment. Indeed, the very nature of a trip demands that this be so.

Distance to the CBD is one way of summarizing a large number of environmental features that in some way may affect trip generation rates. However, at least for Modesto, the effect of distance is minimal once related variations in family size and vehicle ownership have been accounted for. Residential density is another environmental variable that, primarily through its effect on the rate at which walking trips are substituted for vehicular trips, is related to reported generation rates.

This section borrows from recent work in sociology in an attempt to describe the social environment in which a family lives, more fully and with a greater degree of precision than is possible through geographic measures such as location or residential density. The device used consists of three mutually independent indexes derived from census data to form a social area typology (4). This set of indexes, known as the Shevky-Bell typology, has been shown to exhibit a strong association with certain aspects of social behavior, such as neighborhood participation and political preference (5). To the extent that urban travel is a manifestation of urban social behavior, it is reasonable to expect that these indexes will help explain variations in urban trip making as well.

Three basic forms of social differentiation are proposed in the Shevky-Bell typology. Each local area (census tract, block, or enumeration district) is described in terms of social rank (economic status), urbanization (family status) and segregation (ethnic status). Using census statistics, these indexes are developed in the following manner:

1. Social Rank.—This index contains two elements: (a) the proportion of blue-collar workers, defined as the ratio of (1) craftsmen, operatives, and laborers to (2) all employees; and (b) education level as measured by the proportion of persons 25 years old and older who have completed eight or fewer years of schooling. The social rank index is inversely related to both ratios; hence, it attains a maximum value where no residents fall into the blue-collar jobs, and all residents 25 years and older have more than eight years of education.

2. Degree of Urbanization.—This index contains three elements: (a) fertility rate, defined as the ratio of children under five years of age to the female population of child-bearing age, "14 to 45" years of age; (b) female labor-force participation rate, meaning the percentage of women over 14 years of age who are in the labor force, and (c) incidence of single family dwelling units, or simply the percentage of single units to total dwelling units. The degree of urbanization index would be increased by (a) lower fertility rate, (b) higher female labor force participation rate, and (c) lower proportion of single dwelling units. In a sense, this index meters, in a rather negative way, the degree of attachment to the home. High values for this index imply less attachment to the home because of fewer children, higher likelihood of being employed, and less permanency of dwelling unit type in terms of average tenure.

3. Extent of Segregation.—This index is defined as the proportion of an area's residents who belong to certain minority groups, such as non-whites, foreign born Eastern Europeans, etc. It measures the extent to which these minority groups live in relative isolation.

From census tract data for Los Angeles and San Francisco, Shevky and Bell have shown that these three indexes are mutually orthogonal; that is, the frequency distribution of any one index is independent of the values assumed by the other two indexes. This is a highly desirable feature insofar as the indexes are used in multiple correlation analysis.

The impact of these social area indexes on trip generation rates was investigated with the aid of data for 57 traffic analysis zones in the Chicago area. From the CATS O-D survey, the following information was obtained for each of the 57 zones: average trips per occupied dwelling unit, Y; average car ownership, A; and average household size, H. The social area indexes for each census tract were computed from the 1950 population census data. Because each traffic analysis zone typically contains more than one census tract, some form of averaging proved essential. The three social area indexes for each traffic analysis zone represent weighted averages of the corresponding indexes for its constituent census tracts, where weights were proportional to land areas. Complete data for all 57 zones are given in Table 12.

The degree of association between pairs of variables is summarized by the matrix of correlation coefficients given in Table 13. Each coefficient indicates the direction (positive or negative), and closeness of the linear association between two variables; a value of zero corresponds to no association.

Inspection of the correlation matrix reveals several interesting results. As expected, the trip generation rate, Y, is most closely correlated with average car ownership A. The urbanization index, X_2, exhibits almost as high a negative correlation with trip frequency. This latter correlation may be interpreted as follows. A low urbanization index reflects greater attachment to the home as measured by larger proportions of children, fewer women in the labor force, and larger fractions of single-family dwelling units. Families who choose to reside in such low urbanization zones presumably have exhibited a preference for a way of life centering around the home. This preference must, in general, be accompanied by a commitment to greater travel demands. Indeed, the negative correlation of -0.883 between Y and X_2 would seem to support this line of argument.

The remaining two indexes, social rank, X_1, and segregation, X_3, show only modest correlations with trip generation rates. Furthermore, the three indexes were found to be approximately orthogonal to one another as advertised by Shevky and Bell.

The first model which was attempted related the trip generation rate, Y, to the three social area indexes, ignoring both car ownership and household size. The multiple

TABLE 12

SOCIAL AREA INDEXES AND RELATED VARIABLES FOR SELECTED TRAFFIC ANALYSIS ZONES (Chicago)

Traffic Analysis Zone	Trips per Occupied DU, Y	Average Car Ownership, A	Average Household Size, H	Social Rank Index X_1	Urbanization Index X_2	Segregation Index X_3
6	3 18	0.59	3 26	28 32	60.10	21 01
10	3 89	0 57	3.13	20.89	65 71	21.61
25	3 98	0 61	3.02	25 99	63 19	12 57
28	4.16	0 61	3 14	28 52	66 24	17 61
34	3 60	0 63	3 75	27.18	58.36	35 32
41	4 10	0 66	3 24	27 95	59 58	14 73
57	4 36	0 71	2 77	39 91	64 64	11 61
58	4 87	0.77	2 74	48 36	67 88	10 71
60	5 85	0 84	3 02	42 15	56 86	8 20
61	4 97	0.74	2 84	38 14	62 44	7.94
65	3 54	0 67	2.93	51 30	68 67	12.72
67	4 31	0 64	3 87	43 90	59 49	27 33
73	4 54	0 73	3 16	30 27	57 76	18 70
74	4 82	0 86	3 42	32.18	63 06	14 52
79	4 04	0 66	3 54	34 45	47.73	3 82
81	4 60	0 64	3.49	43.32	59.36	8 73
84	3 40	0 50	2.76	75 32	75 81	11 40
88	4 65	0 58	2.91	62 20	75 26	58 43
97	3 02	0 53	1 83	82 53	83 66	8.32
102	9 14	1 11	3 00	67 31	38 21	11 49
104	4 30	0 70	2 94	64 01	55 51	17.95
106	4 24	0.80	3 19	51 16	52 44	8 10
108	5 00	0.77	2 61	59.15	59.38	4 67
110	5 93	0 96	3 24	48 51	46 51	6 82
113	5 11	0 86	2 95	47 44	51.17	10 43
119	5 84	0.92	2 95	57.34	58.60	6 53
122	4 70	0 80	3 00	62 60	62 40	3.37
125	4 54	0 79	2 71	73 00	67 23	10 10
146	5 51	0 91	3 46	33.96	41.29	14 36
153	5 10	0 75	3 38	43 67	56 64	17 94
155	4 70	0 83	3 11	52 74	54.02	9 38
156	5 17	0 76	3.20	52 29	58 35	3 02
158	5 41	0 87	3 24	43 42	47.78	12 75
159	6 46	1.16	3 60	45 94	51.21	16.49
161	6 03	0 90	3 02	61.53	54.92	2.80
166	4 79	0.53	3 09	49 37	58 63	62.53
167	4 83	0.75	2.46	87.38	65.67	6 92
169	6 30	0 78	3 36	55.85	59.00	16 34
171	4 94	0 69	2 94	50.15	61.09	9 51
173	6 01	0 96	3 27	67 01	48 39	4 25
175	6 39	0 86	3 32	62.18	50.04	3 85
203	5 82	1 09	3 29	45 58	46.47	7.54
205	6 25	1 15	3 58	60.85	26 36	3 41
249	6 13	0 90	3 09	55 59	43 58	3 62
255	6 70	1 02	3 02	75 73	35 89	2.17
260	7 10	1 00	3 33	57 84	28.28	3 78
262	7 89	1 32	3 58	79 69	25 37	2 42
275	7 80	1 06	3 17	57 01	31 97	7 20
282	8 02	1 02	3 35	50 93	38 17	9 17
280	7 20	0 98	3 43	49.75	34 69	9 86
278	5 14	0 82	3 31	36.36	46 98	7 61
352	5.56	0 94	3 21	62 27	36 27	47 73
380	5 74	0 90	3 52	42 64	26 15	4 17
382	6.77	0 62	3 92	21.66	24 08	11 36
385	4 94	0 77	3 02	49 18	51 39	8.73
391	7 64	0 93	3 37	34 74	44 54	15 08
393	7 25	0 75	4.50	26 21	44 80	16 44

linear regression equation, estimated by least squares, is given by

$$Y = 8.47 + 0.0172X_1 - 0.0744X_2 - 0.0023X_3 \tag{4a}$$

$$(R^2 = 0.8381) \tag{4b}$$

R^2 denotes the multiple coefficient of determination, uncorrected for degrees of freedom. The three indexes together account for 84 percent of the variance among zones in trip generation rates. The segregation index, X_3, exercises so slight an impact on trip generation rates, that it was omitted in the second model.

In the second model, average trips per occupied dwelling unit, Y, was expressed as a linear function of four explanatory variables: car ownership, A; household size, H; social rank index, X_1, and urbanization index, X_2. The least squares estimates for the parameters of this equation are given by

$$Y = 2.18 + 3.404A + 0.516H + 0.0119X_1 - 0.0343X_2 \tag{5a}$$

$$(R^2 = 0.9597) \tag{5b}$$

The four explanatory variables account for 96 percent of the variance in Y, and when corrected for degrees of freedom, 95.7 percent. Car ownership taken alone accounts for 83.6 percent of the variance. The regression coefficient for X_2 shows the expected change in trips per DU as the result of a unit increase in the urbanization index, X_2. When car ownership is ignored, as in Eq. 4, this coefficient is -0.0744, but the inclusion of car ownership in Eq. 5, reduces the coefficient to -0.0344. The partial regression coefficient for car ownership of +3.4 is substantially lower than that reported in the published CATS report, reflecting, as it does, the effect of the other variables included in Eq. 5.

In summary, the results of this preliminary analysis appear promising. The urbanization index does exert a significant effect on trip generation rates, even when the car ownership effect is controlled by multiple regression techniques. The remaining indexes for social rank and segregation have only slight impacts on trip frequencies. A qualification concerning the use of zonal averages is, however, in order. All the correlations and regression equations are based on data that refer to arithmetic averages, applicable to the reporting households in each traffic analysis zone. As shown in the following section, such regression techniques often prove misleading because of the heterogeneity of households within each traffic analysis zone. Yet, the results are sufficiently striking to warrant further investigation.

In addition to helping to provide a fuller explanation of variations in trip generation, social area analysis may yield a much needed clue to urban travel patterns on the whole.

TABLE 13

CORRELATION COEFFICIENTS FOR SOCIAL AREA INDEXES AND RELATED VARIABLES

Variable	Y	A	H	X_1	X_2	X_3
Trips per occupied DU, Y	1	+0.916	+0.437	+0.211	-0.883	-0.287
Average car ownership, A		1	+0.286	+0.322	-0.713	-0.397
Average household size, H			1	-0.595	-0.572	+0.085
Social rank index, X_1				1	+0.021	-0.183
Urbanization index, X_2					1	+0.249
Segregation index, X_3						1

Trip interchange and trip length, particularly relating to work and social trips, may be better understood through greater knowledge of the social characteristics of households. For example, work trips from an area of known social rank would tend to be attracted to certain kinds of jobs. Information of this nature would be of considerable value in improving the accuracy of the various traffic models used to compute future interzonal movements. Again, knowledge of the social rank of a household as compared with the rank of the area in which that household is situated would aid in predicting the distribution of social and recreational trips. In this instance, the greater the disparity between the social rank of an individual family and the mean rank for the neighborhood, the greater should be the number and average length of social trips made by the family. Analyses of these sorts require that the relationships between trip making and social indexes developed in this study on an area basis be refined to consider individual households. Such research is now being carried on at Northwestern University and will be reported on when the results are available.

IMPROVEMENT GAINED THROUGH GROUPING OF DATA

Most of the conclusions presented in the previous sections have been based on data from either individual dwelling units or from groups of dwelling unit so arranged that the independent variable was identical for all units within each group. It is both interesting and instructive to compare results so obtained with those that would be achieved through the customary procedure of working with average values for traffic zones or other areal groups.

To facilitate comparison, Eqs. 1, 2, and 3 have been repeated in Table 14, along with similar equations based on average values for 58 traffic census zones composed of a sample of 630 individual dwelling units in Modesto used in the original computations. As may be seen from Eq. 3 and 3a, for example, the coefficient of variation may be reduced by averaging from a value of about 24 percent to just a little below 16 percent, whereas the multiple correlation coefficient goes from 0.55 to 0.83.

Although the grouping of data, by averaging out random variations, does produce a seemingly more precise estimate of average trip generation in the least-squares sense, it also results in a less accurate estimate. The bias resulting from aggrega-

TABLE 14

LEAST SQUARES RELATIONSHIP BETWEEN FAMILY SIZE VEHICLE OWNERSHIP AND TRIP FREQUENCY FOR INDIVIDUAL DWELLING UNITS AND FOR AGGREGATES OF DWELLING UNITS

Basis of Values	Equation No.	Multiple Regression Equation[1]	Variable[2]			
			σ_e	C%	R	R^2
630 individual DU	1	$T = 0.467 + 0.831p$	0.76	25.4	0.47	0.22
	2	$T = 1.229 + 1.379v$	0.78	26.0	0.44	0.19
	3	$T = -0.137 + 0.632p + 0.950v$	0.72	24.0	0.55	0 30
58 traffic census zones	1a	$T = -0.627 + 1.216p$	0.51	17.0	0.82	0.67
	2a	$T = 0.653 + 1.850v$	0.62	20.7	0.70	0.49
	3a	$T = 0.648 + 0.964p + 0.608v$	0.49	16.3	0.83	0.69

[1] T = average daily number of person trips from home; p = number of persons per dwelling unit; and v = number of vehicles per dwelling unit.

[2] σ_e = standard error of estimate; C% = coefficient of variation ($\sigma_e/\overline{T}$); R = coefficient of multiple correlation; and R^2 = square of coefficient of multiple correlation. R^2 (100 percent) is a measure of percent of variation in T which is "explained" by variation in independent variables.

tion of data may be seen by comparing the regression coefficients developed in the two sets of equations. The coefficients associate with family size, p, and vehicle ownership, v, are seen to be higher in every case where aggregative values are used. In other words, aggregating data in this fashion results in estimates of the effects of the independent variables on trip generation which are invariably higher than those obtained by single-unit analysis. Uncritical use of grouped data may lead not only to a reliance on faulty relationships, but, also, because of the false degree of precision introduced, to potentially rewarding areas of investigation being ignored or rejected.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to H.E. Davis and W.N. Kennedy of the Institute of Transportation and Traffic Engineering, and D. Foley of the Department of City and Regional Planning of the University of California for their aid and encouragement. The assistance of the Highway Planning Survey of the California Division of Highways in providing much of the basic data is also greatly appreciated.

The initial data collection and analysis on which the section relationships between occupation and trip generation is based were conducted by Joseph Stowers of the U.S. Bureau of Public Roads, as part of his work towards the Master of Engineering degree at Northwestern University.

The author wishes to thank Dennis McElrath of the Northwestern University Department of Sociology and Walter Oi of the Northwestern University Transportation Center for their aid in preparing this section. A more complete discussion of the appliability of the social area typology will be found in "An Analysis of Urban Travel Demands" by Dr. Oi and the author, to be published early in 1962 by Northwestern University Press.

The authors also wish to thank James Pipin, of the Bureau of Public Roads, who performed much of the preliminary work for the analysis for Table 12 in conjunction with his Masters' thesis in Civil Engineering at Northwestern University.

REFERENCES

1. "Modesto Traffic Survey." California Division of Highways, Sacramento (1956).
2. Schmidt, R.E., and Campbell, M.E., "Highway Traffic Estimation." The Eno Foundation, Saugatuck, Conn. (1956).
3. Edwards, A.M., "Social-Economic Grouping of the Gainful Workers of the United States." Jour. Amer. Statist. Assoc., 28: 377-387 (Dec. 1933).
4. Shevky, E., and Bell, W., "Social Area Analysis." Stanford University Press (1955).
5. Kaufman, W.C., and Greer, S., "Voting in a Metropolitan Community: An Application of Social Area Analysis." Social Forces, 38: 196-204 (March 1960).

An Iterative Assignment Approach to Capacity Restraint on Arterial Networks

ROBERT SMOCK, Detroit Area Traffic Study

• ONE OBJECTIVE of contemporary traffic planning research is to devise a method for the computer assignment of interzonal volumes to major street networks in a way that respects the capacity of the streets. The Detroit Area Traffic Study has developed a program for a medium-size computer that represents one solution to this problem. Before describing the new procedure, this paper discusses some of the background of the problem, and, after describing the procedure, the paper mentions the place for arterial assignment in the total process of transportation planning.

It has been common practice for transportation planners to consider the results of an assignment of partial interzonal volumes to a single set of best paths through a proposed freeway network. (That part or percentage of each interzonal volume to be assigned to the freeway network is determined by a "diversion curve" which causes the assigned percentage to vary with the varying merit of a freeway route as compared to a non-freeway route.) (1). Volumes thus assigned have two uses. They aid in providing economic justification for the proposed network when they indicate appropriately high future traffic volumes on it. They also aid in the geometric design of the freeway suggesting the number of needed lanes.

Volumes thus assigned have definite limitations with which planners are familiar, and for which they must compensate in some way. Freeway "desire" assignments have been utilized regardless of their shortcomings because there has been no better way to perform the essential task of estimating the volume to be expected on the various parts of proposed facilities. The nature of their chief shortcoming may be noted when "desire" assignments are described.

In this paper, any assignment which places all of each assigned interzonal volume on a single "best" path will be called a "desire assignment." (Whether or not the assignment first discards a part of each volume on the basis of a diversion curve, the main point is that only one set of best paths is computed. A "best" path is that series of links which constitutes the route through the network for an interzonal trip which is fastest, or shortest, etc.) The fundamental limitation of such an assignment for planning purposes appears when volumes thus assigned exceed the capacities of parts of the tested network. The volumes on all other parts of the network then become questionable because it is not possible to anticipate the consequences for the whole network of the diverting of excess volumes from the over assigned parts.

Detailed information suitable for either economic justification or geometric design, therefore, cannot be provided with guaranteed reliability by desire assignments, if parts of the network are assigned volumes beyond their capacity. The efforts to develop more elaborate assignment procedures have not arisen from this problem alone, however, but also from the problems involved in linking a freeway network to a system of existing or proposed major streets. There can be no doubt that an existing street system will have to have its capacities adjusted upward in some places and perhaps downward in other places, if it is to link efficiently with a new freeway network. These problems call for research to create a computer program that will assign realistic traffic volumes to large arterial networks that include both freeways and other major arteries. In addition to helping with the linkage problem, such a program would have the value of providing estimates of future traffic on surface major streets so that their improvement might be better planned independently of freeways.

The research task has divided into two parts: the computation of best paths through "large" networks, and the assignment of "realistic" volumes. Not many years ago, the computation by an electronic computer of best paths through a freeway network as large as fifty interchanges was impossible. Yet there are at least a hundred intersections in the major street systems of even medium-size cities. Only within the last few years has it become possible to work with sufficiently large networks. Experimental programs were in use in various places earlier, but the first manual for an assignment procedure for large networks was not published until 1960 (2).

As an example of one of the earlier programs, a desire assignment was made to the 1,000-intersection major street system (including two freeways) for Detroit as of 1958. This produced the useful information of a freeway desire assignment in a much more extensive form, but it had all the limitations of a desire assignment, too. For example, it assigned 300,000 vehicles per day to parts of the freeway network which could handle only about one-third that volume, and indicated no traffic volume at all on Detroit's "main street" approaching the CBD. These volumes were too unrealistic to help plan the adjustments in the surface street system called for by the expected traffic-pattern changes created by the freeways.

The production of "realistic" assigned volumes has proved to be a more difficult problem. A number of approaches to its solution have been tried at a number of research centers (3). The iterative (i.e., repeated-assignment) solution described below has three characteristics that particularly recommend it. First, it produces significantly fewer assigned volumes that are in excess of capacity than does a desire assignment. Second, it produces assigned volumes that are significantly closer to traffic counts than does a desire assignment. Third, it includes a particularly efficient computer program that allows a capacity-restrained arterial assignment to be made at a reasonable cost.

PROCEDURE FOR ARTERIAL ASSIGNMENT

The procedure for arterial assignment reflects the assumption that a desire assignment will place volumes on freeways or other superior facilities that are in excess of the capacity of those facilities and, therefore, significantly different from what traffic counts would actually be. The goal of this procedure is to redistribute the excess volumes to realistic alternative paths in such a way as to produce assigned volumes that will be closer to actual traffic counts than were the desire-assigned volumes. The name given this procedure is the Wayne arterial assignment method.

Network

The assignment network consists of a number of nodes representing the intersections of major streets, and straight-line, two-way links between nodes (4). The nodes are identified by sequential numbers, and a link is specified by the statement of two such node numbers. The nodes are also coordinate coded so that the computer can determine distances between them; i.e., link lengths.

A generalized measure of capacity and a measure of "typical" speed are associated with each link. These measures vary with (a) the width of the facility, (b) the area, classified as CBD, intermediate, or outlying, and (c) facility type, classified as freeway, high-type areterial, or low-type areterial.

The capacity number represents the number of vehicles that can traverse the link in 24 hours under "typical" urban conditions including 10 percent signal failure at peak hour (5). A link's capacity is estimated by averaging the capacities of the intersections at its ends. This measure of capacity does not equal the absolute maximum number of vehicles that link could handle under conditions of greater congestion.

Certain of the nodes are designated "O-D intersections." They serve as "centroids" or points of trip end. Each traffic analysis zone is associated with a specific O-D intersection. Best paths are computed only between O-D intersections and not between all intersections, but the computer considers all intersections when it is determining best paths.

Volumes

The vehicular volumes to be assigned are contained in a nondirectional trip table; i.e., the volume going from A to B is combined with the volume going from B to A. Each interzonal volume is identified by two zone numbers. Intrazonal volumes are disregarded as if they were served by the local streets not in the major-street or arterial network.

Assignment Procedure

The program for securing an arterial assignment can be summarized in eight steps. Describing them requires that reference be made to five quantities designated V, X, R, e, and A.

1. A link value hereafter called V_1 is computed for each link. The quantity V_1 represents the time required to travel from end to end of the link (cf., 6, p. 110). It is estimated (by the computer) by dividing the length of the link as determined from its two coordinate codes by a "typical" speed which varies by type of facility and by area.
2. For each node designated an O-D intersection, a "tree" is computed. The paths that make up the tree represent best or shortest-time paths linking the O-D intersection of reference to every other O-D intersection. A best path is that sequence of links with the minimal sum of V_1.
3. The interzonal volumes are assigned to their paths. The sum of interzonal volumes accumulated on a link is said to be that link's assigned volume. It is designated X_1.
4. The program then determines R_1 or the ratio for each link, by dividing X_1 by the link's capacity. That is, R_1 for a link represents the assigned volume on that link after the first or desire-assignment pass, expressed as a ratio to the capacity of that link. It may be 0.0 if no volume is assigned to the link, or it may be 1.0 if the assigned volume is the same as capacity, or it may be 4.0 or 5.0 if the assigned volume exceeds capacity to that extent, or it may be any number between the extremes.
5. The value of each link (V_1) is changed on the basis of R_1. The formula by which the nature of the change is determined calls for an increasing "stretching" of the link value as R_1 increases, in the form of an exponential curve upwards. In other words, link travel time increases at an increasing rate as congestion increases. For measures of R_1 below capacity the formula allows a reduction of the link value in such a way that it cannot fall below about one-third of the original value. The exponential number determining the shape of the capacity-restraint curve is called e, and is approximately 2.7. The formula specifies that

$$V_2 = e^{(R_1 - 1)} V_1$$

The decision to use e in this particular formula was based on a combination of mathematical reasoning and trial-and-error experiment. The experimentation over an extended period that produced this formula, with the five axioms and three theorems that provide its mathematical rationale, are described by Smulick (7).

6. The second pass of an iterative arterial assignment begins with the computation of V_2 for each link. The network for the second pass differs from the network at the time of the desire assignment in that all links that have been desire-assigned volumes beyond their capacity now require more time to travel, and links desire-assigned volumes less than their capacity now require less time to travel. The trees of best paths computed through the network in which each link is described by V_2 differ significantly from the trees for the desire assignment. Assigning the interzonal volumes to the new trees produces a new volume, or X_2, on each link.
7. The computer averages X_1 and X_2 to produce A_2. The quantity A (or average assigned volume) at the conclusion of any pass may be considered the end result of the procedures, or each A_2 may be divided by link capacity to produce R_2. For each link a third link value may be computed according to

$$V_3 = e^{(R_2 - 1)} V_1$$

8. By averaging assigned volumes, computing R, revising V, and re-assigning, an indefinitely large number of passes could be made. However, at the conclusion of the desire assignment the R's range from 0.0 to 4.0 or 5.0, and the capacity-restraint formula works to alter link values more extensively the farther R is from one. If the second pass is successful, then the assigned volume at its conclusion, or A_2, is nearer to capacity than was the desire-assigned volume. Therefore, the difference between V_1 and V_3 will be less than the difference between V_1 and V_2. As subsequent passes produce volumes even closer to capacity, subsequent V's return even closer to V_1. This means that the assigned volume on a link comes closer, with each subsequent pass, to the level at which the typical speed of that link is actually possible; i.e., volume and speed approach a balance. It also means that after some particular pass, the majority of trips will be back on their original best paths and relatively little change from pass to pass is to be expected thereafter. This is one basis for considering the capacity-restrained arterial assignment to be complete. Another basis would be a pass which produced volumes little changed from those of the preceding pass.

To summarize, the eight steps are (a) to determine link travel time, (b) to trace best paths between all zones, (c) to assign volumes, (d) find the percentages of capacity represented by the assigned volumes, (e) to compute adjusted link travel times, (f) to compute new paths and assign volumes again, (g) to average assigned volumes, find percentage of capacity, and readjust link travel time, (h) to repeat assignments until a predetermined approximation of balance is attained.

Testing the Procedure

An arterial assignment of this type has been made to the major street system of the City of Flint, Mich., as that system existed in 1950. The system consists of 143 links and 99 intersections and includes no freeways. At the conclusion of the desire assignment to this network, 10 percent of its links had been assigned volumes which were more than 150 percent of the link capacity including some loaded with four or five times the volume they could actually carry. Another 25 percent of the links were loaded to less than one-half their capacity, including some assigned no volume at all.

A third of the interzonal paths computed for the desire assignment called for less than 10 min of travel time. Another third required between 10 and 15 min, and the final third required more than 15 min but less than ½ hr. These travel times assume that all vehicles could travel at speeds typical of city streets. Using the same typical speeds as a basis for comparison, best paths for the second pass were significantly longer. Forty-nine percent of those paths required 15 min or more to travel, and about 10 percent required 30 to 40 min, in terms of the original travel times. Only 25 percent of the paths remained the same as on the first pass.

Dividing volumes between the paths of the first and second passes and applying the capacity restraint formula on the basis of the new volume-capacity ratios produced a new set of link values or V_3, some of which were closer again to V_1 than were the second set of travel times. The net effect of this change was that more than one-half of the paths of the third pass were the same as the desire paths. At this point the assignment could be considered complete, but three additional passes were made as a test of the underlying assumptions. Only the expected small variations were observed.

Averaging the assigned volumes of the first three passes produced a significantly more realistic assignment. The volumes on about two-thirds of the links had shifted closer to capacity, and almost all of the volumes not shifting closer to capacity were those which were within 50 percent in the first place. Ninety-seven percent of the links were loaded to less than 150 percent of their capacity, which means that they could actually carry the volumes assigned to them although some of them would be congested.

In this particular case then, a solution to the problem of desire assignment was found. Unfortunately, however, there are a large number of "solutions" that would create a final balance. For example, a number of crosstown trips could merely be routed around the outer edge of the city. Congestion on links in the city's center would be relieved, a balance between volume and speed could be demonstrated, and a solution would have been found. The assigned volumes would be useless for traffic planning purposes, however, because they would not represent the unique solution that approximates actual traffic counts.

Part of the reason that the 1950 Flint network was selected for these experiments was that an actual 24-hr, midweek traffic count was available for all of its links. Some of the counts were below capacity and some above; they averaged 80 percent of capacity. At the conclusion of the desire assignment one-half the assigned volumes were more than 50 percent off from count, about equally divided between being too low and too high. During the second and third passes two-thirds of the assigned volumes shifted closer to traffic count. Almost all of the volumes not shifting closer to count were those which were within 50 percent in the first place. Of the final assigned volumes, three out of four were within 50 percent of traffic count (compared to one-half after the desire assignment). Only a few links were loaded significantly low. Twenty-three percent of the links continued to be loaded to more than 50 percent above count after the third pass, but this might be expected inasmuch as the capacity measure that was the basis of the adjustment tended, on the average, to be higher than count. This would mean that values of links overloaded on the desire assignment sometimes would not be adjusted enough to push volumes down to count even when properly adjusted in terms of capacity.

The important fact is that more than 90 percent of assigned volumes were either within 50 percent of count in the first place or shifted closer to count during the capacity-restrained assignment passes. It is this fact that would give validity to 1980 volumes assigned by this method.

Practicality of Procedure

It has been demonstrated, then, that this method achieves its goal of placing the excess volumes of a desire assignment on realistic alternative paths in the sense that its final assigned volumes approximate traffic counts significantly more closely than desire-assigned volumes. Its practicality for adoption by highway planners depends, however, on its costs for personnel and machine time, as well as its validity. Freeway desire assignments are performed for traffic engineers less often then their usefulness warrants, in part because of their cost. At first glance, therefore, a program for arterial assignment that calls for a detailed description of the total major street system, and then prescribes assignment by repeated passes, appears to be impractical.

This is not necessarily the case, however, because of two factors. The first is the simplification of network description previously suggested. All necessary information may be provided by (a) a map of major streets and (b) an inventory specifying pavement width and the location of one-way streets and divided highways. This presumes the existence of a trip table and a system of coordinates from an O-D survey, of course. The other factor in reducing costs is the shorter running time of an improved computer program for finding minimum paths and assigning volumes to a network. The improved program is called the branch method for arterial assignment and it includes the following five features:

1. Basic to the branch method is the concept of branch paths. A branch path is a path from an intervening node to the destination contained in a path from origin to destination. A branch path of a minimum path is also a minimum path. Consider, for example, the minimum path from origin node i to node j found in the build-up of tree i. If the minimum path from i to j passes through three intersections (j_1, j_2, and j_3), then, while determining the path from i to j, three other minimum paths are defined which are branch paths. The branch paths are from node j_1 to node j, from j_2, to j, and from j_3 to j. In the branch method, during the tracing of paths for any tree all branch paths are traced and information which can be used during the computation of later trees is stored. In fact, many later trees are completely defined during the build-up of the first few of them.

2. A second feature was suggested by an investigation of the branch pat concept. This is the technique of tracing and recording individual paths during tree build-up,

rather than after a tree is finished. This in itself saves considerable machine time, and in the branch method volumes are assigned to links at this point, rather than afterwards, resulting in a further time saving.

3. Another technique that contributes a time saving is the tracing of one-way paths rather than two-way paths, because link values are symmetrical; i.e., the value of a link joining two nodes is the same in one direction as in the other.

4. Sequencing of nodes during tree build-up, in the sense of putting them in the most convenient numerical order, has had considerable application elsewhere (2, 8) and was found important for the branch method.

5. The final technique which is incoporated had long been published (9) but had found little practical application. It involves keeping track of the adjacent node in a path from destination to origin during tree build-up for use in later path tracing.

By means of these various techniques the branch method for arterial assignment achieves a reduction in machine time great enough so that the running of several passes is feasible in terms of cost. A three- or four-pass assignment can be made for no more than twice the cost of a single freeway assignment. Because more than twice as much information is provided, this may be considered an entirely reasonable cost level.

The branch method is now programed for the IBM 650-Ramac, and can handle a network of 240 intersections. This is judged sufficient for all Michigan cities except Detroit. The program includes an output-analysis subprogram which can print out, at the conclusion of any pass (a) the value for each link; (b) the assigned volume (X and A) on each link; (c) the capacity, and also the assigned volume as a percentage of capacity, for each link; (d) the intersections composing all best paths; and (e) the total travel time (or sum of V_1) for each path. The branch method is now being programed for the IBM 7070 to handle a network of 1,000 intersections.

ARTERIAL ASSIGNMENT AND TRANSPORTATION PLANNING

On the basis of experience in the recent past, it should be assumed that this and any other existing arterial assignment procedures will be refined and improved rapidly, in the next few years if not months. For example, experiments on the program described in this paper are being continued to increase its flexibility, and perhaps to improve the equal-share way of dividing interzonal volumes over alternate paths. Even after an arterial assignment method is valid, reliable, and not too costly; however, it will not be widely used unless there is some agreement as to its importance for transportation planning.

There has been some disagreement as to the wisdom of making major research investments in "capacity restraint" (3, p. 18ff). Part of the reason for this is a suspicion that a computer may not be able to "simulate" traffic as well as an experienced traffic engineer because his mind can take more of reality into account. However, this argument applies equally well to freeway desire assignments and they are performed anyway. The reason is that the wisest traffic engineer cannot do arithmetic as fast as a computer, and it takes considerable arithmetic to study the transportation system of a metropolitan area. But it also takes considerable interpretation and judgment before the computer's arithmetic can be turned into well-planned transportation, whether the figures are from desire or capacity-restrained assignments.

A specific objection to capacity restraint is that it could make any system "look good" in the sense of producing balanced volumes on a badly planned network. It is true that a tranportation system could be proposed that would call for freeways constructed diagonal to major desire lines, and that arterial assignment might load them to capacity anyway, and in this sense make the network "look good." However, trip times and distances through such a network, on the average, would be greater compared to those through a well-planned network. The Wayne method can determine trip times for a given network, and these can be compared to trip times in alternate networks. It is doubtful, therefore, that planners need to be deceived by a balanced assignment to a poorly-planned system. Instead, arterial assignment may play a useful role in determining the best-planned network among a number of proposals.

In highly generalized terms, the stages of transportation planning might now take this form:

1. The basic data for transportation planning, which are person and vehicle volumes moving between traffic analysis zones, are secured by an O-D survey. Alternately, basic data may be obtainable by means of synthetic models.
2. Interzonal volumes for some future year (selected for planning purposes) are provided, either by computer iteration based on projections of land uses or by some kind of model.
3. Desire lines may be determined by the rapid and inexpensive method of zone assignment (10) to help in the process of planning new facilities where needed.
4. New facilities in the form of public transportation, freeways, or improved streets and highways are planned and proposed as traffic engineers and planners consider them to be appropriate.
5. Arterial assignments can test the relative merits of alternative proposals, helping with both processes of economic justification and geometric design.
6. Capacity-restrained arterial assignments can assist in the planning of adjustments in the existing transportation system, as they are required by the changes brought about by new facilities.

ACKNOWLEDGMENTS

The development of this procedure has been under the general supervision of Albert J. Mayer, Director of the Detroit Area Traffic Study and Associate Professor of Sociology at Wayne State University. Sponsors are the Michigan State Highway Department, the Wayne County Road Commission, and the City of Detroit, in cooperation with the U.S. Bureau of Public Roads. Research and program development at the Computing Center of the University is under the general supervision of Walter Hoffman, Director, and under the immediate supervision of James Smulick with the assistance of Maggie Goodwin. The project as a whole is under the immediate supervision of Robert Smock, Assistant Director of the Traffic Study and Research Associate of the University, with the assistance of Patricia Ferman.

REFERENCES

1. "Traffic Assignment." HRB Bull. 61 (1952).
2. Mertz, W.L., "Electronic Computer Program for Assignment of Traffic to Street and Freeway Systems." U.S. Bureau of Public Roads (1960).
3. Mertz, W.L., "Review and Evaluation of Electronic Computer Traffic Assignment Programs." HRB Bull. 297, 94-105 (1961).
4. "Defining Arterial Segments for Traffic Assignment Purposes." Detroit Area Traffic Study (1957).
5. "Determining the Capacity of Arterial Segments." Detroit Area Traffic Study (1957).
6. "A Policy on Arterial Highways in Urban Areas." AASHO (1957).
7. Smulick, J., "A Mathematical Model for Travel Assignment." Master's essay, Department of Mathematics, Wayne State Univ. (1961).
8. Pollack, M., and Wiebenson, W., "Solutions of the Shortest-Route Problem—A Review." Operations Research, 8:No. 2 (1960).
9. Moore, E.F., "The Shortest Path Through a Maze." Proc., Internat. Symp. on the Theory of Switching, pt. 2 (April 2-5, 1957). In Annals, Computation Lab., Harvard Univ., Vol. 30 (1959).
10. Smock, R., "Traffic in Detroit in 1953 and 1958." Detroit Area Traffic Study (1961).

Evaluation of Gravity Model Trip Distribution Procedures

WALTER G. HANSEN, Alan M. Voorhees and Associates, Inc., Washington, D.C.

•DURING THE past decade there has been increasing realization that to plan transportation systems for dynamic urban areas properly it is necessary to be able to forecast changes in travel demands resulting from anticipated or proposed changes in the land use patterns and transportation systems of these areas. This realization has resulted in a concerted effort to develop an urban transportation planning process capable of providing quantitative information on future traffic movements of sufficient precision to enable cities to make an informed choice between the many alternate land use and transportation programs open to them. The heart of such a process is a procedure capable of synthesizing zone-to-zone movements for alternate configurations of land use and transportation facilities.

Several such procedures, generally referred to as "traffic models" have been developed by various organizations through the country. A trip-opportunity model developed by the Chicago Area Transportation Study has been utilized in both Chicago and Pittsburgh (1). Another procedure is currently being developed by the Penn-Jersey Study for use in that area (2). Yet another procedure, and the one which has been most widely applied, is the so-called gravity model (3, 4). Studies based on this procedure have been conducted in Hartford, Conn.; Baltimore, Md.; seven cities in Iowa; and is presently being used in a transportation study of the Los Angeles region.

For the most part, comprehensive origin-destination studies were not conducted in conjunction with these applications of the gravity model. Rather, selected travel data (such as screenline crossings, volume counts, employee data, and a limited number of home interviews) were utilized to calibrate the model to local conditions and check the resulting estimated travel demands. A comparison and evaluation of gravity model procedures using a complete home interview survey was carried out by the Iowa State Highway Department in Cedar Rapids. The findings are reported in an unpublished paper (5).

The Office of Research, Bureau of Public Roads, initiated a research project in the fall of 1960 to evaluate more fully this traffic estimating procedure. The project used the Washington, D.C., metropolitan area as a study area. This selection was made for several reasons, the most important being the availability of comprehensive origin-destination data for both 1948 and 1955, thereby making it eventually possible to test directly the applicability of this as well as other traffic models over a period of time. The first phase of this project, the one described by this paper, was an evaluation of the trip distribution characteristics of a gravity model based on analysis of and comparison with 1955 origin-destination travel data. Additional investigations into the trip production and attraction aspects of the gravity model traffic estimating procedures, as well as application and evaluation with 1948 travel data, are being conducted by the Bureau of Public Roads as a part of its continuing urban research program.

GRAVITY MODEL

The general formulation of the gravity model is

$$T_{i-j} = P_i \frac{A_j/d_{i-j}^{b}}{A_i/d_{i-i}^{b} + A_j/d_{i-j}^{b} + \ldots A_n/d_{i-n}^{b}} \qquad (1)$$

in which

T_{i-j} = number of trips produced at zone i attracted by zone j;
P_i = total trips produced by zone i;
A_j = total attraction of zone j;
d_{i-j} = measurement of the separation between zones i and j normally expressed in terms of driving time; and
b = empirically determined exponent.

Eq. 1 was changed to the following form for computational purposes and obtaining more flexibility in the research program:

$$T_{i-j} = \frac{P_i A_j F(d_{i-j}) K_{i-j}}{A_1 F(d_{i-1}) K_{i-1} + A_j F(d_{i-j}) K_{i-j} + \dots A_n F(d_{i-n}) K_{i-n}} \tag{2}$$

in which

T_{i-j}, P_i, A_j = same as in Eq. 1;
$F(d_{i-j})$ = an empirically determined set of friction factors replacing the inverse of distance d_{i-j} raised to a power b; and
K_{i-j} = a specific zone-to-zone adjustment factor to allow for the incorporation of the effect on travel patterns of factors not otherwise accounted for in Eq. 1.

The use of a set of friction factors rather than the inverse function of distance greatly simplified the computational requirements of the model. In addition, it did not commit the research project to a constant exponential function of distance which previous studies have shown to vary for a given trip purpose.

The K_{i-j} factor was incorporated into the model to permit adjustment of the model for social and economic linkages not accounted for by the other parameters of trip production and attraction and interzonal separations. Previous research has indicated the importance of such factors on urban travel patterns, and one of the objectives of this project was to determine the effect and magnitude of such factors on urban travel patterns in the Washington area (6).

This study stratified the total travel demands of the area into the following six trip purpose categories:

1. Home-based work.
2. Home-based shopping.
3. Home-based social-recreational.
4. Home-based school.
5. Home-based miscellaneous.
6. Non-home-based.

The specific definition of these purpose categories is the same as those used by the 1955 origin-destination survey. The home-based miscellaneous category is composed of the personal business and medical-dental-eat trips. The non-home-based category includes all trips with neither their origin nor destination at home.

It should be pointed out that before this study was made, the 1955 survey data were processed so as to link trips that were originally coded as change mode and serve passenger trips. The procedures used were similar to those developed by the Pittsburgh Area Transportation Study. This was done to obtain a more precise picture of the ultimate destinations and purpose of the travel demands in the area. As shown by the studies in Pittsburgh and Chicago, although this procedure reduces the total number of trips it does not change the vehicle-miles of travel in an area significantly.

The distribution by trip purpose of the total trips and travel in the Washington area is shown in Table 1. Over 90 percent of the total trips and travel in the Washington area in 1955 had either their origin or destination at home. The trips and travel are expressed in terms of person-movements. This study, unlike previous research in this field, deals with total person-movement rather than with the movement of vehicles.

As was previously stated, this phase of the research was concerned with only the trip distribution aspects of the gravity model. Therefore, the zonal trip productions and attractions (P_i and A_j) by purpose for each of the 436 zones comprising the Washington metropolitan area were taken directly from a summary of 1955 origin-destination survey.

The measurement of zonal separation used by this study was off-peak minimum path driving time plus terminal time. Interzonal driving time was obtained through the use of the standard tree-building computer program. Intrazonal driving times were estimated on the basis of the interzonal driving times to the adjacent zones.

In the development of a model for forecasting person-movements, the determination of interzonal separation involves considerable compromise. This is due to the sizable range between the levels of service (speed of travel) offered by the various modes of travel. Although it would have been possible in this study to construct separate models for transit and auto travel based on their respective levels of service, such a procedure would require that the mode split be determined in developing the zonal production and attraction figures when estimating future travel. From an over-all view of urban traffic forecasting, it was felt that the determination of mode split should be made after the zone-to-zone distribution of person-movements.

An estimate of terminal time was made for each zone. This estimate was based on the type and intensity of land development within each zone. Although this estimate was quite subjective, it was incorporated in this study for two reasons. First, it was felt that people consider the total travel time (driving time plus terminal time) rather than only the driving time associated with a contemplated trip. Second, it was felt that one of the reasons that previous research in this field has indicated that the exponent of distance for a given purpose varies with trip length was a result of not incorporating terminal time into this measurement of zonal separation. The estimated terminal times varied from 6 min within the central portion of the region to 3 min in the outlying suburban residential areas.

TABLE 1

DISTRIBUTION OF TRAVEL BY TRIP PURPOSE, WASHINGTON, D.C., 1955[a]

Trip Purpose	Trips		Person-Hours[b]	
	Number (X 10^3)	Percent	Number (X 10^3)	Percent
Home-based:	1,075	43.4	255	53.7
Work				
Shopping	335	13 5	40	8.5
Social-rec.	326	13.1	63	13.2
School	217	8.7	29	6.1
Miscellaneous	247	9.9	44	9.3
Non-home-based	282	11.4	44	9.2
Total (all purposes)	2,482	100.0	475	100.0

[a] Source: Home Interview Origin-Destination Survey, Washington, D. C., 1955.

[b] Based on minimum path zone-to-zone driving time.

CALIBRATION OF MODEL

After the information on zonal trip production and attraction and zonal separation was prepared, the next phase of the research was the calibration of the model to reflect the over-all travel characteristics of the Washington metropolitan region. This was accomplished through a step-by-step process:

1. Determining friction factors.
2. Balancing zonal trip attractions.
3. Adjustment for systematic geographical variations.

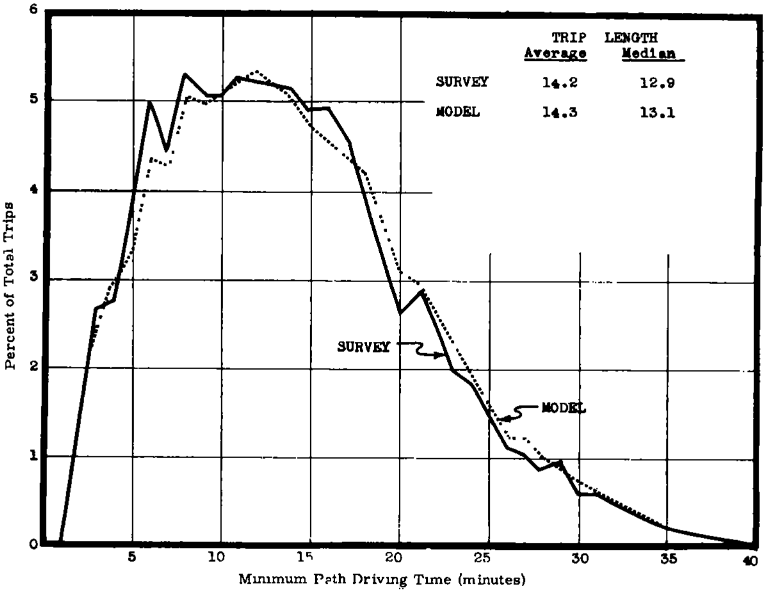


Figure 1. Comparison of work trip length frequencies, Washington, D C., 1955.

TABLE 2

COMPARISON OF TRIP LENGTH FREQUENCIES, WASHINGTON, D.C., 1955

Trip Purpose	Trip Length (min of driving time)[a]			
	Average		Median	
	Survey	Model	Survey	Model
Home-based:				
Work	14.2	14.3	12.9	13.1
Shopping				
Social-rec.	11.6	11.6	10.0	10.0
School	7.9	7.8	6.8	6.6
Miscellaneous	10.7	11.2	10.0	10.1
Non-home-based	9.3	9.3	7.0	7.0

[a] Based on minimum path zone-to-zone driving time

Determining Friction Factors

The best set of friction factors associated with each purpose category was determined through a process of trial and adjustment. This was done by assuming a set of friction factors for each trip purpose and calculating all zone-to-zone movements. The resulting estimated over-all trip length frequency distribution was then compared to that obtained from the O-D survey and the assumed friction factors were adjusted accordingly. The process was then repeated. Four such iterations were required in this study. This was because for the initial run it was assumed that all friction factors were equal to 1; in other words, it was assumed that travel time had no effect on travel patterns. This was done to determine how fast the procedure would close on the desired trip length frequency. Operationally, this step of the calibration process should take no more than two runs using reasonable first approximations.

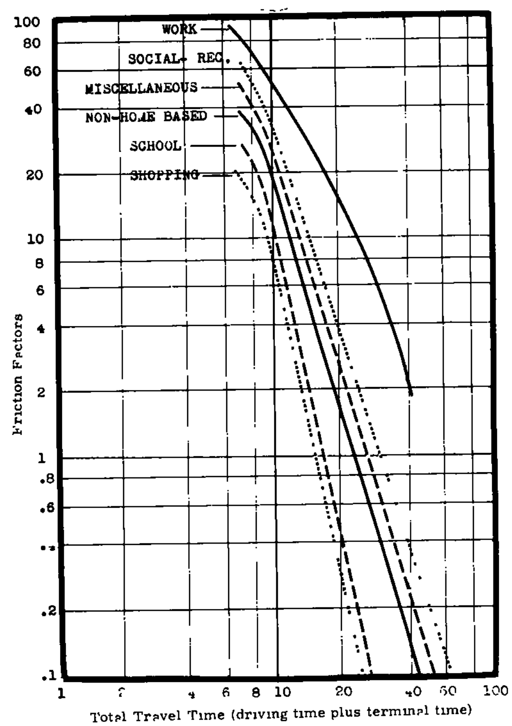


Figure 2. Friction factors, Washington, D. C., 1955.

The results of this step are shown in Figure 1 and Table 2. Figure 1 shows the close correspondence of the estimated trip length frequency for home-based work trip with that obtained by the O-D survey. Measures of this comparison for all of the purpose categories are given in Table 2. As can be seen, the close correspondence shown in Figure 1 for work trips exists for all trip purpose categories.

The sets of friction factors resulting from this step are shown in Figure 2. These are shown as a function of total travel time, and it can be seen that the friction factors for each purpose, with perhaps the exception of work, could be approximated very closely with a constant exponent. (Care should be taken in comparing the friction factors developed by this study with the findings of previous research which used driving time alone as a measurement of zonal separation.) The tendency to curve down at the low travel time is probably a result of too low an estimate of intrazonal times. These sets of friction factors were used throughout the remainder of the study.

Balancing Zonal Trip Attractions

A review of the gravity model formulation will show that there is no guarantee that the number of trips assigned to each zone by the gravity model will necessarily equal the attractions that were originally used. Therefore, the next step in the calibration process was the adjustment of the model to bring the number of trips assigned to a zone into balance with the trip attraction of that zone. This was accomplished by adjusting the attraction of each zone in accordance with the amount of under attraction or over attraction resulting from the previous estimate. The model was then rerun with these adjusted zonal attractions.

The extent of this adjustment varied considerably by purpose of trip. Work trips and non-home-based trips required the smallest amount of adjustment. Most of the areas were within ± 15 percent. There was, however, a discernible pattern to these adjustments. The central area of the city had received too many trips, whereas the zones in the outlying sections of the area were generally too low.

One factor creating this overestimate was the use of off-peak driving times. By using off-peak driving times the accessibility and therefore the attractiveness of the central area was overstated due to the high peak-hour congestion and relatively high transit usage associated with this area.

The pattern for shopping trips was just the reverse of that observed for work trips. For this purpose, the central area of the region received too few trips and the suburban areas too many. The extent of the underestimate to the central area was quite large (40 percent). It is felt that this situation would be considerably improved if shopping trips were further stratified into convenience and shopping goods trips. That is, a separate model should be used to distribute the larger, less frequent travel related to the purchase of specialized major items found only in the central area and major competing suburban shopping centers.

Social-recreation trips and miscellaneous trips exhibited a pattern similar to shopping trips, but to a lesser extent. School trips tended to vary considerably, primarily as a result of the small volumes involved.

The results obtained in this phase of the calibration process would vary considerably from city to city. In smaller cities, where decentralization of employment and shopping facilities is normally not as pronounced as it is in the larger metropolitan areas, the extent of the adjustments required would be considerably less than required in this analysis. For example, in the previously cited study in Cedar Rapids, Iowa, no adjustment of this type was required.

Final Review and Adjustments

The estimated zone-to-zone movements resulting from the balancing of trip attractions were then assigned to a zone centroid network on a minimum distance basis. The O-D information was assigned in an identical manner and the two were compared to determine whether any systematic geographical differences existed. Two patterns were discernible.

The first was the fact that the gravity model was overestimating the trips across the Potomac River. This is by no means an isolated case. Similar results have been obtained by application of the gravity model in Hartford, Boston, and New Orleans. An analysis was made to determine specifically the types of trips producing this overestimate. The results are given in Table 3 which shows that the model was consistently high for all trip purposes and for travel by both the residents of Maryland and D. C., and Virginia. This indicates quite clearly that the factor creating this overestimate is directly associated with the river, as this is the only factor common to these various types of trips.

Also, work trips were overestimated to a greater extent than were the other trip purposes. Based on these observations, it was concluded that this overestimation was

TABLE 3

COMPARISON OF TRIPS CROSSING THE POTOMAC RIVER

Trip Purpose	Person-Trips by Residents of					
	Maryland and D. C			Virginia		
	Survey	Model	% Diff.	Survey	Model	% Diff.
Home-based:						
Work	71,496	83,169	+16	99,730	120,034	+20
Shopping	1,945	3,549	-	6,588	6,855	+ 3
Social-rec.	12,416	13,227	+ 7	18,869	21,471	+14
Other	8,801	9,028	+ 3	12,238	15,394	+26
Non-home-based	13,561	14,043	+ 3	12,120	13,676	+12
Total (all purposes)	108,219	123,016	+14	149,545	177,430	+19

due to high peak-hour congestion associated with the present river crossings, and that off-peak travel times did not reflect a true relative measure of the transportation service offered in this area.

A study of peak and off-peak travel times made by the AAA showed that travel time for routes from the central area crossing the Potomac River to Virginia increased approximately 5 min more during the peak periods relative to the other routes from the central area to Maryland. Therefore, 5 min additional travel time was placed on all Potomac River crossings, and the model was rerun. This 5-min constraint brought the model crossings into agreement with those obtained by the O-D survey.

The second factor noted in this examination was a systematic difference with respect to work trips attracted to the Central Business District. This pattern is shown in Figure 3. This figure indicates the amount of increase or decrease required to bring the gravity model calibrated as previously described into agreement with the surveyed data.

To those familiar with Washington, this pattern is no surprise, as it is the logical result of the economic and social patterns that exist in the Washington area. It results from the fact that the bulk of the employment opportunities within the central area are middle or upper income, white collar jobs. However, the labor force, concentrated adjacent to and extending east of the central area, are low income, blue collar workers. As a result of this heterogeneous residential pattern, the model overestimated the trips from the close-in low income areas and underestimated those from the higher income outlying areas.

To incorporate the influence of this stratified occupational-economic pattern, specific zone-to-zone adjustment factors were determined and used to adjust the model.

RESULTS

The results obtained by the gravity model calibrated as described to the over-all characteristics of the Washington area are shown in Figure 4 in the form of comparisons of screenline crossings. Examination of this figure shows that there are no significant systematic differences in the model. This is further indicated by Figure 5. In only eight of the screenline comparisons were there differences greater than 10 percent, as indicated by the dashed lines.

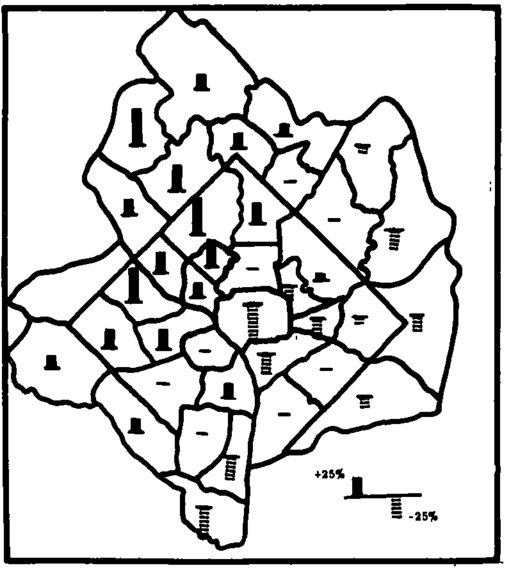


Figure 3. Comparison of work trips attracted to CBD, Washington, D. C., 1955.

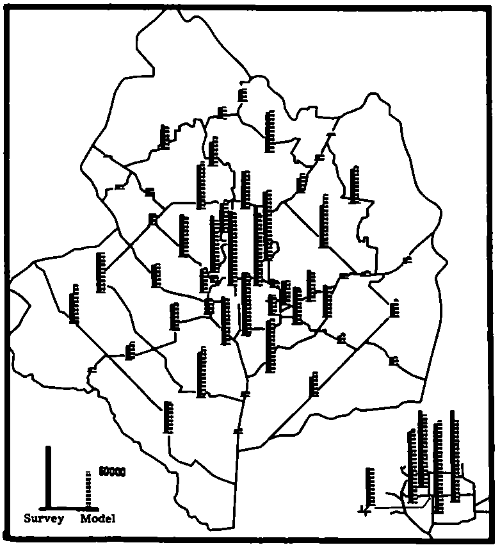


Figure 4. Screen line crossings, all purposes, Washington, D. C., 1955.

Similar comparisons are shown in Figures 6 and 7 for non-work and work trips respectively. The estimated work trips show a much closer correspondence to the O-D figures than do the estimated non-work trips. A review of the information showed that much of the differences shown in Figure 6 were a result of the shopping trip estimates. Again, it is felt that additional stratification of this category of trips would have substantially improved these results.

The information shown in Figure 7 is for work trips after the adjustments were applied to correct for the effect of the social-economic factors previously discussed. The information on Figure 8 is a similar comparison without the adjustments. A

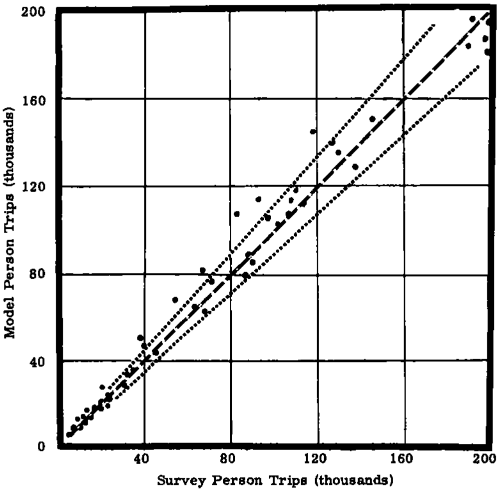


Figure 5. Comparison of screen line crossings, all purposes, Washington, D. C., 1955.

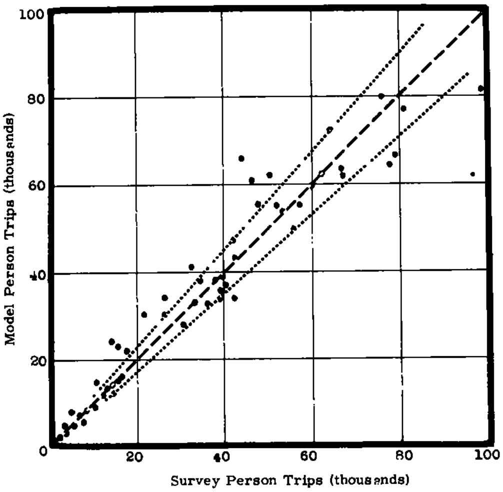


Figure 6. Comparison of screen line crossings, non-work trips, Washington, D. C., 1955.

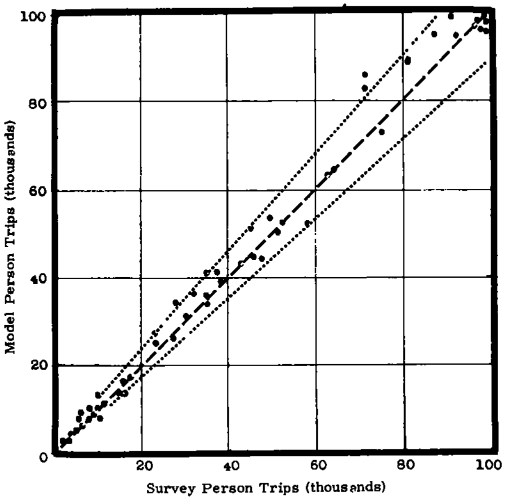


Figure 7. Comparison of screen line crossings, work trips, adjusted, Washington, D. C , 1955.

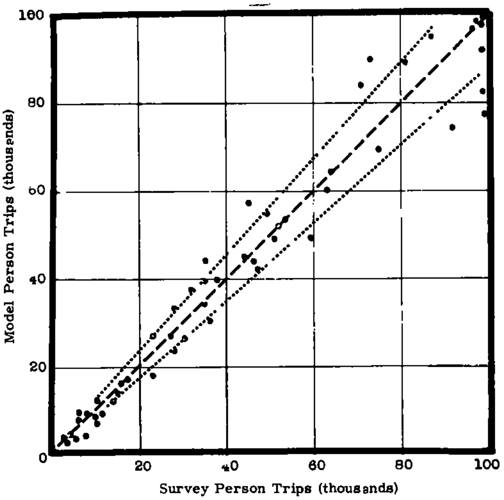


Figure 8. Comparison of screen line crossings, work trips, unadjusted, Washington, D. C., 1955.

comparison of these two charts indicates the importance of these factors on the travel patterns of the Washington area and the need to consider them in estimating urban traffic patterns.

The gravity model estimates and O-D survey of work and non-work travel were assigned in an identical manner to a zone centroid network and a statistical evaluation of the resulting comparisons was made. The results of this comparison, in terms of absolute differences, are shown in Figure 9. As shown, only 20 percent of the resulting loadings exhibited differences greater than 2,000 trips. Again, the work trips show closer correspondence to the survey data than do the non-work trips.

Table 4 gives an evaluation of these loadings by volume group. The percent of differences in the estimated volumes decreases as volume goes up, and for volumes greater than 10,000 persons the differences are less than 15 percent.

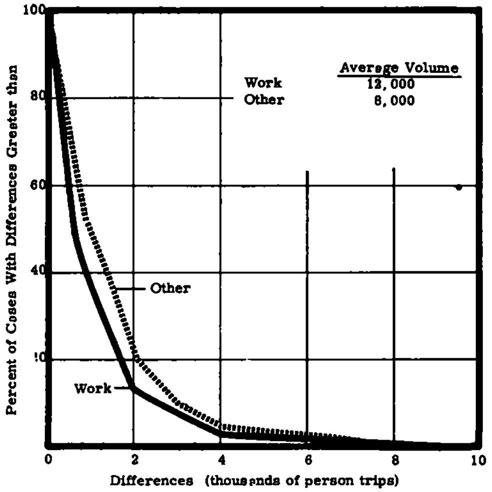


Figure 9. Differences between model and survey trips loaded on zone centroid network, Washington, D. C., 1955.

One of the major problems faced by anyone evaluating traffic estimates is the determination of what constitutes sufficient reliability; in other words, how good is good enough. A review of the screenline crossings indicates that with the possible exception of two cases the differences would not be likely to influence a transportation decision. In addition, the results of the statistical evaluation are as good, if not better, as those associated with the other phases of the transportation planning process.

TABLE 4

ANALYSIS OF DIFFERENCES GRAVITY MODEL VS O-D SURVEY LOADED ON SAME NETWORK, WASHINGTON, D. C., 1955

Volume Group	Work			Non-Work		
	Obs.	Standard Deviation	% Standard Deviation[a]	Obs.	Standard Deviation	% Standard Deviation
0- 499	34	144	54	22	219	72
500- 999	40	271	28	30	437	62
1,000- 1,999	101	408	27	76	506	32
2,000- 2,999	94	701	28	72	849	34
3,000- 3,999	65	734	21	84	968	27
4,000- 4,999	63	838	18	80	1,202	26
5,000- 5,999	47	816	15	77	1,324	24
6,000- 7,999	61	1,145	16	109	1,531	22
8,000- 9,999	55	1,045	12	78	1,815	21
10,000-14,999	116	1,541	12	148	1,873	15
15,000-19,999	80	1,880	11	62	2,776	16
20,000-24,999	39	2,072	9	33	2,222	10
25,000-49,999	96	2,711	8	42	3,645	11
50,000-74,999	14	5,126	8	-	-	-
Over 75,000	10	4,505	5	-	-	-

[a] Expressed as a percent of the mean O-D volume for each volume group.

Based on the results of this examination, it is concluded that the basic gravity model formulation can serve as a framework for forecasting urban traffic. Further, properly calibrated to the over-all travel characteristics of an urban area, the gravity model provides estimates of interzonal trip distribution sufficiently precise for transportation planning purposes.

One of the major findings of this study was the measurement of the influence that factors other than those of trip generation and travel time have on travel patterns in the Washington area, and the need to analyze, understand, and incorporate the impact of these factors when estimating urban travel demands.

Unfortunately, at the present time, these factors can only be incorporated into the model and future traffic forecasts as over-all adjustment factors based on a comparison with surveyed travel data. This does not stem from a lack of understanding of the factors creating these travel patterns, or an inability to express these relationships in a quantitative form. Continuing research has developed several relationships between the K-values and social-economic data for the Washington area. The real limitation lies in the inability, with present techniques, to forecast with any degree of confidence the socio-economic factors creating these travel patterns. Therefore, major improvements in this area of traffic estimation must come from the development of more knowledgeable land-use forecasting techniques.

Although it is not possible to generalize on the applicability of the specific adjustments made to the basic model in this study, it is felt that the general calibration process as outlined provides an analytical framework for developing a gravity model for any city.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the Bureau of Public Roads for permission to prepare this report based on unreported research which was done while he was with that organization. This research was one phase of a broad continuing program of investigations into the area of urban traffic forecasting being conducted by the Bureau.

The interpretation of this research and the conclusions drawn are solely those of the author. Neither approval or disapproval of these findings on the part of the Bureau of Public Roads is intended or implied.

REFERENCES

1. "Final Report." Chicago Area Transportation Study, 2:111 (July 1960).
2. Tomazinis, A.R., "A New Method of Trip Distribution Analysis in Urban Areas." HRB Bull. 347, 77-99 (1962).
3. Voorhees, A.M., " A General Theory of Traffic Movement." Proc., Inst. of Traffic Engineers (1955).
4. Wiant, R.H., "A Simplified Method for Forecasting Urban Traffic." HRB Bull. 297, 128-145 (1961).
5. "Comparison of the 1956 Cedar Rapids-Marion Origin Destination Interview Data to Traffic Model Calculations." Iowa State Highway Department, Cedar Rapids (Oct. 1960).
6. Voorhees, A.M., "Use of Mathematical Models in Estimating Travel." Jour. Highway Div. Proc., ASCE, pp. 134-135 (Dec. 1959).

A New Method of Trip Distribution in an Urban Area

ANTHONY R. TOMAZINIS, Chief, Transportation Flow Simulation Section, Penn-Jersey Transportation Study, and Assistant Research Professor of City Planning, University of Pennsylvania

This paper introduces a new method of simulating and projecting trip interchanges within an urban area. * The method is based on probability theory but it also utilizes certain aspects of the gravity models. It has been developed with 1947 O-D data of the Philadelphia metropolitan area and it is currently used in analyzing the 1960 data gathered by the Penn-Jersey Transportation Study.

- THE PURPOSE of this paper is to introduce a new method of trip-end distribution within urban areas. Such a method should be able to reproduce substantially the trip interchange between areal units within a metropolitan region. It should be based on sound and rigorous mathematical derivation and founded on theoretical concepts that satisfactorily explain the manner in which individuals and activities form their trip interchange patterns in urban conglomerations. Beyond these rather basic conditions any method dealing with a problem of such wide dimensions should be conducive to wide application under "laboratory conditions" in any part of the country, with various data, and by any qualified traffic engineer or tranportation planner.

At present, there are three accepted methods of trip-end distribution which have been used in various transportation studies (1, 2, 3). (Besides these three methods one should mention the important variance to gravity models introduced by Wynn (4). There is another method developed by the staff of the Detroit Area Traffic Study but it has not, as yet, been utilized by any other study group since then.) In all three methods, however, there are certain shortcomings referring to their basic theoretical framework or their mathematical formulations which oblige researchers either to impose extensive personal subjective judgment or to expand trends and relationships that they know will not necessarily hold true for the future. (It would suffice perhaps to mention here the controversey over the unstable and highly subjective exponent, X, of the distance in the gravity formulas. The same can be said about the value of L of the CATS formula, although this parameter is defined in more sophisticated terms and is within mathematical limits. Similarly, reference to the arguments concerning the stability of projected trends by the Fratar method should also suffice the need here.)

The following method, developed as a research project of the Penn-Jersey Transportation Study is an attempt to meet the stated requirements. The method is primarily based on the probability theory already introduced to the problem by other researchers, and its final step utilizes one of the known methods of successive approximations (e.g., 1). (Credit should be given to the staff of the Detroit Area Traffic Study for developing the first concept of "probability interchange" and to the staff of the Chicago Area Transportation Study, especially Mr. Schneider, for pioneering introduction of the probability theory concepts to the problem of interzonal movement.) The application of the method has produced extremely encouraging results with data from the 1947 Philadelphia-Camden origin-and-destination survey.

---

*Since presentation of this paper, continuing research under the direction of the author has resulted in substantial modification of the mathematical form of the model. The later model is programmed for the IBM 7090 computer for the simulation of the entire 1960 pattern of travel in the region.

DERIVATION OF THE RELATIONSHIPS

If a total population or "universe" N is assumed, then within this universe there are two subpopulations H and S. Part of subpopulation H is also part of subpopulation S and vice versa. If one member of the universe N is randomly selected given that this member is also a member of the subpopulation H, what is the probability that this selection is also a member of the subpopulation S? In other words, what is the probability to randomly select a member of the common subpopulations H and S? Then, the probability that the choice is a member of subpopulation H is

$$P_{(H)} = \frac{H}{N} \tag{1}$$

The probability that the choice is a member of the subpopulation S is

$$P_{(S)} = \frac{S}{N} \tag{2}$$

The probability that the choice is a member of both subpopulations H and S is

$$P_{(HS)} = \frac{GHS}{N} \tag{3}$$

in which GHS = the members participating in both subpopulations H and S. If the probability that $P_{(H)}$ will take place is desired, given that $P_{(S)}$ has already taken place, it would be necessary to try to define the conditional probability of $P_{(H)}$ which in terms of formal probability theory is given as

$$P_{(H/S)} = \frac{P_{(HS)}}{P_{(S)}} = \frac{\frac{GHS}{N}}{\frac{S}{N}} = \frac{GHS}{S} \tag{4}$$

in which $P_{(H/S)}$ = the conditional probability of $P_{(H)}$ given $P_{(S)}$. (Almost every advanced text of probability theory treats the concept of conditional probability sufficiently; for instance, (5).)

The concept can easily be presented in graphic terms as in Figure 1 where N is the universe (total population), H is one subpopulation, S is the other subpopulation, and GHS is the common subpopulations.

This concept of conditional probability can now be adapted to the problem. As a starting point there should be an estimate, or projection, of the total trip opportunities (expressed as trip ends) in the urban area, and the trip opportunities within each subarea (district, zone, etc.). This estimation, or projection, should be based on the findings of a trip generation analysis utilizing observed relationships between land use, transportation facilities, and traffic. Then, the total trip opportunities in the urban area is the statistical total population, "universe" N expressed as total trip destinations. Subpopulation H is the number of trip opportunities (destinations) contained in the area bounded by the areal equivalent of the travel time between the district of origin and the district of destination. Thus, if a district of destination is 26 min travel time from the district of origin (centroid to centroid), then the subpopulation H is all the trip opportunities in the area within 26 min from the district of origin. This is defined by the proper "time code." Each time code can include the area between 2, 3, 6, or any agreed-on time interval in minutes. It should be clear that for the purposes here the subpopulation H is the total cumulative trip opportunities in all time codes until the time code of the district of destination is reached.

Subpopulation S is the total trip opportunities (destinations) within the district of destination only. Moreover, subpopulation S is entirely included in subpopulation H. Thus, in this case, the common subpopulation GHS is the same as S, as shown in Figure 2.

Then, utilizing the equation of conditional probability and having population GHS = S,

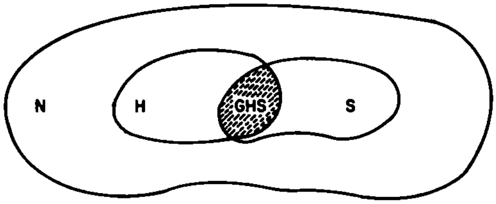


Figure 1.

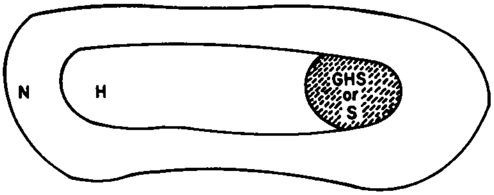


Figure 2.

$$P_{(H)} = \frac{H}{N} ; P_{(S)} = \frac{S}{N} ; P_{(SH)} = \frac{S}{N} = P_{(S)}$$

which gives

$$P_{(S/H)} = \frac{P(SH)}{P_H} = \frac{\frac{S}{N}}{\frac{H}{N}} = \frac{S}{H} \qquad (5)$$

Eq. 5 implies that the probability that a trip is going into a district is the ratio between the trip destinations in the district divided by the total trip destinations inside the area delineated by the time code of the district of destination (and having as basis the district of origin). In simpler terms the probability that a trip will go to a district depends on the ratio between the trip opportunites in the district and its competing opportunities. The new concept of competing opportunities is of special importance. According to this concept, the attracting power of a district is conditioned by the number of trip opportunities in the district and then only by the trip opportunities within the same time-distance from the district of origin. The total number of trip opportunities in the metropolitan region enters only indirectly in defining the pertinent probability. This takes place as follows: The summation of the probability of each district within the region should be unity because the total trips distributed should be equal with the trips available in the district of origin, hence:

$$\sum P'_i = 1 \qquad (6)$$

in which i represents districts 1, 2 ... n = all the districts into which trips are distributed.

To obtain $\sum P'_i = 1$, the $P_{(S/H)}$ of each district is divided by the summation of all the conditional probabilities, hence:

$$\frac{P_i\ (S/H)}{\sum P_i\ (S/H)} = P'_i \qquad (7)$$

The new, adjusted, probability of each district is then multiplied by the trip origins of the district of origin to obtain the trip interchange. Thus the one-way trips from district X to district Y are given by

$$P'_y \times T_x = T_{xy} \qquad (8)$$

in which

P'_y = the adjusted probability of district Y;

T_X = the trip origins in district X; and

T_{xy} = one-way trips from district X to district Y.

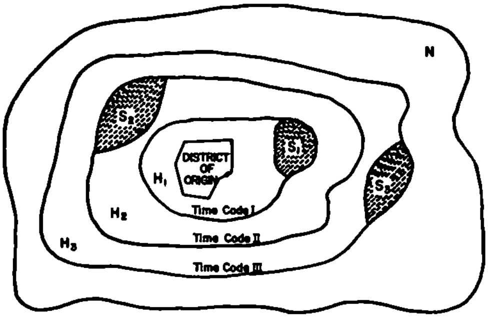


Figure 3

Eq. 8 is practically the final formula of the "theory of competing opportunities." In its general form it expresses the manner in which trips from an area are distributed to any number of other areas. It produces one-way trips given an accurate measurement of trip opportunities in the entire region and every subdivision, and accurate measurements of the time distance between every district of origin and district of destination. (The "time-distance" between districts of course, should be, adjusted for any specific additional impedance which a given link might require; e.g., tolls.) The time-distance measurements are based on the "minimum time path" as it has recently been developed (6, 2:106-107; 7).

When this is repeated for all districts in the metropolitan area, then the total trips going into each district from all the other districts would be estimated. Although the method exactly distributes trips going out of a district, the total trips going into a district might be more or less than the number actually measured or projected through the trip generation techniques. The method has a built-in "balancing out" effect, but it may prove desirable to utilize one of the techniques of successive approximations (e.g., Fratar approximation method) in order to bring estimated and actual trips into a district into perfect balance.

The concept of competing opportunities implies an increase of competing opportunities in a wave-type movement, always increasing the amount of trip opportunities by the amount of opportunities included in each successive time code. Thus the attracting district (potential destination) would have to compete with all the other districts in the same or less time-distance from the district of origin; e.g., with all the potential destinations of equal probability.

The manner according to which this wave-type increase of trip opportunities takes place and the successive derivation of the conditional probabilities is achieved can be shown with the help of Figure 3 and the mathematical formulations which follow, assuming

H_1 = total trip destinations in time code I, including trip destinations of district S_1

H_2 = total trip destinations within time codes I and II, including trip destinations of district S_2

H_3 = total trip destinations within time codes I, II, and III, including trip destinations in district S_3, etc.

then for districts in time code I:

$$P_{(S_1/H_1)} = \frac{S_1}{H_1} = P_1 \text{ and the summation required for the adjusted conditional probability: } \sum P_1 = 1 \qquad (9)$$

for districts in time code II:

$$P_{(S_2/H_2)} = \frac{S_2}{H_2} = P_2 \text{ and the summation required for the adjusted conditional probability: } \sum P_2 = 1 - \frac{H_1}{H_2} \qquad (10)$$

for districts in time code III:

$$P_{(S_3/H_3)} = \frac{S_3}{H_3} = P_3 \text{ and the summation required for the adjusted probability: } \sum P_3 = 1 - \frac{H_2}{H_3} \qquad (11)$$

Thus if there are only three time codes in the urban area, then, the required summation of the conditional probability (Eq. 7) would be

$$\sum P_{i\,(S/H)} = \sum P_1 + \sum P_2 + \sum P_3 = 3 - \left(\frac{H_1}{H_2} + \frac{H_2}{H_3} \right) \qquad (12)$$

To generalize this formula and have the summation for any number of time codes, it is assumed that

K = number of time codes

$H_1, H_2, H_3 --- H_K$ = the total trip opportunities in time codes I, II, III --- K

then,

$$\sum P_{i\,(S/H)} = K - \left(\frac{H_1}{H_2} + \frac{H_2}{H_3} --- \frac{H_{K-1}}{H_K} \right) = K - \sum_{n=1}^{n=K} \frac{H_{K-1}}{H_K} \qquad (13)$$

There are several particular aspects of this new method which should be stressed. First, the method is based on a theoretical concept developed by Bernoulli. This concept, usually called the Bernoulli theorem states that "if the probability of one event is P, the number of attempts is m, and the number of successes n, then the probability, P_K, that the difference between P and the ratio n/m is smaller than any preassigned number (however small) is unity, if the number of attempts is sufficiently large" (for mathematical proof, see 8, ch. 4, pp. 82-116). The essence of this theorem is the basis of the new method when it postulates that the probability of attracting one trip multiplied by the number of origins in the district of origin will turn up the one-way interchange between the two districts (Eq. 8). Such basis, however, sets several conditions, the most important of which is in relation to the minimum number of trips (attempts) required in each case before any distribution be undertaken with reliability. To increase the number of "trips to be distributed," the first step is to aggregate zones into districts. This implies a spatial aggregation that might or might not be of importance, depending on the degree of spatial details required by each study.

A second aspect of aggregation is of increased importance. This involves the aggregation of districts into time codes. Here is a critical point of the new method. The basic objective of the "theory of competing opportunities," as outlined earlier, is the configuration of a function expressing the diminishing probability for interchange at increasing distances from a given district of origin. This probability is defined by the exact number of the competing opportunities in each case. In theory, then, an avoidance of any kind of aggregation would provide a theoretically better estimate of the probability of a trip destination to attract a trip.

Although the new method provides such a potentiality, the reality of the situation makes it impossible. This is so because there is no practical means to determine the actual competing opportunities exactly in each case. Besides, all trip destinations of a particular strata are competing among themselves for the attraction of trip of this strata. The difference is that some of these trip destinations have an edge over the others (higher probability for attraction) because of their closer location. An additional point is that even if the theoretical probability and the computed probability were the same, there would still be the problem of the empirical discrepancy that should be expected between estimates derived by any theoretical probability and the actual observations, or in other words there are the implications of the Bernoulli theorem at the destination points. A reasonable objective then would be an achievement of a balance (at the point of minimum total error) between the error due to the distortion in the rate of diminution of the probability of attraction of each trip destination and the error due to the expected variation between the theoretical probability and the empirical estimates.

Before the width of time codes can be decided, however, another thought should be explored. The objective here is to simulate human behavior in choosing the destination of a trip within a complex set of trip destinations of a region. This takes place on the basis of two elements of experience; e.g., experience with the transportation system considered, and the ability and sensitivity to count and utilize time in small increments. What is implied is that one cannot have a first time code of 5 min for a mass transit system where "waiting time" alone may be more than 5 min. It also implies that for auto travel or mass transit travel one should not have time codes of odd increments (of say, 6.25 min) but of blocks of time that are easily conceived and frequently used by people in their everyday activities; e.g., time codes of 5 or 10 min.

This consideration of simulating human behavior has proven of substantial importance where best results were achieved with time codes of 5 min driving time in distributing auto trips. In the case of mass transit trips the first time code was 20 min in most of the area and 30 min for the districts at the outskirts of the metropolitan region. The rest of the time codes were of 5 min riding time. This variation of the width of the first time code was in response to the variation of "waiting time" in the system, which ran up to 12 and 18 min, respectively.

(The distribution of mass transit trips presents some additional difficulties which no researcher cared to present until now. For instance, all the known methods of trip distribution have the form of a diminishing function; that is, the interchange decreases when the distance from the origin increases. This is not true, however, in the case of mass transit trips where the frequency of trips has its peak around 25 to 35 min of the origin. Such an "amfitonic" function, however, presents more problems than any auto trip distribution function with its "monotonic" form. The problem was faced in Penn-Jersey, but there was not enough data to incorporate any systematic solution with the 1947 O-D data. For 1960 data, the analysis proceeds in a more systematic manner, and the aggregation of the first time codes vary according to a verified relationship with the "mean length" of transit trips of each district. Of course, a need for a sound projection of the "mean length" of transit trips is implied here, a project that is currently under way in the Penn-Jersey Transportation Study.

The preceding prargraphs imply a need to introduce a dichotomy between auto trips and mass transit trips. For a small city without major mass transit facilities this is not an important dichotomy and need not be carried out. However, when such facilities exist in a large scale, then there is a substantial distortion of reality if the various districts would be arranged from a given point of origin on the basis of a single minimum path based on highway facilities. This is true because "combined" (all modes) minimum paths are difficult to estimate objectively. Thus, it became evident that suitable time codes by auto and mass transit should be established in each case on the basis of the pertinent minimum time paths.

Here, two points should be noted. First, a minimum time path is in essence an accumulation of the minimum penalties (expressed in time) per unit of distance overcome in traveling the links of the path. Thus, tolls or any other particular impedance accruing to the traveler on the link should be incorporated in calculating the minimum time path. Second, there is the evident need "to generate" mass transit trips as part of the original trip generation study. This is a basic requirement if a modal split is going to be undertaken. A method of achieving this mass transit trip generation in terms of "percent of total trips" is currently under study.

A further ramification is derived if purpose of trips is taken into account. This is important for many reasons, one of which is the fact that work trips are mainly undertaken during the peak travel hours. Therefore, a peak-hour travel minimum time path is more appropriate. The opposite seems more appropriate for all the other purpose trips.

All the preceding particular explanatory points make evident the extensive potentialities of the new method in studying and analyzing conditions of interaction among activities with complex relationships. It also indicates the degree of refinement the method can reach. Its limits and potentialities are stemming from its dual nature, because it combines the rigorous structure of the theory of probability and the ingenious device of gravity models in arranging districts with the same probability of interaction in terms of a spatial permutation on the basis of time-distance from a given point of origin. (Credit should be given for this device to H. Wynn and A. Voorhees for their extensive and pioneering work on gravity models under various names and forms.) This new method combines features of both methods and lies somewhere between the Chicago probability method and "gravity" models. As it stands today the new method succeeds to state the hypothesis objectively and test it without the help of any subjective "correction" of the results through either the utilization of an exponent (as, for example, in the gravity model) derived as an empirical average of widely varying values, or of a parameter (as, for example, in the Chicago method) derived on the basis of an unknown future trip-length distribution and number of intrazonal trips in a manner not clearly demonstrating mathematically significant relationships. Further, the method can take fully into account future variations in all three important components of the problem; namely, the land use at the origin, the land use at the destination, as well as at the land use between and about the point of origin and potential destination.

Changes in the tranportation system are also readily and explicitly incorporated. In fact, the basic concepts of this method are currently utilized in the method of modal split developed by PJ. The same basic concepts are also under scrutiny for application to a land use or regional growth model.

REPORT ON RESULTS

Before presenting a definite example indicating the manner in which the new method is applied, significant points of the results of the empirical investigations carried out with 1947 O-D data can be reported. Figures 4 to 17 indicate the actual and the probability frequencies of seven test districts. For each district the person-trip interchange by auto and mass transit is separately reported. The 1947 O-D survey included 124 districts. From these, seventeen districts were originally selected. Of these, twelve districts were completely analyzed. Three of these districts are located on the New Jersey side of the metropolitan area and the other nine at various locations within the City of Philadelphia. Application of the new method has produced highly satisfactory results for all twelve districts tested when distributing mass transit trips. The results of auto trip distribution for 8 of these districts was also highly satisfactory. Applying the method to simulate auto interchanges for the remaining 4 districts produced less satisfactory results. In these districts the actual interchange is reproduced with less accuracy although the calculated frequency follows the same general form of the actual frequency of interchange.

The four districts with these discrepancies are the three districts located in New Jersey and the district representing the core of the Philadelphia central business district. The calculated auto interchanges of the three New Jersey districts show a more evenly distributed interchange than actually reported. In fact, districts in New Jersey consistently receive more trips from other New Jersey districts than the method predicts. The reverse is true for districts on the other side of the Delaware River which receive less trips than trips predicted with the method. The existence of the Delaware River with a limited number of toll crossings is affecting the trip distribution pattern within the region.

To take the river into account, an additional time penalty of 10 min was established between New Jersey and Philadelphia. This substantially improved the results but did not bring them as close as the results of the Pennsylvania districts. There was, however, no means to improve the results further for many reasons. First, the cor-

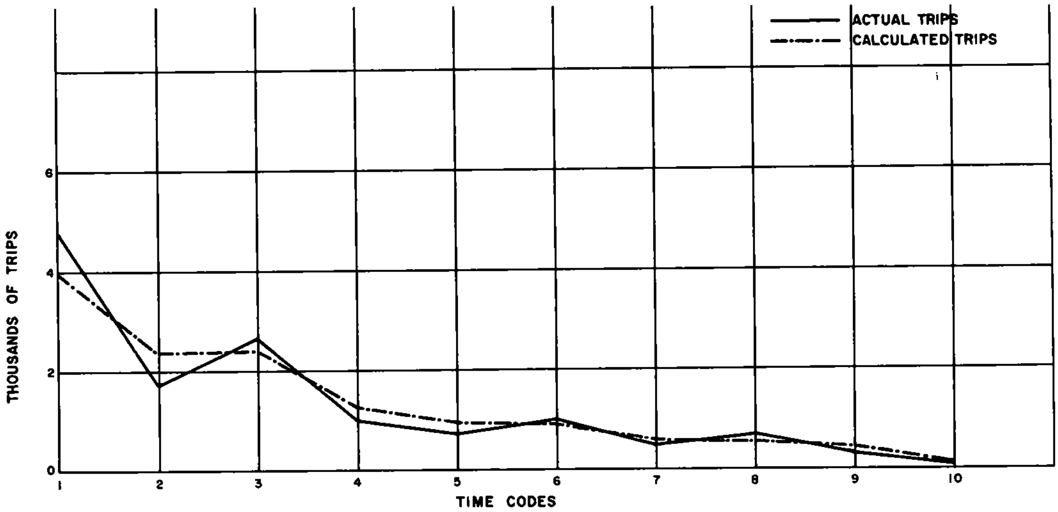


Figure 4. Actual and calculated auto and taxi trip ends distributed by time code, District 012.

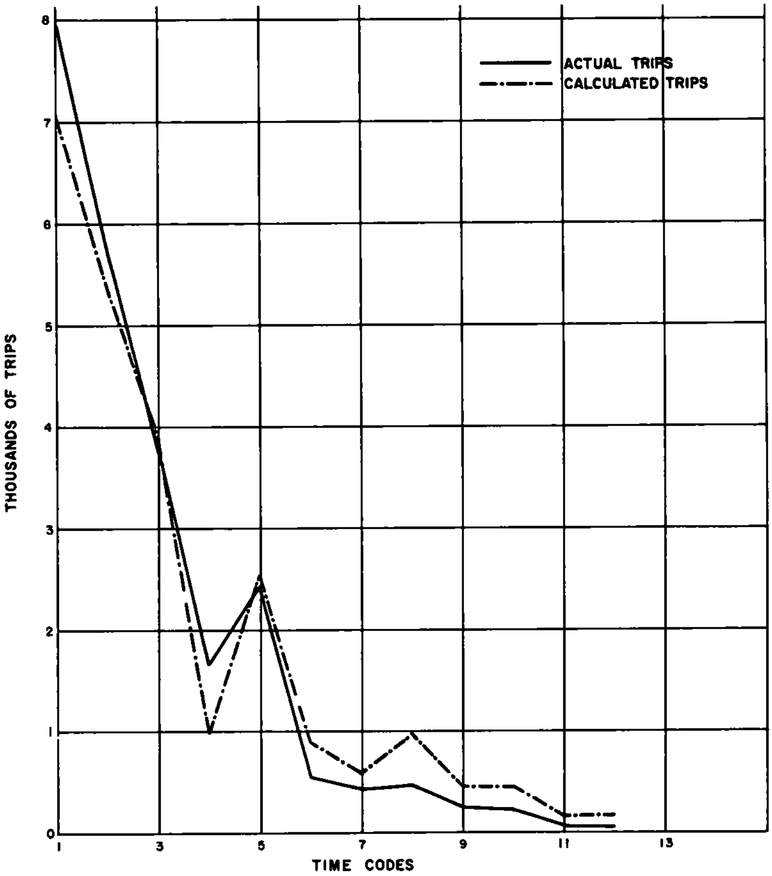


Figure 5. Actual and calculated mass transit trip ends distributed by time code, District 012.

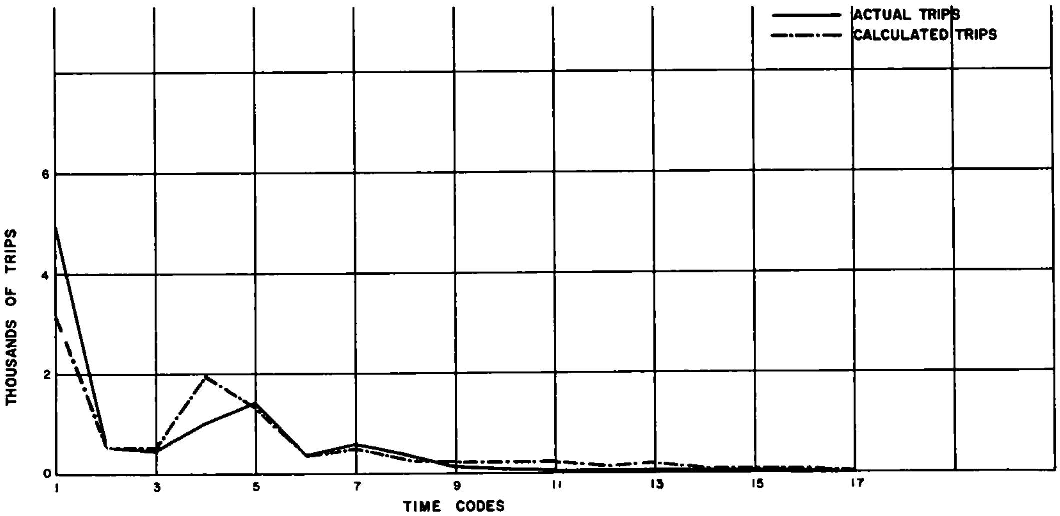


Figure 6. Actual and calculated mass transit trip ends distributed by time code, District 030.

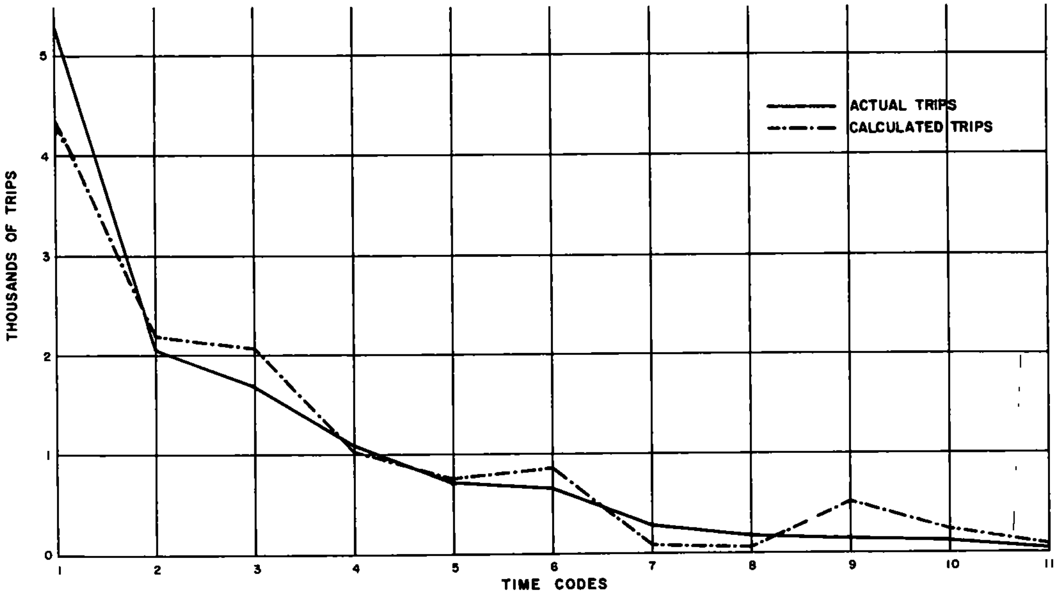


Figure 7. Actual and calculated auto and taxi trip ends distributed by time code, District 030.

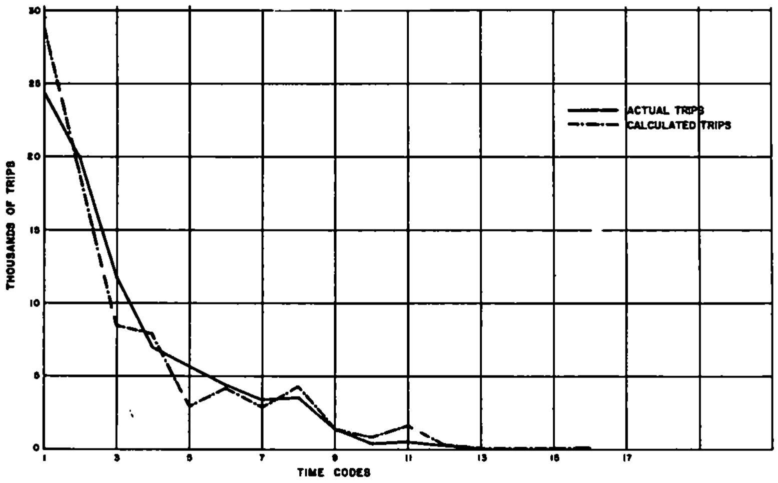


Figure 8. Actual and calculated mass transit trip ends distributed by time code, District 041.

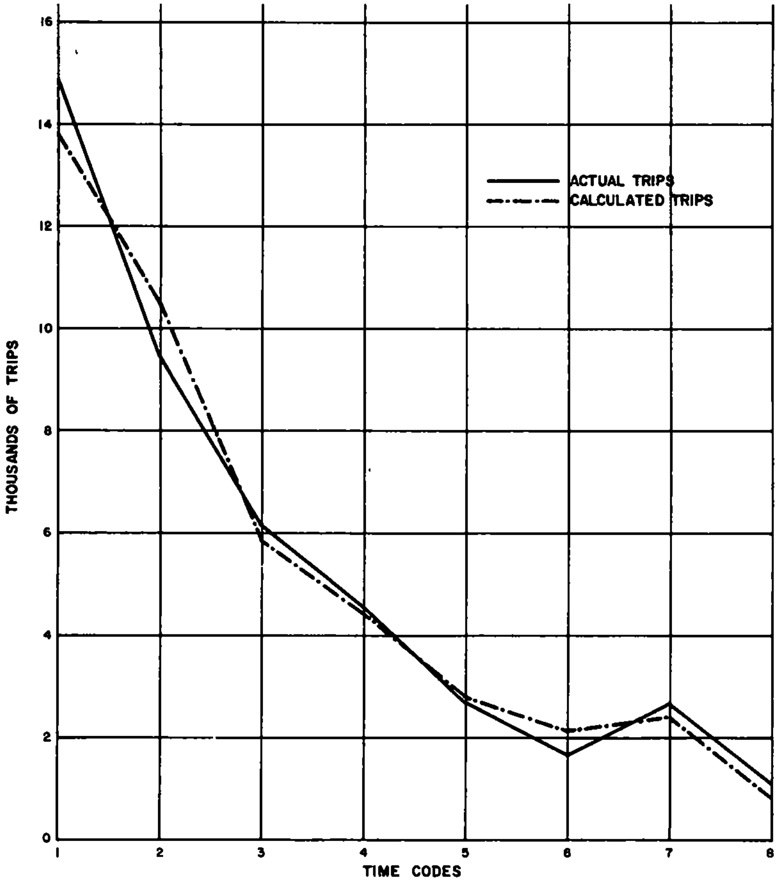


Figure 9. Actual and calculated auto and taxi trip ends distributed by time code, District 041.

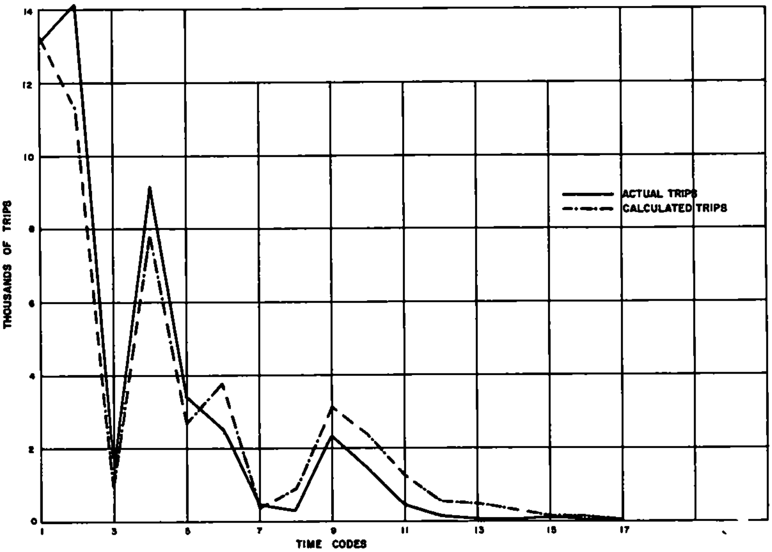


Figure 10. Actual and calculated mass transit trip ends distributed by time code, District 054

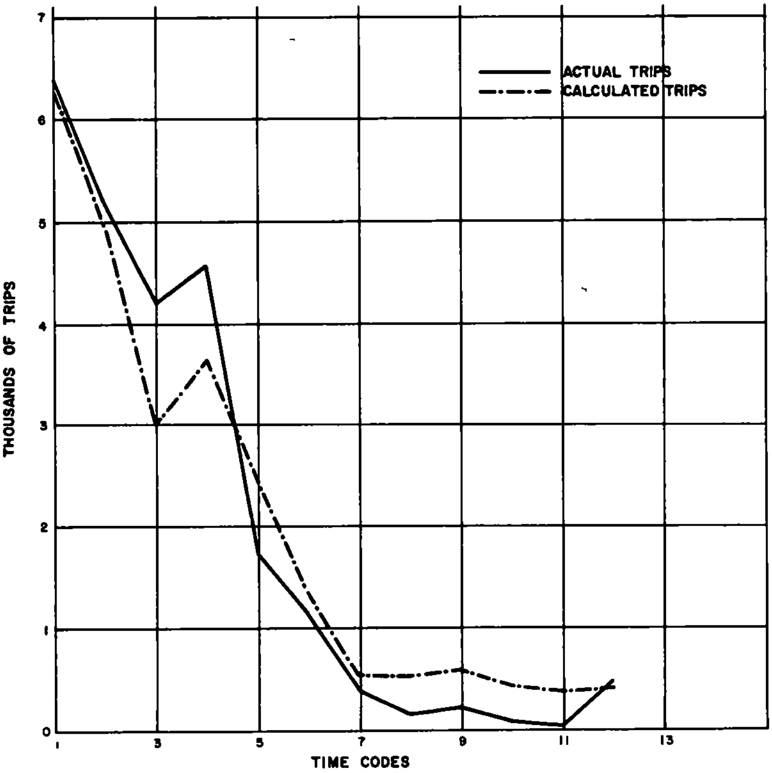


Figure 11. Actual and calculated auto and taxi trip ends distributed by time code, District 054.

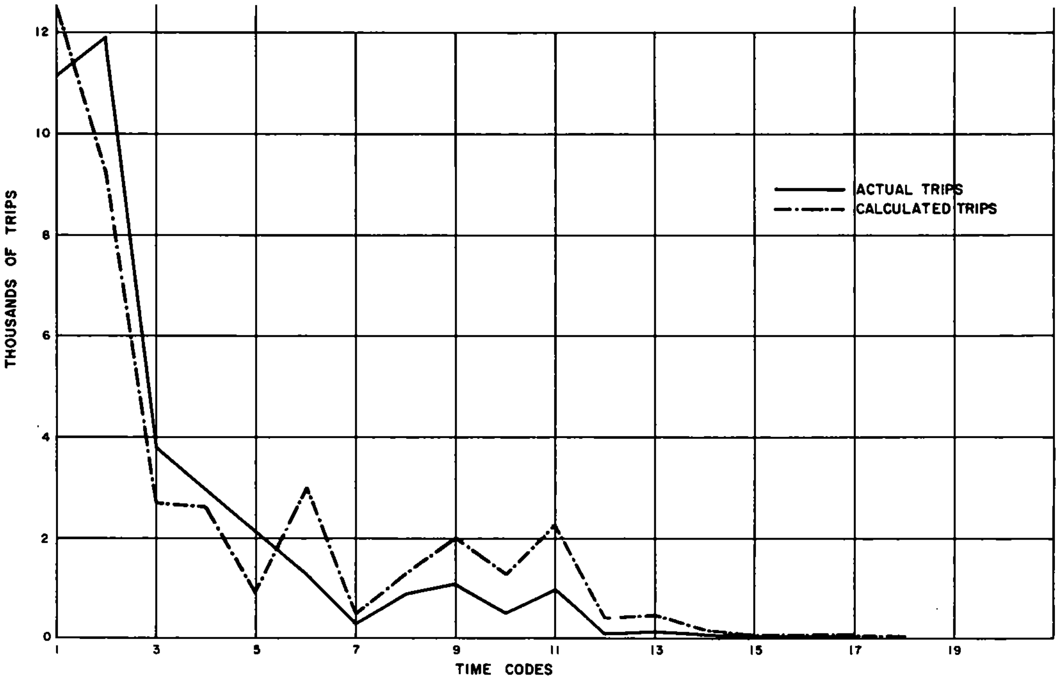


Figure 12. Actual and calculated mass transit trip ends distributed by time code, District 063.

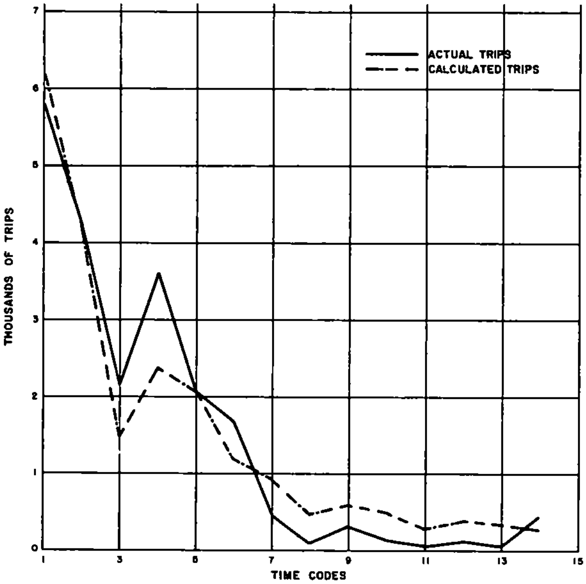


Figure 13. Actual and calculated auto and taxi trip ends distributed by time code, District 063.

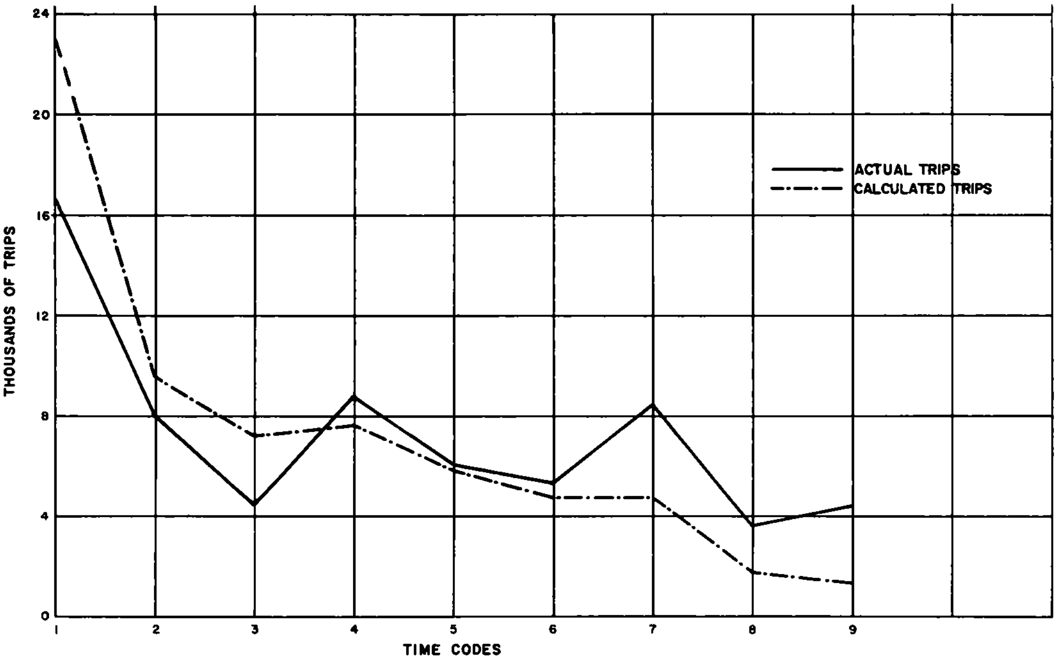


Figure 14. Actual and calculated auto and taxi trip ends distributed by time code, District 000.

don line of the 1947 survey was closer in at the New Jersey side, so even the introduction of a 10-min penalty on the bridges did not substantially alter the relative position of districts for New Jersey origins because within 15 or 20 min all districts in New Jersey could be reached from a bridge. Thus, further time penalties on the bridge could further remove the Pennsylvania districts but it could not produce a difference in the sequence of districts, which, as can be recalled, is crucial in importance.

Second, the 1947 survey reports only unlinked trips. Thus all the trips which consist of two legs—one driving or riding on local bus to Camden and another on the rapid transit to the City of Philadelphia—are shown as two trips, the first of which is shown as having destination the City of Camden, a reporting which is obviously not correct. Third, the results could not be further improved due to an inability to introduce a strata of subclassification of trip interchanges or trip destinations. The 1947 O-D data do not provide for such refinements. Thus, the results are reported as they were reached but the three improvements outlined—all within the model for 1960 trip distribution analysis—would turn up highly satisfactory results when they would be incorporated, as it is done currently with the 1960 data. (Preliminary results of the 1960 data analysis incorporating only the two first improvements and distributing trips only by mode (all purposes aggregated) have already verified this belief.)

The case of district 000, representing the core of the CBD of the City of Philadelphia, is similar in nature. The method reproduces the general form of the distribution but distributes more trips to districts close by and less trips to districts further out than the actual interchange does. No improvement of the original frequency was possible, however, with the 1947 data. This was so because of the reasons of this discrepancy. First, the home interview data do systematically understate non-home-based, intra-CBD trips because trips are reported in the original home interveiw questionnaire by the housewife who usually does not know all the non-home-based trips made by her husband. Second, the parking situation in and around the CBD intervenes to

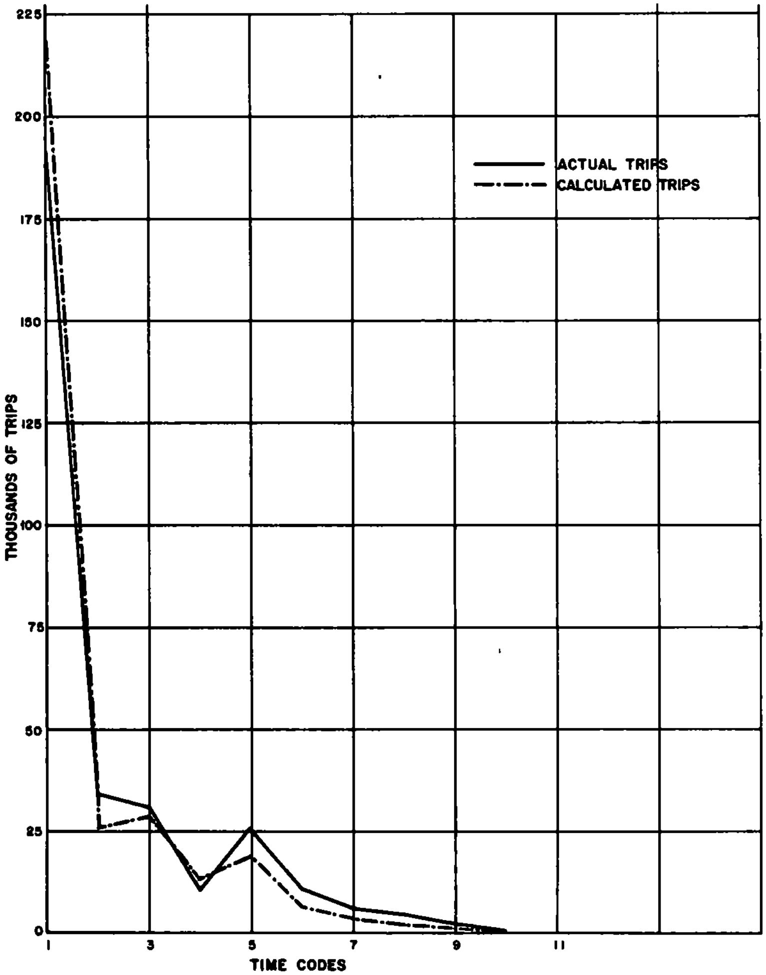


Figure 15. Actual and calculated mass transit trip ends distributed by time code, District 000.

alter circumstances further. One can speculate that some people do not use cars to travel within the CBD and in its vicinity (e.g., within 5 to 15 min driving time) in the City of Philadelphia because it is excessively costly to travel on these links and parking a car may be inconvenient and costly. Thus, in the case of the downtown area, potential auto trips result in either a combined multipurpose trip or in a mass transit trip, or most frequently in a trip on foot.

There is, however, a third important reason. Auto trips made to downtown are not made in the same proportion by the entire population of a region. These trips are primarily made by a certain stratification of the population that can afford the expenses of taking a car into the CBD. The spatial distribution of these people, however, is highly localized in every metropolitan region with a concentration toward the outer areas of the region.

The 1947 O-D data used for this analysis do not permit any of the above reasons to be taken into account. This, of course, is not the case concerning the 1960 data where subdivisions of trip interchanges and trip destinations by population strata is possible. In addition, parking limitations in the CBD can be taken into account in reproducing the inter-downtown auto trips. (Again, preliminary results of the 1960 data analysis

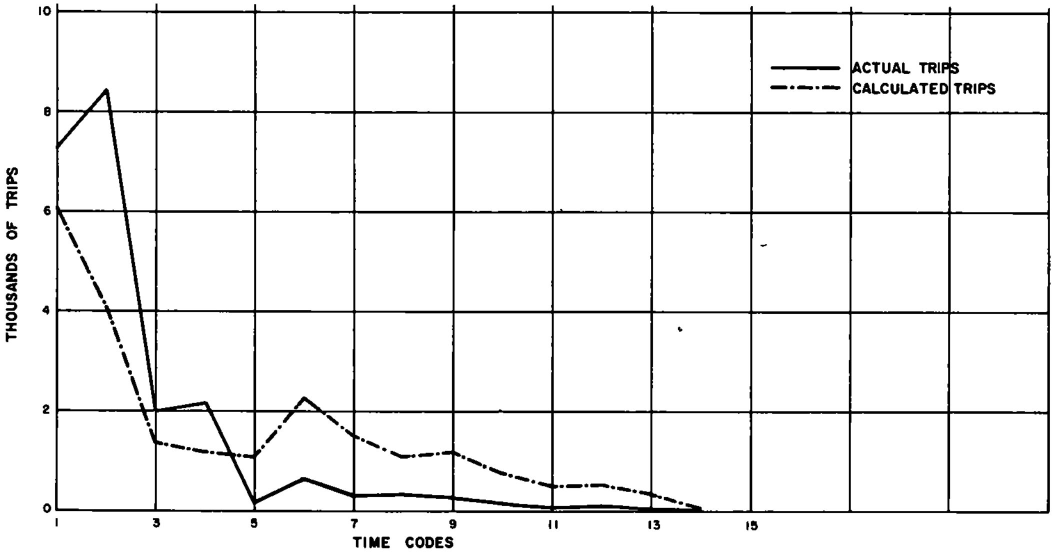


Figure 16. Actual and calculated auto and taxi trip ends distributed by time code, District 421.

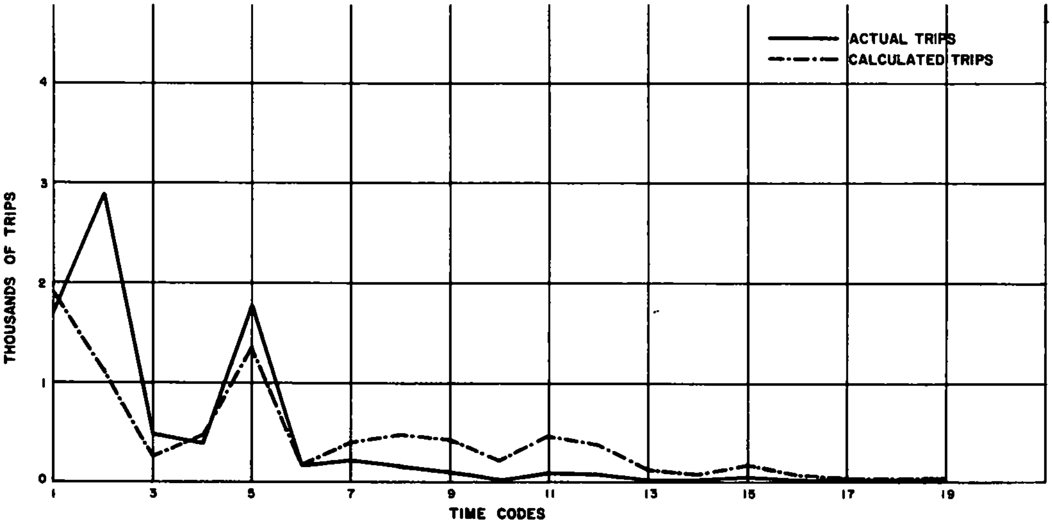


Figure 17. Actual and calculated mass transit trip ends distributed by time code, District 421.

have turned up extremely satisfactory simulation of actual interchanges of auto trips when only a 5-min parking penalty was incorporated for trips going into a congested district. Mass transit trips of the CBD did not present a problem in either case.)

These discrepancies as well as the degree of simulation achieved by the new method are shown by the seven districts reported here. Five of these districts are taken from ones with good results and two (district 000 and New Jersey district 421) are taken from the four districts with less satisfactory results.

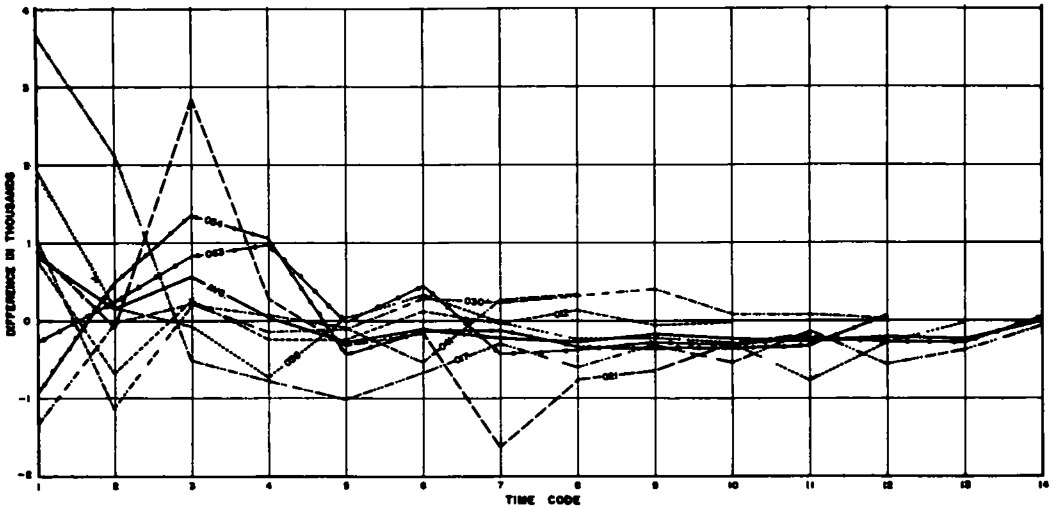


Figure 18. Absolute differences between actual and calculated auto and taxi trip interchanges, by time code.

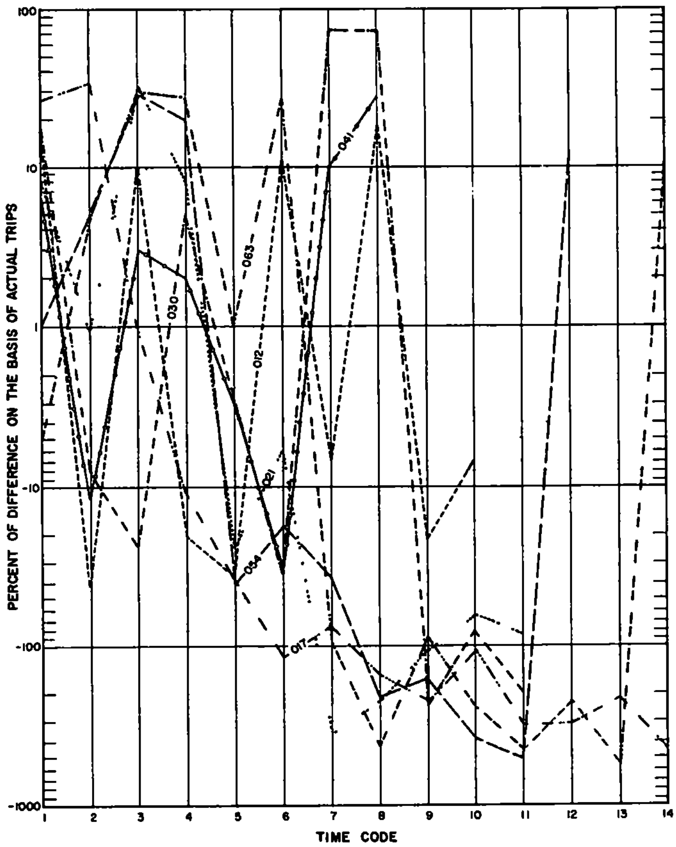


Figure 19.

COMPARISON AND FURTHER TESTS

When the trip-end distribution analysis of these twelve districts was completed, then a number of tests and comparisons were undertaken. First, graphs were compiled as in Figures 18 and 19 where the differences in the interchange of auto and mass transit trips of all districts, grouped by time code, were depicted. The differences were graphed on absolute as well as percent basis. These figures show that the absolute differences are larger at the early time codes, where the total interchange is large, too. This relationship is shown in the second graph where for the early time codes the percent of differences are much smaller than they are at the further out time codes. To study the interchanges in more detail, the graph of Figure 20 was formed. In this graph each interchange of auto trips of the seven reported districts is plotted. In this figure the relation between actual and calculated trips becomes very clear. The reader would notice that as long as the actual interchange is below 1,000 trips the relationship is much farther out from the 45° line which represents a perfect reproduction. This observation is entirely what should be expected according to the theoretical concepts explained earlier because they are variations which the theory of probability expects normally in a phenomenon of stochastic nature as the phenomenon of trip interchange within an urban region. Also, however, most of this variation falls below the 45° line. This means that the calculated trip interchange of longer trips is frequently higher than the reported actual trip interchange. Two reasons stand behind this systematic varia-

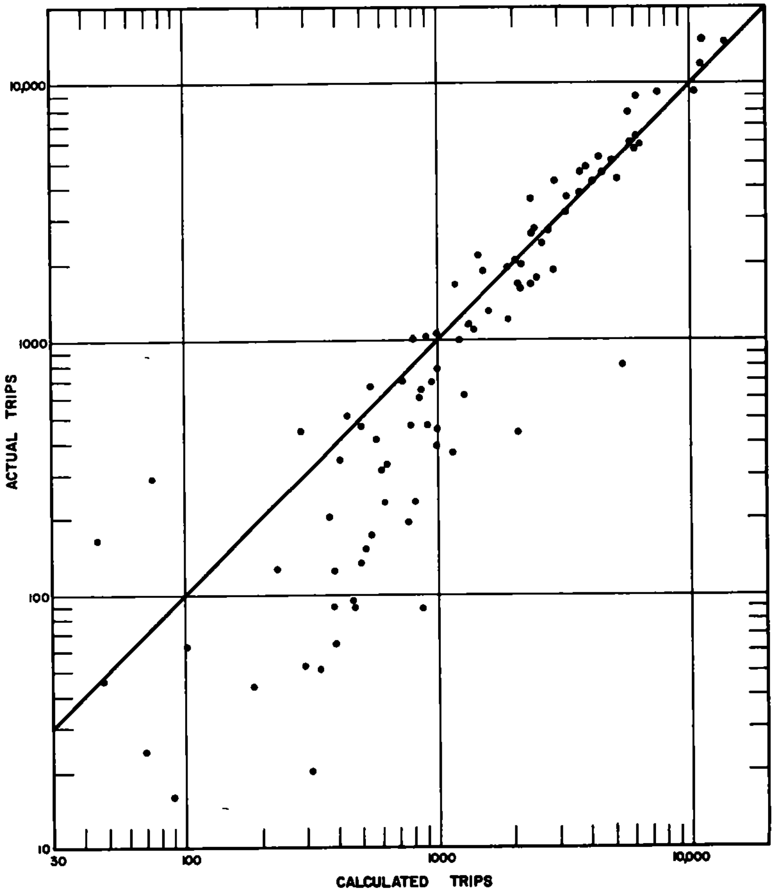


Figure 20.

tion: (a) the fact that the 1947 O-D data were not factored after screenline checks were made, and (b) the fact that in the analysis the internal-external trips (trips going to the stations) were not subtracted.

(Since the basic theory of this method, as well as some other methods, is probabilistic in nature, it would be a mistake to distribute trips on the basis of a "universe N," which misrepresents the situation. For instance, the number of trips going from the city to Washington, D. C., should not be estimated on the basis of the number of trips counted at the entering station. Thus, when trips of a district are distributed, the trip destinations at the stations should be subtracted from the "universe," and the origins that are going out of the metropolitan area subtracted from the district. When this process is completed, then the distribution of the trips from the stations to all dis-

TABLE 1

ACTUAL INTERCHANGES AND PROPORTION OF ERROR OF PREDICTED INTERCHANGES OF VEHICLE TRIPS FOR SEVEN ANALYSIS DISTRICTS BY TIME CODES OUTWARD FROM EACH DISTRICT CENTER (PJTS 1947 O-D data)[a, b]

Time[c] Code	District 012		District 017		District 021		District 030		District 041		District 054		District 063	
	Actual Trips	% Var	Actual Trips	% Var	Actual Trips	% Var	Actual Trips	% Var.	Actual Trips	% Var	Actual Trips	% Var	Actual Trips	% Var
1	4,734	-16	14,901	- 27	12,129	- 08	5,290	- 18	14,837	- 07	6,367	- 01	5,745	+ 08
2	1,670	+41	7,765	- 35	5,075	+ 01	2,005	- 08	9,427	+ 12	5,161	- 05	4,212	- 03
3	2,652	-10	5,090	+ 00	9,002	- 32	1,675	+ 24	6,082	- 03	4,212	- 29	2,132	- 32
4	1,006	+21	4,325	+ 12	3,655	- 08	1,071	- 05	4,528	- 02	4,571	- 20	3,606	- 35
5	690	+37	2,524	+ 38	1,282	+ 25	701	+ 03	2,682	+ 0:	1,748	+ 41	2,077	- 01
6	1,032	-12	1,215	+ 127	2,436	+ 06	644	+ 35	1,629	+ 33	1,156	+ 17	1,667	- 29
7	465	+07	1,129	+ 75	438	+ 369	288	+ 74	2,698	- 10	411	+ 38	467	+ 97
8	660	-18	490	+ 165	365	+ 215	168	- 73	1,113	- 28	173	+ 213	88	+ 434
9	339	+22	178	+ 224	614	+ 106	151	+ 241			232	+ 166	310	+ 92
10	45	+07	450	+ 112	473	+ 64	127	+ 82			94	+ 390	133	+ 269
11			43	+ 314	202	+ 84	24	+ 192			64	+ 517	52	+ 471
12			193	+ 302							508	- 13	124	+ 214
13			169	+ 212									50	+ 576
14			16	+ 450									443	- 35

[a] Dotted line separates interchanges below 1,000 trips Such interchanges present more limited stability due to stochastic nature and limited number of events

[b] Var = variation of calculated trips based on actual (e g , calculated trips - actual trips + actual trips)

[c] Each time code equal to 5-min driving time from the district of origin

TABLE 2

ACTUAL INTERCHANGES AND PROPORTION OF ERROR OF PREDICTED INTERCHANGES OF WEIGHTED VEHICLE TRIPS FOR SEVEN ANALYSIS ZONES BY TIME RINGS OUTWARD FROM EACH ZONE CENTER[a, b, c]

Trip Time (min)	Zone 001		Zone 003		Zone 012		Zone 067		Zone 118		Zone 487		Zone 553	
	Actual Trips	% Var	Actual Trips	% Var	Actual Trips	% Var	Actual Trips	% Var	Actual Trips	% Var	Actual Trips	% Var	Actual Trips	% Var
0- 1 9	6,181	+ 57	5,347	+ 59	11,689	+ 33	3,032	- 03	3,522	+ 11	2,079	- 19	15,288	- 20
2- 3 9	7,410	- 26	4,562	+ 18	7,158	+ 96	4,776	+ 33	3,687	+ 52	280	- 02	--	--
4- 5 9	3,459	- 50	2,144	- 02	14,087	- 06	2,439	+ 46	1,403	+ 28	4,357	- 03	9,425	- 36
6- 7 9	3,014	- 04	1,405	+ 21	7,797	- 24	2,823	- 32	3,341	+ 05	971	+ 13	2,460	+ 15
8- 9 9	1,585	+ 21	1,727	- 52	5,622	- 26	1,642	- 08	1,018	- 32	642	+ 111	3,224	+ 10
10-14 9	3,782	+ 37	3,302	- 32	8,769	- 16	3,701	- 27	2,433	- 62	953	- 78	3,620	- 06
15-19 9	3,770	- 16	2,044	- 41	7,110	- 39	1,787	- 01	1,334	- 22	437	+ 112	2,169	+ 31
20-24 9	2,150	- 23	1,359	- 50	5,901	- 47	1,315	- 35	1,555	- 30	291	+ 23	397	+ 210
25-29 9	960	- 13	906	- 57	2,835	- 33	937	- 45	1,170	- 47	425	- 22	535	+ 100
30-34 9	601	+ 20	735	- 56	1,565	- 27	301	- 04	323	- 29	74	+ 405	348	+ 574
35-39 9	942	- 50	272	+ 37	844	- 12	261	- 20	27	+ 441	137	- 01	363	+ 232
40-44 9	314	+ 33	123	+ 00	588	+ 111	107	+ 86	116	+ 40	286	- 64	325	+ 242
45-49 9	410	- 14	88	+ 152	308	+ 18	29	+ 693	85	+ 92	131	- 60	301	+ 00
50-54 9	203	- 24	53	+ 26	246	+ 223	172	+ 35	40	+ 193	42	- 38	206	+ 167
55-59 9	193	- 69	112	+ 09	171	+ 120	36	+ 266	81	- 63	18	- 67	225	+ 21
60 and over	474	+ 45	401	- 11	929	+ 29	183	+ 02	12	+ 675	117	- 75	282	- 03
Total	35,448		24,580		75,o19		23,541		20,147		11,240		39,168	

[a] Source Table 54, 6, 2 126

[b] Dotted line separates interchanges below 1,000 trips Such interchanges present more limited stability due to the stochastic nature and the limited number of events

[c] Var = variation of calculated trips, based on actual (e g , calculated trips - actual trips + actual trips)

tricts is taking place. For each district, the trips coming from the stations are duplicated, and thus the total number of trip origins and destinations in each district is achieved. "Though trips" (e.g., station to station) are estimated separately on the basis of a predetermined and commonly agreed-on "area growth factor.")

For the analysis of 1960 data the first phenomenon (of wider discrepancies of smaller interchanges) cannot be improved very much, as long as the investigation proceeds on the zone or small district level. Over-all check distributions on the basis of large districts can achieve, of course, a substantially closer simulation of interchanges at all levels. As for the under-reporting of certain classifications of trips, it is not expected to be especially troublesome because the 1960 household trip file has been factored on the basis of the results of the screenline checks and the internal-external trips were subtracted and analyzed separately.

After these tests were completed, a comparison of the results reached in PJ with the detailed results reported by CATS was undertaken. Tables 1 and 2 give these results. It is evident from these tables that the results reached by the new method are generally at least as good as the results reported by the CATS method.

Finally another test was carried out along the lines suggested by Brokke and Mertz (9) and followed in the Wilbur Smith studies (e.g., 10, 11). The results are given in Table 3 and in a graphic form in Figure 21. This figure should be compared with the results reported in the Wilbur Smith studies (10, pp. 188-191; 11, pp. 137-140) and by Brokke and Mertz (9, pp. 63-68) in their testing of the Detroit and Fratar methods in the Washington, D.C., area. By comparing these results, and observing Figure 21, it is once more verified that (a) the accuracy of simulation (and henceforth projection) increases substantially when the magnitude of interchange increases, and (b) this accuracy does not level off at a point of 10 percent but it continues to increase when the magnitude of trip interchange increases.

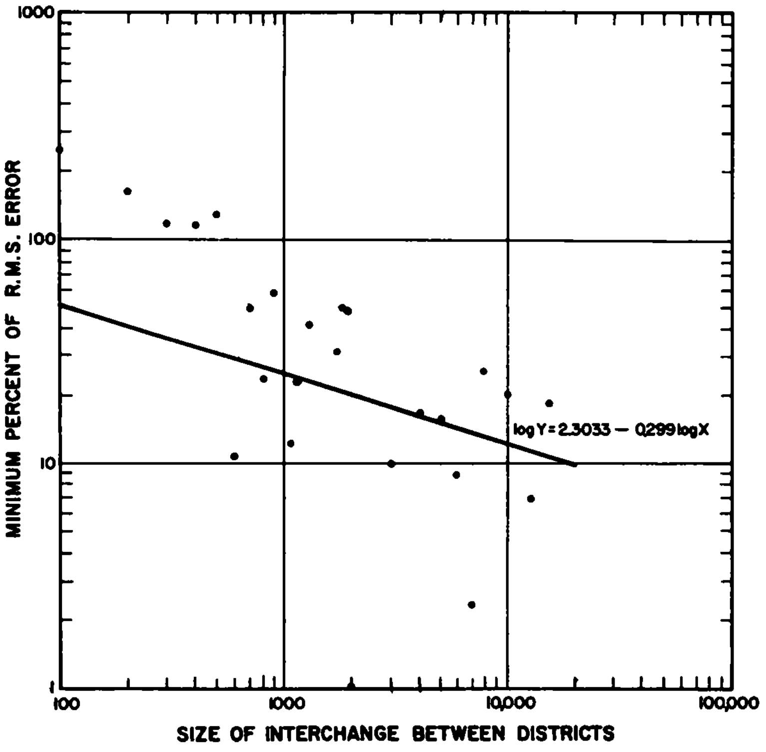


Figure 21.

TABLE 3

PERCENT OF ROOT MEAN SQUARE OF EACH GROUP OF INTERCHANGE,[a] AUTO TRIPS

Interchange	RMS	RMS Percent of Interchange	No. of Pairs in Group
0-100	248.24	248.24	12
100-200	347.26	173.63	8
200-300	375.10	125.03	4
300-400	480.58	120.14	5
400-500	682.44	136.49	7
500-600	66.00	11.00	1
600-700	350.34	50.05	5
700-800	199.87	24.28	2
800-900	519.73	57.75	2
1,000-1,100	147.61	13.42	3
1,100-1,200	273.67	22.80	3
1,200-1,300	541.72	41.67	2
1,600-1,700	539.63	31.74	4
1,700-1,800	723.00	40.17	1
1,800-1,900	753.80	39.67	2
1,900-2,000	37.00	0.02	1
2,000-3,000	311.59	10.39	6
3,000-4,000	657.43	16.44	4
4,000-5,000	774.81	15.50	6
5,000-6,000	528.88	8.81	5
6,000-7,000	158.12	2.26	2
7,000-8,000	2,136.00	26.72	1
9,000-10,000	2,089.19	20.89	3
10,000-12,500	911.00	7.01	1
12,500-15,000	2,684.25	17.90	2

[a] RMS can also be called "standard error of estimate" because it is same estimate (12, pp. 259-260).

(There is a slight difference, however, between the two sets of data. Brokke and Mertz compare projected trips from 1948 to 1955 to actual trips counted by the 1955 O-D survey. Instead, the author compares actual trips with simulated trips at the same date, having the first set of data as the basis for deriving the second set of data with no projection problems entering into account at all.)

CONCLUSIONS

Concluding this phase of the analysis the author reviewed the steps taken. The original dissatisfaction with existing methods of trip distribution led to a new approach with emphasis on structural simplicity and objective projection capabilities. As a result it was decided to test this method further with the 1960 data, a job which is currently under way.

EXAMPLE

Assume that there is a small city of about 150,000 to 200,000 people. Figure 22 shows the assumed over-all outline of the urban development, with two major highways crossing at the central business district. The entire area is divided into districts for the purpose of a transportation study. Assume that the city has no mass transit system and all trips consist of auto trips. A total of 24 districts are outlined on the basis of particular features and characteristics. A trip generation study is then carried out,

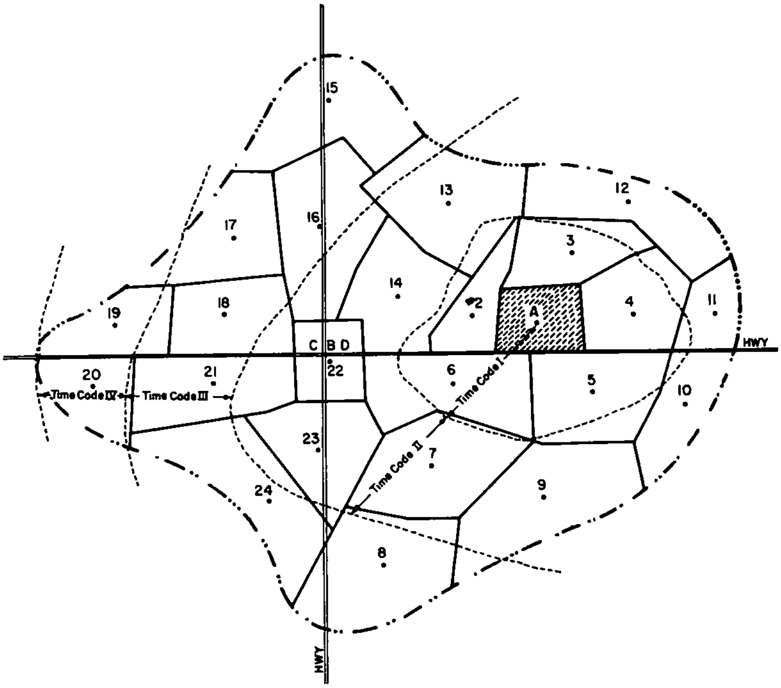


Figure 22.

TABLE 4

TIME CODES AND TRIP ENDS
(on the basis of District A)[a]

District A Origins	Time Code I		Time Code II		Time Code III		Time Code IV	
	Dist.	Destinations	Dist.	Destinations	Dist.	Destinations	Dist.	Destinations
17,000	A	16,500	7	19,000	15	17,000	19	6,000
	2	14,000	9	4,000	16	36,000	20	9,500
	3	12,000	10	3,000	17	18,000		
	4	4,000	11	2,500	18	14,000		
	5	11,000	12	6,500	21	28,000		
	6	17,000	13	14,500	24	11,000		
			14	26,000	8	7,500		
			22	65,000				
			23	46,000				
Time Code Total		74,500		186,500		131,500		15,500
Cum Total		74,500		261,000		392,500		408,000

[a] Thus, on the basis of these data H_1 = 74,500; H_2 = 261,000, H_3 = 392,500; H_4 = 408,000.

and on the basis of such a study, auto trip-ends generated in each district are estimated.

Suppose that it is desired to find out how the trip origins of district A are distributed to the other 23 districts. On the basis of the average travel time between district A and each other district, a set of time codes can be established expressing distance in minutes between district A and all other districts. Suppose the time codes are defined as an interval of 5 min travel time and the area boundaries are reached in 4 time codes as shown in Figure 22. The data are ready to enter in Table 4. The trip destinations in each district take the place of S in Eq. 5. The total trip destinations in each time code takes the place of H in the equation.

Table 5 gives the districts, the trip destinations in each district, and the time code of each district. Then the original conditional probability of each district ($P_{(S/H)}$ = S/H) is established. This column is summed up and the denominator of Eq. 7 $\left[\sum P_{i\,(S/H)}\right]$ is established. The summation is then checked with the help of Eq. 13.

TABLE 5

ESTIMATED INTERCHANGE BETWEEN DISTRICT A AND ALL OTHER DISTRICTS

District	Destination	Time Codes	$P_{(S/H)} = \frac{S}{H}$	$P_{i\,(S/H)} = \frac{P_{(S/H)}}{P'_{i\,(S/H)}}$	Est. Trip Ends[a]	Actual Interchange Between A and j[b]
A	16,500	1	0.2215	0.1060	1,802	
2	14,000	1	0.1879	0.0899	1,528	
3	12,000	1	0.1611	0.0771	1,311	
4	4,000	1	0.0537	0.0257	437	
5	11,000	1	0.1477	0.0707	1,202	
6	17,000	1	0.2282	0.1092	1,856	
7	19,000	2	0.0728	0.0348	592	
8	7,500	3	0.0219	0.0105	179	
9	4,000	2	0.0153	0.0073	124	
10	3,000	2	0.0115	0.0055	94	
11	2,500	2	0.0096	0.0046	78	
12	6,500	2	0.0249	0.0119	202	
13	14,500	2	0.0556	0.0266	452	
14	26,000	2	0.0996	0.0476	809	
15	17,000	3	0.0433	0.0207	352	
16	36,000	3	0.0917	0.0439	746	
17	18,000	3	0.0459	0.0220	374	
18	14,000	3	0.0357	0.0171	291	
19	6,000	4	0.0147	0.0070	119	
20	9,500	4	0.0233	0.0111	189	
21	28,000	3	0.0713	0.0341	580	
22	65,000	2	0.2490	0.1191	2,025	
23	46,000	2	0.1762	0.0843	1,433	
24	11,000	3	0.0280	0.0134	228	
Total	408,000		2.0904[c]	1.000	17,000	17,000

[a] Origins in A × $P^{1}_{1(S/H)}$.

[b] If available.

[c] $\sum P_{(S/H)}$.

The next column of Table 5 presents the adjusted probability P'_i of each district which is reached by applying Eq. 7. The next step is to multiply the adjusted conditional probability of each district with the trip origins of the originating district (district A in this case). This is the application of Eq. 8. The result is given in the next column and is compared with the actual interchange, if known. Accuracy of results depends on accuracy of measurements of time-distance between districts and trip opportunities within each district. Limits of accuracy can vary depending on the degree of significance each study accepts. If desired, the entire process can be programed for an electronic computer.

REFERENCES

1. Fratar, T., Jr., "Vehicular Trip Distribution by Successive Approximations." Traffic Quart. (Jan. 1954).
2. Voorhees, A.M., and Morris, R., "Estimating and Forecasting Travel for Baltimore by Use of a Mathematical Model." HRB Bull. 224, 105-114 (1959).
3. Lynch, J.T., Brokke, G.E., Voorhees, A.M., and Schneider, M., "Panel Discussion on Inter-Area Travel Formulas." HRB Bull. 253, 128-135 (1960).
4. Wynn, F.H., and Linder, C.E., "Tests of Interactance Formulas Derived from O-D Data." HRB Bull. 253, 62-85 (1960).
5. Feller, W., "An Introduction to Probability Theory and Its Applications." Vol. 1, Ch. 5, Wiley (1960).
6. "Final Report." Chicago Area Transportation Study.
7. Moore, E.F., "The Shortest Path Through a Maze." Internat. Symposium on the Theory of Switching, Harvard Univ. (1957).
8. Fry, T., "Probability and Its Engineering Uses." Von Nostrand, 12th ed.
9. Brokke, G.E., and Mertz, W.L., "Evaluating Trip Forecasting Methods with an Electronic Computer." HRB Bull. 203, 52-75 (1958).
10. "A Highway Planning Study for the St. Louis Metropolitan Area." Wilbur Smith and Assoc. (1959).
11. "Kansas City Metropolitan Area Origin and Destination Survey." Wilbur Smith and Assoc. (1959).
12. Mills, F.C., "Statistical Methods." Holt (1955).

Occupation, Commuting, and Limited-Access Highway Use

STANLEY H. UDY, JR., Yale University

•THIS PAPER reports the results of an exploratory study of occupational differentials in limited access highway use by commuters in greater New Haven, Conn. The study was carried out with two main objectives in mind: (a) exploration of the feasibility of using city directory data in the analysis of work trips, and (b) exploration of the possible relationship of occupational differences to commuter use of limited-access highways.

A potential, and often actual problem of any traffic study requiring information beyond sheer volume of movement is the time and expense of field interviewing, particularly of respondents at home. Such interviewing is unnecessary, however, if use can be made of accurate data that have already been collected. A good city directory is a potential and frequently neglected source of such data. In the directories covering greater New Haven, for example, not only is the name given together with the residential address for every resident of working age, but in addition fairly complete and reliable information is given on the marital status, occupation, and place of work of each person listed. Furthermore, the New Haven directory is not untypical in this respect. If such information is reliable and complete, it would therefore seem that city directories could be used instead of expensive home interview survey results as primary sources of data in certain kinds of work-trip studies. One problem that appears amenable to analysis through this source under certain conditions is the question of the relationship of occupational status to commuter use of limited-access highways. This question itself is of some importance as it bears on the broader question of the differential social distribution of benefits of limited-access highway construction. Do some occupational groups benefit more than others? If so, to what extent, and with what possible implications? It is admittedly true that one cannot go into this question as deeply with city directory data as one could with a home interview survey, but any limitations imposed by restricting oneself to data already available in city directories should be balanced against the much greater cost of a field survey. In the case of the study to be reported here, for example, it is estimated that to obtain the same data through a home interview survey, approximately ten times as much money would have to be expended, with no appreciable increase in the accuracy of the results.

METHOD

The object of analysis is the possible existence of occupational differentials in opportunity to use the Wilbur Cross Parkway for commuting purposes among residents of greater New Haven. This particular limited-access divided highway was opened for traffic in 1949, and has therefore been in operation for a sufficiently long period to permit the development of stable patterned consequences of its existence. For this reason it was selected for study in preference to other possibilities in the area. As a potential commuting facility, however, it suffers the disadvantage of not actually passing through the New Haven central business district. It passes around central New Haven through the northern and western parts of the city and its metropolitan area, and thus more nearly resembles a circumferential than an axial artery. It does nonetheless possess some axial features in that it has direct connections with similar facilities for Hartford, New York City, and intermediate points to the north, east, and west.

A systematic sample of 3,516 employed residents of the greater New Haven area was drawn from the 1958 editions of the two city directories (1, 2) covering New Haven, North Haven, East Haven, West Haven, and Hamden, Conn. (The outlying towns of Woodbridge and Cheshire, covered by the directories, are not included in the study.) The name, residential address, occupation, and place of work of each person was recorded from information given in the directory. On the basis of available speed and delay data, it was determined whether each person in the sample would be able to save time in commuting by driving via the Parkway; those in a position to do so were classed as having an opportunity to use the Parkway. Occupations were classified according to a modified version of the Alba Edwards scale, by standard methods prescribed by the U.S. Bureau of the Census (3). Occupational category was then run against use opportunity, with statistically significant results.

The sample was then controlled for type of commuting. Commuting was designated as "local," "intermediate," or "long distance" depending on whether the workplace was located in the same area from which the sample was drawn, in the civil boundaries of an immediately adjacent municipality, or elsewhere, respectively. Such a control added some information and suggested some reasons for the original results.

All persons drawn in the original sample were looked up in the 1948 directory covering the same area—the last directory published before the opening of the Parkway. For each of the 2,255 persons who also proved to be unmistakably listed in 1948, it was again determined through speed and delay data whether the person was already then in a position to enjoy an opportunity to use the Parkway when it was opened for traffic. It was then possible by comparing the respective postions of each person in 1958 and 1948 to ascertain changes in use opportunity in each case. Persons who were not in a position to use the Parkway in 1948 but had subsequently changed their residence and/or workplace so that they were in a position to use the Parkway in 1958 were classed as having an increased use opportunity. Increased use opportunity was then run against 1958 occupation, with statistically significant results defensible in terms of the previous findings.

Some comments are in order regarding difficulties leading to attrition in the sample. The 3,516 cases used represent approximately 75 percent of those originally drawn. Eighteen percent of the original number were dropped as unemployed or not in the labor force, as occupation and workplace were omitted from the directory. Considering that the directory seeks to list all residents of working age, whether actually in the labor force or not, and because the New Haven area was in a period of economic recession, in 1957-58 this figure was adjudged as not excessive, although it seems probable that as to completeness the directory is somewhat biased in favor of higher status occupations. Eight percent were dropped because of ambiguous workplace designations. Such ambiguity assumed two forms: (a) workplace designated by name of firm rather than by actual street address, in cases of firms with more than one possible address and (b) person residing in the area covered by one directory, but working in the area covered by the other directory, or outside the area entirely. In such cases, the town or city worked in constituted the only information available as to workplace location, except in the case of persons in higher status occupations. Frequently the available information was sufficient to determine whether the commuter should be assigned to the Parkway or not, particularly in the case of intemediate and long-distance commuters. However, in the case of the 8 percent dropped it was not; almost all of these were local commuters.

FINDINGS

Use of City Directory Data

A random subsample of 30 persons was drawn from the original sample and interviewed at home, as a check on the accuracy of the city directory. One instance of an incorrect workplace was found, and another instance of an incorrect occupation appeared. This occupation, however, when classified according to the scheme here employed, fell into the proper category despite the fact that it was incorrect in detail. These results are essentially in accord with field tests of the accuracy of the New Haven Directory made over the years by various researchers. For example, Hollingshead and Redlich (4, p. 31) found a 99 percent level of accuracy in addresses given—a degree of accuracy superior to that of the 1950 U.S. census in this area. Davie and Myers (5) found a level of accuracy of 82 percent in exact occupational titles given in the New Haven directory, which level, however, increased to slightly over 95 percent when the occupations were classified according to the scheme used here. (For a general discussion of the use of city directory data, see 6.) A representative of the directory publishing company was also contacted and asked to describe the canvassing method used. According to this representative, each household is called on and relevant data obtained for the whole household from any adult member. In the even that nobody is home, one call-back is made, at which point, if necessary, the required data are obtained from the nearest available neighbor, and subsequently checked against company employment records when possible, with the latter source considered authoritative in case of discrepancies. If at this point data are still lacking, an additional attempt is made to contact some adult member of the household. The same method is used for all directories published by this company.

In view of the finding presented, the author concludes that use of city directory data in traffic studies is practicable, subject to certain limitations:

1. The canvassing method used should be similar to the one described, in that it should provide for call-backs and cross-checks.
2. Conditions in the area studied should be such that no positive motivation exists to avoid being listed in the directory, as for example in cases where the directory is used as a source for compiling State or municipal income tax rolls.
3. The information available in the directory must of course be adequate for purposes of the study concerned. In the case of the New Haven area directories, the following data are available in addition to the information used in the present study on residential address, occupation, and workplace location: sex (insofar as it can be inferred from first names), marital status, home ownership, type of dwelling unit (inferred from the number of other households residing at the same address), and position in household (head, wife of head, or other). However, no data on age, race, and religious or ethnic background are given in this or in most other city directories with which the author is familiar. For purposes of the present study, probably the most serious deficiency is lack of information on race. The fact that negroes are more restricted than whites as to both choice of residential location and job is well known and amply documented. One might thus reasonably expect such restrictions to have consequences for commuting patterns. But owing to lack of data, it was impossible either to control for this variable or to assess any effects it might have had on the results.

Within the limitations described it was concluded that city directory data can be used in certain types of traffic studies, and that their use, where appropriate, will materially reduce the cost of such studies.

Occupation and Parkway Use

One conclusion that immediately emerges from this study is that not very many people living in the New Haven area are presently in a position to benefit from use of the Parkway for commuting purposes. Out of the 3,516 persons in the sample, only 222, or roughly 6.3 percent, are in a position of use opportunity. In view of the location of the Parkway this is perhaps not surprising, but the implication remains that limited-access highways located in this fashion seem unlikely to enjoy much use for commuting purposes. Furthermore, as Table 1 shows, the overwhelming majority of those having use opportunity are long-distance or intermediate commuters, rather than local ones.

Among those in a position to use the Parkway, however, significant differences exist, as between occupational categories, with sales and professional and technical personnel predominating (Table 2).

A clue as to the mechanism producing these differences is given in Table 3; sales, professional, and technical workers appear more likely to commute longer distance than do other occupational groups. When type of commuting is controlled for, signifi-

TABLE 1

TYPE OF COMMUTING AND USE OPPORTUNITY, 1958[a]

Type of Commuting	Percent with Use Opportunity	n
Long distance	68.1	207
Intermediate	30.7	104
Local	1.5	3,205
Total	6.3	3,516

$^a\chi^2 = 1,565.32$; d.f. = 2; $P<0.001$.

TABLE 2

OCCUPATIONAL USE OPPORTUNITIES 1958[a]

Occupational Category	Percent with Use Opportunity	n
Sales	16.0	174
Professional and technical	10.5	455
Foremen and craftsmen	6.4	559
Operatives and Manual Workers	5.3	954
Managers, proprietors, and officials	4.8	599
Clerical	4.1	604
Service	2.9	171
Total	6.3	3,516

$^a\chi^2 = 54.49$; d.f. = 6; $P<0.001$.

cant occupational differences indeed disappear, except that sales personnel commuting for long distances are still significantly more likely to be in a position to use the Parkway then are other long-distance commuters.

One may still inquire as to "why" these differences emerge, granted that the immediate reason may lie in the distance of the work trip. There exist at least two major tendencies in industrial social organization which operate to produce tendencies toward differential occupational distribution of benefits from technological improvements—including, presumably, new highway construction. First, the higher the socio-economic status of a person's occupation, the greater the extent to which he will be in a position to secure such benefits, for not only do higher status occupations generally command greater economic resources buth they also carry with them greater power, prestige, and influence.

In the case of work trips, a number of studies (not involving limited-access highways) have shown that distance of journey to work tends to increase as occupational status rises, presumably because people of higher status are in a better position to stand the cost of increased distance, do not ordinarily have to report for work at such an early hour, and enjoy greater freedom of choice in residential location (e.g., 7, 8; for a general treatment of occupational and social stratification, see 9, 10; for the class

TABLE 3

OCCUPATION AND TYPE OF COMMUTING, 1958[a]

Occupational Category	Percent Long Distance	Percent Intermediate	Percent Local	n
Sales	16.0	3.4	80.6	174
Professional and technical	13.1	2.8	84.1	455
Foremen and craftsmen	5.0	4.8	90.2	559
Managers, proprietors, and officials	4.8	2.6	92.6	599
Operatives and manual workers	3.9	2.9	93.2	954
Clerical	3.4	1.4	95.2	604
Service	1.7	2.9	95.4	171
Total	5.8	2.9	91.3	3,516

$^a\chi^2 = 108.29$; d.f. = 12; $P<0.001$.

structure of New Haven, see 4, esp. ch. 4). In the present results, however, the occupational ranking of use opportunity does not entirely correspond to the known ranking of the same categories by socio-economic status. In particular, use opportunity for sales personnel appears "too high", whereas use opportunity for managers, proprietors, and officials, as well as for clerical workers, appears "too low."

These discrepancies, however, make sense in terms of a second social tendency. In no developing industrial economy do all sectors of the economy develop at the same rate. From the standpoint of personnel, those sectors that are the most highly developed technologically are by and large the most stable, and those sectors that are relatively less well developed are the least stable. In the case of the latter it is a question of a constantly shifting allocation of human resources to compensate for the relative lack of technological development. Any technological innovation that increases efficiency in this sector is therefore likely to enjoy maximum utilization by persons holding the occupations involved (11).

At present, in the American economy the occupations affected are those involving high-level distribution activities, professional services, and, to a lesser degree, certain types of skilled work (11). These are the three occupational categories that are found to rank highest in opportunity to commute via the Parkway. In what more specific way would one expect the Parkway to be a relevant technological innovation for these groups? The relatively high rates of job mobility exemplified in this sector may be presumed to have two possible consequences: (a) a high incidence of temporary residence—workplace dislocation leading to a relatively high aggregate prevalence of Parkway commuting use; and (b) a disposition on the part of the people involved to locate residentially in such a way as to maximize flexibility in job location, thus also leading to a relatively high degree of Parkway commuting use, but on a more permanent basis in each case. Table 4 is consistent with the operation of either of these mechanisms, particularly the second. Of people who lived in greater New Haven in both 1948 and 1958, the occupational ordering of a shift (either of workplace, residence, or both) from a position of no use opportunity to one of use opportunity corresponds generally to the gross ordering of use opportunity for 1958 given in Table 2.

Of the two possible explanations proposed, it thus appears that the second is more nearly in accord with the facts; occupational differentials in commuter use opportunity for the Parkway appear to be largely a function of the sector of economy of the occupation. Occupational status per se, though it may enter in as a secondary factor, does not seem to be the overriding consideration.

One must be wary, however, of leaping from these data to the generalization that sector of economy of occupation, rather than status, determines differential commuter use of all or even most limited access highways. On the contrary, indications are that the Wilbur Cross Parkway is one of a class of rather special cases. Its location in the New Haven area is such that it is not used very much for commuting purposes. In particular, it is not on the whole very useful for what one usually thinks of as the "typical commuter"—one who works in a central business district and lives in the suburbs. Business executives, other managers, and clerical workers would largely fall in this category. For an axial facility, the use pattern may well be different; in such a case the tendency for high status to make possible a longer commuting distance would be more likely to manifest itself, and the over-all result might well be a clear differentiation by occupational prestige. On the other hand, the findings reveal a countervailing tendency that apparently results from the actions of a significant class of commuters. It is hypothesized that the strength of this tendency relative to that generated by differential status would vary according to the way the limited-access facility is laid out. This suggests the desirability of comparative research on different types of facilities to determine (a) relative aggregate volumes of commuter traffic, and (b) the form of occupational benefit distribution peculiar to each type of layout.

CONCLUSIONS

This exploratory study has (a) demonstrated the feasibility of using city directory data for certain types of work trip studies conducted under certain conditions, and (b) shown that occupational differentials affect commuter use of limited-access highways. In the particular case studied, the sector of the economy of the occupation was found to be the major determinant of use differences. Although such a tendency may be general, there is reason to believe that its strength relative to that of occupational status per se may vary according to the way the facility in question is laid out relative to the central business district. The desirability of further research along these lines is indicated.

TABLE 4

INCREASED USE OPPORTUNITIES, 1948-1958[a]

Occupational Category	Percent Increase	n
Sales	8 4	106
Professional and technical	4. 6	260
Foremen and craftsmen	3. 7	375
Operatives and manual workers	3. 6	624
Clerical	2 5	320
Service	2 5	117
Managers, proprietors, and officials	1. 5	453
Total	3 3	2,255

[a] χ^2 = 15 55, d. f. = 6; P <0. 02.

ACKNOWLEDGMENTS

The author wishes to thank the Bureau of Highway Traffic, Yale University, for providing the funds necessary to carry out this study. Gratitude is due Frederick W. Hurd, Director of the Bureau, and Kent T. Healy, for their cooperation, and Lionel Lewis and Sarah West, for their research assistance.

Maps and distance data were kindly supplied by the Southern New England Telephone Company; speed and delay data, by the Bureau of Highway Traffic of Yale University and by the City of New Haven. Additional runs were made by the author and his assistants, in areas where data proved to be lacking or incomplete.

REFERENCES

1. "The Greater New Haven Directory, Including West Haven, East Haven, Woodbridge." Price and Lee, New Haven, Vol. 118 (1958).
2. "Hamden, Cheshire, North Haven Directory." Price and Lee, New Haven, Vol. 3 (1958).
3. "Alphabetical Index of Occupations and Industries." U.S. Bureau of the Census (1950).
4. Hollingshead, A.B., and Redlich, F.C., "Social Class and Mental Illness." Wiley (1958).
5. Davie, M.R., and Myers, J.K., Unpublished report compiled 1950-51.
6. Goldstein, S., "Patterns of Mobility, 1910-1950—The Norristown Study." Univ. of Pennsylvania Press, (1958).
7. Duncan, B., "Factors in Work-Residence Separation." Amer. Sociol. Rev., 21: 48-56 (Feb. 1956).
8. Reeder, L.G., "Social Differentials in Mode of Travel, Time and Cost in the Journey to Work." Amer. Sociol. Rev., 21:57-63 (Feb. 1956).
9. Barber, B., "Social Stratification." Harcourt Brace (1957).
10. Kahl, J.A., "The American Class Structure." Rhinehart (1957).
11. Fourastie, J., "The Causes of Wealth." Free Press, Glencoe (1960).

A Method for Determining the Optimal Division of Express and Local Rail Transit Service

ALAN BLACK, Chicago Area Transportation Study, Chicago, Illinois

•MUCH RESEARCH has been devoted to the optimization of highway systems, and several papers have been published on such topics as the optimal spacing of expressways. However, relatively little study has been given to the optimization of mass transit systems. This paper describes an attempt to optimize one facet of a mass transit system. It is illustrative of the type of research that might profitably be devoted to studies of transit networks.

Certainly mass transit is deserving of research. In virtually all metropolitan areas, transit systems—including railroads, rapid transit, and busses—are experiencing a critical pinch between increasing costs and declining demand. Yet highway congestion has led many city planners and other observers of the urban scene to prescribe increased reliance on mass transit as the cure to traffic ills. Such programs would require substantial public investment, because the financial difficulties of transit systems have made them unattractive to private investors. It is a matter of public concern, therefore, to make every effort to provide the most efficient and economical transit systems.

The most important rail transit routes are radials carrying passengers to and from the central business district (CBD). The concept advanced here is that there should be a breakpoint on radial routes, with local trains serving the area between the breakpoint and the CBD, and express trains serving the area beyond the breakpoint. Express trains would carry CBD-bound riders non-stop from the breakpoint to the CBD. Express and local service could correspond to suburban railroad and rapid transit, respectively.

The question considered in this paper is the optimal location of the breakpoint between the two types of service. The objective is to find the breakpoint for which the total costs to the community will be the least.

This paper describes the general method for computing costs and determining the least cost breakpoint and demonstrates the application of the method to an actual situation in the Chicago region. It analyzes the behavior of the breakpoint and the factors that influence it. It also contains an evaluation of the method, with a discussion of its strengths and weaknesses.

METHOD

The problem is set up in an idealized form in which certain simplifying assumptions are made. The route to be considered is a radial route extending a fixed distance from the CBD and serving a given number of riders in a sector of the metropolitan area. Each of the stations along the route could serve either express or local trains.

The locations of the stations and the number of riders boarding or debarking at each station are taken as givens. Passenger volumes may vary from station to station, but the volume using any single station is assumed to be constant. It is assumed that all riders must be served by rail, and that they do not have the choice of an alternate mode of travel. Only those trips originating or terminating at the CBD are considered; these generally form the bulk of trips on a radial rail line.

For identification, the stations are numbered, starting at the CBD terminal, as 0, 1, 2, 3, etc., up to z, the station farthest from the CBD. The stations need not be uniformly spaced.

Two types of transit service are to be provided over this route: (a) local trains will run out from the CBD as far as a certain station, designated as station m-1, making all stops; and (b) express trains will run non-stop from the CBD to station m, and then will make all stops from station m to station z.

The problem is to find that breakpoint between local and express service for which all the riders in the corridor will be served at the least total cost, under a given set of conditions. The unknown is station m, the nearest stop for express trains. Each station is considered to be a potential breakpoint, and the total costs for each value of m are calculated.

Assumptions

The following are explicit statements of certain assumptions made in the problem:

1. All person-trips originate and terminate at the transit stations.
2. All person-trips have one end at the CBD terminal, station 0.
3. The number of train cars operated is proportional to the number of riders accumulated at the maximum load point on the line. This means the average car-loading at the maximum point is constant. (For local trains, the maximum point is between stations 0 and 1; for express trains, between stations 0 and m.)
4. The number of riders boarding or debarking at each station is constant.
5. Operating costs per car-mile are constant.
6. Delays at stops consume a constant amount of time per stop.
7. All trains run from terminal to terminal, with no equipment added or subtracted in midroute.
8. All trains run at maximum speed except when decelerating or accelerating for stops.
9. All express trains stop at all express stations, and all local trains stop at all local stations.

Objective

The objective is to minimize total costs, which consist of daily travel costs and capital costs for both express and local service.

Daily travel costs include three components: (a) operating costs for the railroad company or transit authority; (b) time required for passengers to travel at the maximum speed of the trains; and (c) time losses that passengers incur from delays at stops. Capital costs include the cost of constructing the lines plus the cost of equipment (rolling stock) required to serve the passenger volumes. To determine total costs, it is necessary to put daily travel costs and capital costs on a comparable basis, which can be done by converting both to annual costs.

Maximum speed travel time is important only to the extent that the two types of trains have different maximum speeds. If the same equipment is used on local and express service, or if the two types of trains have the same maximum speed, then the total maximum speed travel time for all riders becomes constant, and can be ignored.

Certain other costs have been omitted. One of these is the cost of waiting time for passengers at stations. It is assumed that the average waiting time for each passenger is constant, so the total waiting time for all passengers is also constant, and can be ignored. The cost of passengers traveling to and from transit stations is also omitted, because of the assumption that all trips originate and terminate at transit stations. Because it is assumed that all trips have one end at the CBD, no transfers are involved and the cost of transfer time is not considered. These costs are discussed later.

The cost of fares to passengers has not been included. It is the actual cost of providing the service which is of concern, and not what the passengers pay for the service. Fares are not a good indicator of actual operating costs, because they are often not sufficient to cover costs. Although fares represent a real cost to passengers, basically they are intended to reimburse the transit operator for its operating expenses. To include fares as well as the operating costs of the transit operator would be double counting.

Daily Travel Costs

Computation of the cost items included in daily travel costs may best be expressed in mathematical terms. The following factors are used:

p_i = number of passengers boarding or debarking at station i per day;

d_i = distance of station i from 0 (in miles);

k_1 = monetary value of one hour;

k_2 = express train car-mile operating cost,

k_3 = local train car-mile operating cost;

k_4 = average daily express train car-loading at maximum load point;

k_5 = average daily local train car-loading at maximum load point;

k_6 = maximum speed of express trains (in miles per hour);

k_7 = maximum speed of local trains (in miles per hour);

k_8 = time delay caused by one express train stop; and

k_9 = time delay caused by one local train stop.

Most of these items are self-explanatory. A time delay consists of the time lost by a train in decelerating for a stop, standing at the station to discharge and load passengers, and accelerating to maximum speed again.

All of the k's are assumed to be constant. The values of p_i and d_i are constant for any given station (any value of i), but vary from station to station. In the expressions that follow, these two factors appear only in summations, and the values of these summations depend on the value of m. The only independent variable is m.

The sum of the daily travel costs is made up of six cost items: operating costs, maximum speed time costs, and delay time costs, each for express and local trains. Computation of each of the six items is

$$\text{Local operating costs} = \frac{d_{m-1}\; k_3 \sum_{1}^{m-1} p_i}{k_5}$$

$$\text{Express operating costs} = \frac{d_z\; k_2 \sum_{m}^{z} p_i}{k_4}$$

The summations represent the number of passengers carried at the maximum load point on the line. Because z is the station farthest from the CBD, d_z is the distance of an express train run. Because m - 1 is the farthest station with local service, d_{m-1} is the distance of a local train run.

$$\text{Local maximum speed costs} = \frac{k_1 \sum_{1}^{m-1} p_i\; d_i}{k_7}$$

$$\text{Express maximum speed costs} = \frac{k_1 \sum_{m}^{z} p_i\; d_i}{k_6}$$

The summations represent the number of passenger-miles. Dividing by the speed converts this to the total passenger time.

$$\text{Local delay costs} = k_1 k_9 \sum_{1}^{m-1} i \; p_1$$

$$\text{Express delay costs} = k_1 \; k_8 \sum_{m}^{z} p_1 \quad (i - m + 1)$$

For local trains, i, the number of the station, also indicates the number of stops passengers boarding at i will sustain. Each passenger boarding an express train at a station, i, will sustain i - m + 1 stops. The summations represent the total number of delays that all passengers will experience.

Daily travel costs equal the sum of these six items. The use of summations in these expressions precludes the possibility of differentiating them. However, in any actual problem, the number of potential values of m would be limited, and so it would be neither especially difficult nor time-consuming to compute costs for all possible values of m, and to determine the minimum point by inspection.

Capital Costs

One component of capital costs is the amount of equipment—the number of train-cars—required to serve the passenger volume. The amount of equipment needed is that amount required to carry the passenger volume in the peak direction during the peak period of the day. During the rest of the day, the transit operator can get by with less equipment.

The basic relationship which determines the minimum number of passenger cars necessary is

Cars required = round trip time x car trips required

The reasoning behind this is simple: after a car passes any point on a line, it must make a round trip before it can pass that point again (going in the same direction). During this period (the round trip time) there must be one car in use for every car required to pass that point (as determined by the passenger volume). For a transit line, it is the number of car trips required at the maximum load point which determines the number of cars required.

Round trip time includes maximum speed time, plus delay time for all stops, plus layover time at the two terminals.

To determine the car trips required during the peak hour, it is necessary to determine the proportion of the daily, two-way volume that will occur in the peak direction during the peak hour. This volume must be converted to car trips. In doing this, a peak-hour car-loading should be used, rather than the daily average car-loading, since car-loading during the peak hour is much greater than the daily average.

This general rule holds: if the round trip time is x minutes, then the amount of equipment needed is determined by the greatest number of car trips required in the peak direction during any x consecutive minutes of the day. However, available data do not permit ready determination of the peak of x consecutive minutes, so it is necessary to approximate the distribution of travel over the day. In this problem, estimates of the proportion of daily travel during the peak hour and adjacent hours are used, and it is assumed that the demand is evenly distributed within each of these hours.

Three new factors must be introduced:

k_{10} = proportion of daily, two-way passenger volume occurring during peak hour, in peak direction;

k_{11} = ratio of peak-hour, peak-direction car-loading to daily average car-loading, at maximum load point; and

k_{12} = layover time for trains.

For simplicity, it is assumed that k_{11} and k_{12} are the same for both local and express trains.

The desired expressions for the peak hour and peak direction are

$$\text{Local car trips} = \frac{k_{10} \sum_{1}^{m-1} p_i}{k_{11}\, k_5}$$

$$\text{Express car trips} = \frac{k_{10} \sum_{m}^{z} p_i}{k_{11}\, k_4}$$

$$\text{Local round trip time} = 2 \left[\frac{d_{m-1}}{k_7} + k_9\, m + k_{12} \right]$$

$$\text{Express round trip time} = 2 \left[\frac{d_z}{k_6} + k_8\, (z - m + 2) + k_{12} \right]$$

The number of cars required equals the product of car trips per hour and round trip time, in hours.

This solution is fine, as long as round trip time does not exceed one hour. When it exceeds one hour, this method causes the number of cars required to exceed the number of car trips required during the peak hour. This would be all right if the passenger volume during the peak hour extended into the adjacent hour, but in fact it does not.

When the round trip time exceeds one hour, the number of cars required equals the number of car trips required during the peak hour plus the round trip time minus one hour times the number of car trips required during the next-to-peak hour. If the round trip time exceeds two hours, the same technique may be extended.

A transit operator requires some spare cars, so once the number of passenger cars required for the peak period of the day is determined, this figure is increased by 10 percent. If the cars are not self-powered and engines are also required, the number of engines needed can be based on a ratio of passenger cars per engine. Then the final figures are multiplied by unit costs to determine the total cost of equipment.

The other component of capital costs is construction cost. Express track must run the full length of the route, so its construction cost is constant. The number of stations is constant, regardless of location of the breakpoint, so this cost is constant. The cost of constructing local track is the most important variable construction cost. This can be crudely estimated on a per-mile basis, or fairly detailed cost estimates for each section of the route can be developed.

Figuring Total Costs

To add daily travel costs and capital costs together, both must be in the same terms, so both are converted to annual costs. Daily travel costs are figured for an average weekday. This can be converted to annual costs by multiplying by the ratio of annual passenger volume to an average weekday volume.

Capital costs can be converted to annual costs by multiplying by the capital recovery factor. The capital recovery factor converts an investment (first cost) into a uniform annual series of payments which reflect the time value of money. An interest rate, representing the minimum attractive rate of return, and a facility life span must be assumed. The resulting annual cost is the amount that would have to be paid every year if the first cost were borrowed at the specified interest rate for the specified facility life.

DEMONSTRATION OF THE METHOD

To illustrate the method, it was applied to an actual situation in the northwestern sector of the Chicago metropolitan region. This sector is served by a suburban railroad line, the Wisconsin Division of the Chicago and North Western Railway, and a rapid-transit line, the Logan Square elevated branch of the Chicago Transit Authority. The railroad line extends beyond the boundary of the metropolitan region into Wisconsin. The rapid transit line extends to Logan Square, about five miles from the Loop.

This situation is of some interest because the CTA proposes to extend its line in the median strip of the Northwest Expressway, which is adjacent to the railroad tracks, to a terminal at O'Hare Field. Space has been left in the expressway median strip for this.

Construction of the extension has not begun due to lack of funds. The CTA has been actively, but unsucessfully, seeking an appropriation from the State Legislature. The Chicago and North Western Railway is opposed to the extension, on the grounds that it would divert a large number of the railroad's passengers. Consequently, the question of whether the CTA line should be extended is a significant issue.

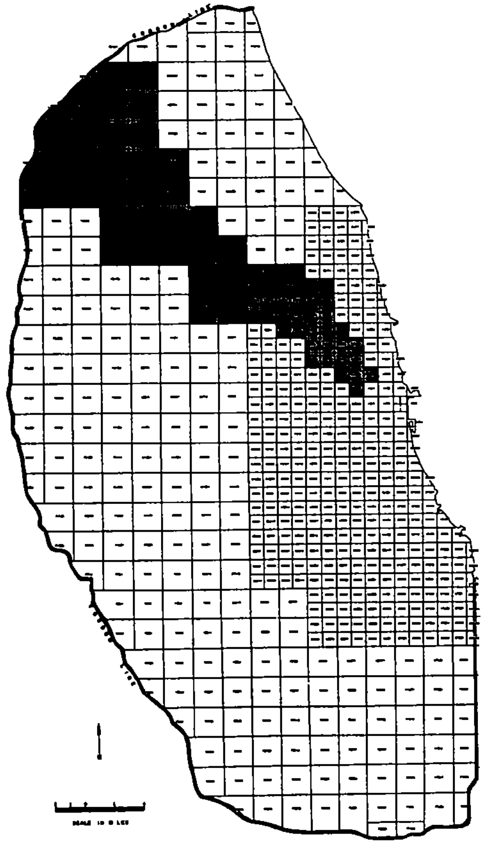


Figure 1. Sector served by rail transit route.

TABLE 1

VALUES OF d_i AND p_i USED IN DEMONSTRATION

Station (i)	Miles from CBD (d)	No. of Riders (p)
1	1	7,390
2	2	7,056
3	3	5,250
4	4	9,054
5	4.5	19,368
6	5	4,792
7	5.5	9,674
8	6	4,026
9	7	10,818
10	8	4,934
11	9	4,060
12	10	7,252
13	11	1,424
14	12	5,890
15	13	10,124
16	15	1,872
17	17	4,226
18	18	1,302
19	20	7,460
20	22	5,158
21	24	8,580
22	26	2,742
23	28	1,554
24	32	12,670
Total		156,676

The actual situation can be somewhat modified so that it fits the format of the idealized problem described, and a least cost breakpoint can be determined. The railroad line may be regarded as express service, and the CTA line as local service. It is necessary to assume that the railroad and rapid transit lines would be adjacent (which is not entirely true) and each station could be used by either one. It is assumed that the sector contains a constant number of transit riders who are indifferent as to which type of service they use. Only trips originating or terminating in the central area can be considered.

Accurate data were not readily available to use for inputs in the problem, so approximations were made. Because of this and the simplifying assumptions, there is no pretense that this exercise answers the question of whether the CTA line should be extended. This must be regarded purely as a demonstration of how the method works.

Values Used

The route is 32 miles long, ending at the boundary of the study area delineated by the Chicago Area Transportation Study (CATS). Besides the CBD terminal, the route has 24 stations. The distance of each station from the CBD and the number of riders boarding or debarking at each station are given in Table 1.

The sector used as the trade area for the route consists of 75 CATS analysis zones, and is shown in Figure 1. (External trips using the C & NW line were also included.) This consists primarily of 72 zones from which, according to a 1980 transit assignment made by CATS, (Assignment 88; CATS unpublished) transit riders would use either the C & NW line or the proposed CTA line to reach the CBD. Three other zones close to the CBD were added to create a more realistic situation, inasmuch as the assignment showed no passengers using some of the close-in CTA stations.

The locations of the stations were taken from the 1980 network used in the assignment. Three stations were omitted in the portion of the CTA route which would diverge from the railroad line and swing west to O'Hare Field. In two cases, stations were combined.

The volumes of riders using each station were based on 1980 estimates of central area transit trips generated by each zone in the sector. The trips from each zone were assigned to the station they would use in taking the shortest time path to a particular zone (Zone 001) in the heart of the CBD, according to the 1980 transit network coding. Certain modifications were made. Zones using the stations that were omitted were reassigned to other stations according to shortest time path calculations. The three zones added to the sector were assigned to stations which appeared reasonable.

Essentially, the processes described so far consisted of consolidating the two transit routes (railroad and rapid transit) of the 1980 assignment into a single route and allocating all the central area trips in the sector to stations on that route.

The value of time used was $0.85 per hour. This is the value used in CATS economic analyses of transit plans.

Operating costs per car-mile were set at $0.65 for rapid transit and $1.00 for railroad. A breakdown of CTA expenses made for 1954 showed that operating expenses, including injuries and damages but not including debt service or depreciation, for the rapid transit system were $0.566 per car-mile. From 1954 to 1960, operating expenses per car-mile for the entire CTA system rose from $0.630 to $0.736. No breakdown by type of equipment was made in 1960, but $0.65 seemed reasonable in view of the 1954 relationship.

In 1954, the Chicago and North Western Railway had directly assigned operating expenses of $0.770 per passenger car-mile for its entire operations. Expenses have risen since then, and it is likely that these particular commuter cars cost more to operate than the average for the entire railroad, so $1.00 seemed a reasonable estimate.

Average daily car-loading at the maximum load point was estimated at 40 passengers per car for rapid transit and 80 for railroad. Chicago cordon count data for 1961 showed the rapid transit system had an average car-loading of 41.8 inbound and 40.3 outbound for the period from 7 AM to 7 PM. No such data were available for the railroad, but

80 seemed reasonable. Although the C & NW's cars have 160 seats, they run many trains at off-peak hours.

The maximum speed of rapid transit trains was set at 45 mph, a figure verified by clocking. The maximum speed of railroad trains was set at 55 mph, based on a study of schedules for long commuter runs.

Delay time for rapid transit was set at 42.5 sec, based on assumed rates of acceleration and deceleration of 2 mph per sec and a standing time of 20 sec. For railroad, delay time was set at 90 sec, based on rates of acceleration and deceleration of 1 mph per sec and a standing time of 35 sec.

The cost of a rapid transit car was estimated at $80,000, which is representative of prices paid in recent years. The cost of a railroad car was estimated at $200,000. This is intended to include the cost of locomotives, and is based on $150,000 for each passenger car and $200,000 per locomotive, with one locomotive required for every four passenger cars. The C & NW, in 1956, paid $145,700 for each passenger car used on its line.

It was difficult to ascertain the construction cost of extending the CTA line, because a number of varying estimates have been made. An average cost of $2,500,000 per mile was adopted as a reasonable approximation. This is not supposed to include the cost of constructing stations, because in the problem it is assumed that the stations will be in existence, regardless of whether they are used by railroad or rapid transit.

In calculating equipment costs, it was estimated that the proportion of the daily, two-way volume occurring in the peak hour and peak direction was 14 percent. The proportions occurring in the two highest adjacent hours were estimated at 11.2 and 3.2 percent. These estimates were based on a combination of data from the 1961 cordon count and a subsample of CATS home interviews.

The ratio of peak-hour, peak-direction car-loading to daily average car-loading was taken as 175 percent, meaning a car-loading of 70 for rapid transit and 140 for railroad. According to the 1961 cordon count, average car-loading for the rapid transit system was 68.9 inbound from 8 to 9 AM, and 76.0 outbound from 5 to 6 PM. Ratios to the 12-hr average were 165 percent for inbound and 188 percent for outbound.

Layover time was estimated at 3 min at each terminal.

In converting daily costs to annual costs, it was assumed that there are 300 average weekday equivalents in a year. In 1960, the CTA rapid transit system had 112,924,491 revenue passengers, which was 297.0 times the 380,182 counted in a spot check on a November weekday.

In converting capital costs to annual costs, the minimum attractive rate of return was put at 10 percent, and facility life was assumed to be 25 years. This produces a capital recovery factor of 0.11017. It was assumed that all equipment required would have to be purchased new. It was assumed that the only construction required would be to extend the rapid transit line outward from its present terminal.

Results

Total costs for each possible value of m were computed, and the minimum point was found to occur when m = 13, the station 11 mi from the CBD. This would mean that the rapid transit line would be extended to the station 10 mi out. Total annual costs for this value of m are given in Table 2. Figure 2 shows the curve of annual costs for all values of m, and Figure 3 shows daily travel costs.

When m = 13, the rapid transit line would carry 93,674 riders, and the railroad line, 63,002 riders. There would be 486,205 passenger-miles on rapid transit, and 1,330,154 passenger-miles

TABLE 2

ANNUAL COSTS FOR m = 13

Cost	Amount (dollars)
Travel:	
Operating	12,127,000
Maximum speed time	8,926,000
Delay time	4,589,000
Total	25,642,000
Equipment	4,098,000
Construction	1,653,000
Total	31,393,000

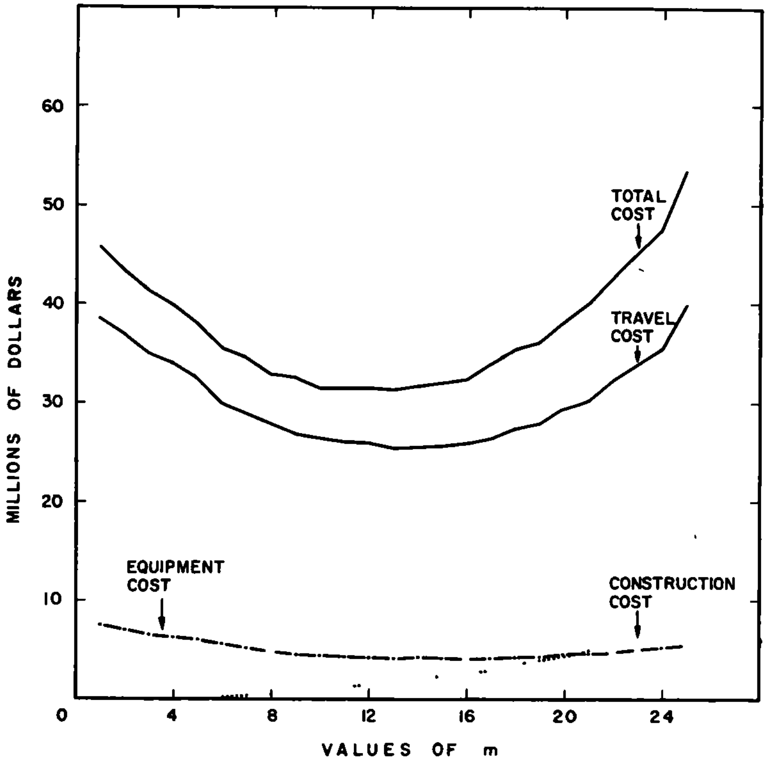


Figure 2. Annual costs for all values of m.

on railroad. Mean trip length would be 5.2 mi for rapid transit riders, and 21.1 mi for railroad riders.

For this breakpoint, daily operating cost per passenger would be $0.1625 for rapid transit and $0.4000 for railroad. Operating cost per passenger-mile came out at $0.0313 for rapid transit and $0.0189 for railroad.

This value of m would require 170 rapid transit cars and 118 railroad passenger cars. Six additional miles of rapid transit track would have to be built.

These calculations were intended primarily to illustrate how the method would be applied to an actual situation. The results appear to be reasonable, but because of uncertainty about some of the approximations and assumptions, they should not be taken too literally. Changes in some of the inputs might well produce a different minimum point.

ANALYSIS

Flatness of Total Cost Curve

The curve of total costs, plotted against values of m, is fairly flat at the bottom (Fig. 2). Total annual costs for m = 12 are only $55,000 greater than the minimum, and for m = 11, only $65,000 greater. Because total costs in this area exceed $31,000,000, these differences are very slight.

This suggests that the precise location of the breakpoint does not matter greatly, and that it could be moved a few stations either way without seriously increasing costs. If total costs were allowed to exceed the minimum by $1,000,000, m could have any value from 10 to 16 (corresponding to distances of 8 to 15 mi from the CBD).

However, beyond these limits, total costs begin to rise sharply. Extension of the rapid transit line from its present terminal to the optimal breakpoint would produce annual savings of $6,851,000.

The flatness of the bottom of the curve lends some importance to securing good estimates of the factors used in solving a problem. Moderate variations in the inputs could well shift the location of the minimum point. However, even if the inputs are changed, the curve will still be flat in approximately the same area.

It would be more reassuring, perhaps, if there were a single breakpoint that was far more advantageous than any other. This does not appear to be in the nature of things. On the other hand, the existence of a range of breakpoints that are approximately equal in cost gives latitude of choice which may be desirable because of the context in which a decision must be made. Other factors that cannot be readily quantified (political, social, economic, or aesthetic) can be taken into consideration in selecting the precise location for the breakpoint.

Influence of Factors on Breakpoint

The least cost breakpoint is a result of a series of pulls in opposite directions, with each pull having a certain weight. Changing the weights of the pulls will alter the location of the breakpoint.

Some of the component cost items take the form of U-shaped curves and may have minimum points that differ from the over-all minimum for total costs. The minimum for travel costs occurs when m = 13, and for equipment costs, when m = 16. Construction costs rise steadily as the value of m increases (Fig. 2).

The minimum for operating costs occurs when m = 13, and delay time costs are minimized when m = 19. Maximum speed time costs increase steadily as the breakpoint moves out, because express trains have a faster speed (Fig. 3).

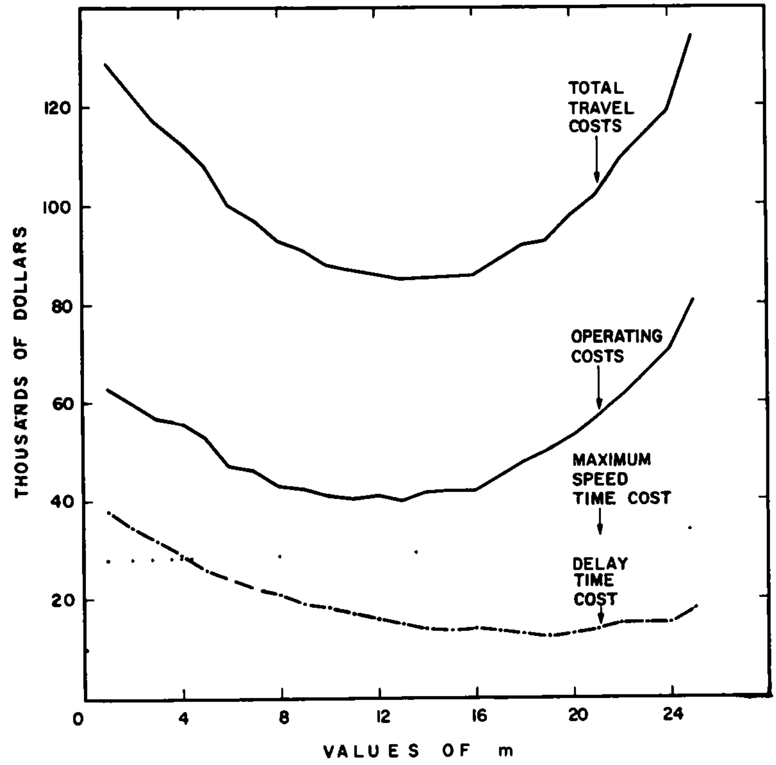


Figure 3. Daily travel costs for all values of m.

What happens to the breakpoint as the magnitude of the various factors changes? In general, any change that favors express service, or makes it comparatively more economical, will move the breakpoint in, whereas any change that favors local service will move the breakpoint out. For example, if express car-loading increases, the breakpoint will move in, but if express operating costs increase, the breakpoint will move out. If local maximum speed increases, the breakpoint will move out, but if local operating costs increase, the breakpoint will move in.

The distribution of riders over the stations on the line is an important factor. As the proportion of riders on the outer parts of the line increases, the breakpoint will move out.

A change in the value of time might move the breakpoint either way. This would depend on the relationship of the minimum point of total time costs (maximum speed time plus delay time) to the over-all minimum point. An increase in the value of time will pull the over-all minimum closer to the minimum point of time costs.

Superiority of Two Types of Service

The provision of both local and express service, instead of only one type of service, produces savings in operating costs, delay time costs, and equipment costs.

Operating costs are proportional to the number of car-miles. Under the assumptions of the problem, cars must travel from terminal to terminal, even if they only carry passengers for a portion of their run and are empty the rest of the way. With one type of service, every train must run the full length of the route. With two types of service, trains in local service will not run the full length of the route, and some of the unneeded car-miles will be eliminated.

Delay time costs are proportional to the number of stops that passengers on trains must sustain. With one type of service, all passengers must sustain delays for all stations between their station and the CBD. With two types of service, express passengers do not sustain delays between the breakpoint and the CBD.

Equipment costs increase directly with round trip time. With one type of service, all trains must make a round trip over the full route length. With two types of service, local trains cover a shorter route and their round trip time is less. Express trains also have shorter round trip times because some of their stops are eliminated.

Cause of Minimum Point

Although the total number of passengers and passenger-miles remains constant, regardless of the value of m, there will be minimum points for operating costs, delay time costs, and equipment costs. This will be true even if the same type of equipment is used on both local and express service (i.e., car-mile operating cost, car-loading, maximum speed, and delay time each have a single value).

As the breakpoint moves out from the CBD, local costs increase slowly at first, but gradually the rate of increase becomes faster and faster. When the breakpoint nears the outer extremity of the route, increments in local costs are very large. The same thing happens to express costs as the breakpoint moves in from the outer terminal. The combination of these two functions produces a U-shaped curve with a minimum point somewhere in the middle of the route.

There is no minimum point for maximum speed time costs, in the sense that there is no point with zero slope. If maximum speed is the same for both types of service, the sum of maximum speed time costs will be constant. If there is a difference, then these costs will be least when there is only one type of service utilizing only the faster equipment.

Likewise, there is no minimum point for construction costs. They will be least if there is no construction. If there is no existing transit route, they will be least if only one type of service is provided. However, the influence of the three factors that have minima is great enough to give the total cost curve a U-shape.

EVALUATION

Strengths

It has been shown that the combination of express and local service can be more economical than a single type of service in accommodating a constant volume and pattern of daily travel movements. Total costs will vary according to the location of the breakpoint. The method described in this paper offers a rational basis for determining the optimal breakpoint. It should provide a sounder foundation for decision than intuitive judgment.

The method is essentially a shortcut procedure for calculating costs. A series of full transit assignments, each using a different breakpoint, could provide more detailed results, but this would require considerable time and expense to carry out. It is unlikely that the results supplied by assignments would be much different.

The method may seem unduly complex to some. A simpler formulation could be achieved, but only at the cost of making the method more academic and less applicable to real situations. The method is intended to utilize actual data.

A mathematically neater solution could be obtained by replacing the summations in the mathematical expressions for computing costs by integrations. It would be possible to develop a continuous curve which described the number of riders at each station (p_i) as a function of distance from the CBD (d_i). This would permit determination of the minimum point by calculus, eliminating the bother of computing costs for all values of m. However, this would necessitate assuming some regular shape to the density of riders according to distance from the CBD—a simplification that would only roughly correspond to reality.

A key component of the method is the separation of travel time into time required for trains to travel at maximum speed and time consumed by making stops. For each passenger, any stop other than those at which he gets on and off is superfluous, and the more of these that can be eliminated, the better. This separation is essential to breakpoint considerations.

The method of calculating equipment needs is reliable. As a check, the method was used to calculate how many rapid transit cars the entire CTA system needs to handle peak-hour loads. It was estimated that 1,012 cars are needed. The CTA has reported that it uses about 1,000 cars on an average weekday.

The exclusion of non-CBD trips is unfortunate, but trips to and from the CBD do make up the bulk of radial transit trips. Tables 3 and 4 derived from 1956 and 1980 CATS transit assignments, give evidence of this.

Weaknesses

As presented in this paper, the method has a number of weaknesses. The simplified, idealized picture on which it is based does not conform to reality quite well enough. It would be desirable to eliminate some of the assumptions and limitations. The principal weaknesses are discussed here.

TABLE 3

TRANSIT TRIPS IN NORTHWEST SECTOR[a]

Transit System	Total	Trips			
		Entering CBD		Short of CBD	
		No	%	No	%
C & NW RR	28,688	27,784	96 8	904	3 2
Logan Sq El.[b]	57,408	57,408	100 0	0	0

[a] According to Transit Assignment 86 (1956 trips to 1956 network)

[b] Between Logan Square and CBD boundary

TABLE 4

TRANSIT TRIPS IN NORTHWEST SECTOR[a]

Transit System	Total	Trips			
		Entering CBD		Short of CBD	
		No	%	No.	%
C & NW RR	46,664	45,496	97.5	1,168	2.5
NW Rapid Transit[b]	143,146	119,504	83.5	23,642	16.5

[a] According to Transit Assignment 88 (1980 trips to 1980 network).

[b] Between O'Hare Field and CBD boundary

Use of Empirical Data. —Some of the factors used as inputs will always be difficult to pin down. Accurate estimates of car-mile operating costs would require a thorough cost accounting analysis. The monetary value of time will always be a subject for debate. Estimates of passenger volumes, especially when forecast for some future date, are susceptible to the usual dangers of predicting how people will behave.

One problem in using data stems from the fact that railroad and rapid transit usage tend to behave differently. Train riding is more concentrated in the rush hours than is usage of rapid transit. Probably the variation in car-loading during the day also differs considerably. In the method, it is assumed that the two types of service are interchangeable, and riders at a station will use whichever type stops there. In calculating the hourly distribution of riding, railroad and rapid transit data were pooled and over-all figures were used.

Probably the ratio of annual passenger volume to an average weekday volume also differs for rapid transit and railroad. In the demonstation, the ratio for rapid transit was used for both.

Assumption of Constant Operating Cost. —Operating costs are pegged to car-miles, and it is assumed that the operating cost per car-mile is constant. This is probably not entirely true. Operating costs actually include both variable and fixed components. In solving such a problem, only the variable costs should be considered. However, it would be very difficult to separate variable and fixed costs, because some would shade into each other.

Operating costs undoubtedly vary in response to factors other than the number of car-miles operated. Train length is probably an important factor; the longer the train, the less the cost per car. Speed may also be significant—certain costs, such as power, would probably rise with increasing speed, but labor costs per car-mile would probably fall. However, working rules give some fixity to labor costs. A train crew may have to be paid whether it operates a train, does some other type of work, or is off duty during the midday.

The complexity of the factors involved makes it appear infeasible to use anything other than over-all operating cost per car-mile.

Use of Average Car-Loading as a Criterion for Car Trips. —It was assumed that the number of cars operated is proportional to the number of riders at the maximum load point on the line, which makes the average car-loading at this point constant. What is needed is some quantitative criterion for determining how many cars will be operated to serve given numbers of riders. This assumption was adopted as such a criterion.

Of course, average car-loading varies greatly according to hour and direction. It also varies considerably between different lines.

As for the criterion a transit operator uses to decide how many cars to schedule, reportedly the CTA schedules enough cars so that the number of standees will be 50 percent of the number of seats at the maximum load point. However, this standard is exceeded on some lines during the rush hour and is not attained during midday hours. The CTA operates an unvarying minimum schedule during midday, regardless of passenger volumes. It is doubtful that transit operators use any systematic quantitative method for determining how many cars to schedule.

Consideration of Waiting Time. —The cost of the time during which riders wait for trains at stations was omitted from the total costs. If some average waiting time were assumed, as is done in transit assignments, then the total waiting time for all riders would be constant.

The major determinant of waiting time is the frequency of trains, which is directly related to the frequency of cars and inversely related to train length. If a constant train length were assumed, then the total waiting time for all riders again would be constant.

Train length was not considered in the method. No satisfactory method for calculating variable train lengths, or train frequencies, was discovered. Again, some systematic quantitative criterion is needed.

Consideration of Time to Reach Stations. —Another cost ignored was the time required for passengers to reach the stations. It was assumed that all trips originated

TABLE 5

RAIL TRANSIT TRIPS IN NORTHWEST SECTOR, C & NW RAILROAD PLUS LOGAN SQUARE ELEVATED[a]

Trips	Number	Percent
To CBD	66,884	77.7
Short of CBD	904	1.0
Through CBD	18,308	21.3
Total	86,096	100.0

[a] According to Transit Assignment 86 (1956 trips to 1956 network).

TABLE 6

RAIL TRANSIT TRIPS IN NORTHWEST SECTOR, C & NW RAILROAD PLUS NORTHWEST RAPID TRANSIT[a]

Trips	Number	Percent
To CBD	131,942	69.5
Short of CBD	24,810	13.1
Through CBD	33,058	17.4
Total	189,810	100.0

[a] According to Transit Assignment 88 (1980 trips to 1980 network).

or terminated at the stations. In the idealized situation in which the two rail lines are adjacent and could use the same stations, the costs of reaching the stations would be constant. However, if the two lines were some distance apart, with stations at different places, then the total time required to reach stations might vary according to location of the breakpoint.

Of course, if the two lines are not adjacent, it becomes questionable whether they both have the same potential trade area.

Consideration of CBD Trips.—It is assumed that all trips have one end at the CBD. Actually, there are two other types of trips: (a) those that never reach the CBD, but have both ends on the transit route outside of the CBD, and (b) those that go through the CBD to some other sector, and only use the CBD as a transfer point.

It would be possible to include these two kinds of trips in the method, provided that the number of riders using each station on the route could be broken down into these three categories of trips (CBD, short of CBD, and through CBD). At present, transit assignments do not put out this information.

If this information were known, then the through-CBD trips would be lumped with the CBD trips and treated in the same way. However, the short-of-CBD trips would require different treatment, because some of these trips would have to transfer between express and local trains. The local line would be extended to m to permit transfer there. For each potential value of m, it would be necessary to know how many passengers would transfer there. Otherwise, it would be impossible to know how many riders would use local or express trains within the breakpoint.

Evidence from the assignments indicates that the number of short-of-CBD trips on the C & NW line is negligible, but that on the rapid transit line these might account for as much as 16.5 percent of all trips (Tables 3 and 4). Of course, these totals include trips occurring anywhere on the line; the number accumulated at any one point would probably be much less.

In one transit assignment (Assignment 97; CATS unpublished), a transfer point between the C & NW and CTA lines was established, but only 520 passengers transferred there.

Although it is not possible to break down the trips at each station into the three categories, it is possible to estimate the breakdown for all rail transit trips in the sector (Tables 5 and 6).

Though it would be desirable to include non-CBD trips, it is not possible to do so at present. In any case, CBD trips make up the vast majority of all trips.

Consideration of Transfer Time.—If short-of-CBD trips were included, then the time required for passengers to transfer between the two types of service should be incorporated in the total costs. The number of passengers transferring for each value of m would be known, and a constant average transfer time could be assumed.

Assumption of Constant Number of Riders at Each Station. —It is assumed that the number of riders boarding or debarking at each station is constant. No account is taken of the effects of fares, frequency of service, comfort, or over-all speed on riding habits. In reality, these factors affect people's choice between railroad and rapid transit, and between rail transit and other modes of travel.

It is also assumed that riders always use the same station, which may not be true. Near the breakpoint, riders might switch to a station farther from the CBD in order to use railroad instead of rapid transit.

It would be possible to develop quantitative expressions for the influence of fares, frequency of service, and over-all speed on passenger volumes. Choices between stations, and between rail transit and other modes of travel, might be approximated through full assignments.

The only point in introducing these complexities would be to increase the realism of the method. Unless it could be shown that the mathematical expressions and assignments were reliable descriptions of how people behave, there would be no advantage in substituting complicated approximations for simple ones.

The assumption that the number of riders using a transit station is constant probably holds for the majority of transit riders. Evidence indicates that only a minority have any real choice between travel alternatives (1). (CATS' findings for the Chicago region are similar.)

CONCLUSIONS

The author believes this general method is the right approach to the search for an optimal breakpoint. Some refinements are needed to make the idealized problem more applicable to actual situations. However, it is seldom possible to represent all the complexities and nuances of a real situation in mathematical abstractions; nor is it really necessary. Beyond a certain point, further gains in precision are superfluous, especially when the results may be used rather grossly, anyhow.

Two types of transit service can be more economical than one, despite the additional capital investment that may be required. Savings in delay time costs, operating costs, and equipment costs have been demonstrated. The location of the breakpoint affects costs. There is a range of possible breakpoints within which costs are at or very near the minimum.

The two most important improvements needed are to include non-CBD trips and to find a better criterion for the number of car trips operated. A better method of estimating operating costs and inclusion of waiting time costs and transfer time costs would also be useful refinements. Other weaknesses are relatively minor.

Although the problem considered in this paper is a specialized one, the method should have considerable applicability. There are several radial routes in Chicago where the question of a breakpoint is pertinent. Undoubtedly there are similar situations in other cities that have rail transit systems. The method can be applied to railroads alone, inasmuch as their routes often have a large number of tracks. It is a common practice for railroads to run both local and express trains over the same routes.

Just as two types of service are more economical than one, it may be that three types would be more economical than two (with three sets of tracks on the same route). Perhaps the optimal arrangement of transit service would be to have non-stop service between the CBD and every station. These possibilities have not yet been investigated.

These are examples of the types of further study of transit systems which might be rewarding. Other topics deserving research include the optimal spacing of transit stations (2), the optimal spacing of radial transit routes, and optimal scheduling of trains.

REFERENCES

1. Keefer, L.E., " 'Choice' Transit Trips." Pittsburgh Area Transportation Study Research Letter, 3: No. 1 (Jan.-Feb. 1961).
2. Schneider, M., "Travel Time Minimization, Transit." CATS Research News, 4: No. 2 (June 2, 1961).

An Evaluation of Land-Use and Dwelling-Unit Data Derived from Aerial Photography

SAMUEL M. HADFIELD, Urban Research Section, Illinois Division of Highways

• A TRAFFIC STUDY of the Fox River Valley region in Illinois has recently been completed by the Urban Research Section of the Illinois Division of Highways. This study had several experimental aspects. Among these was a test of the use of aerial photography as a principal source of land-use and population data. This paper describes the results of this test.

Aerial photography was used because of the lack of other source material, especially for land-use data. This is typical of low-density areas such as the Fox River Valley. Extensive accuracy checks were made, not only to guarantee accuracy for this particular study, but also to establish the reliability of the method for general application. The results of the checks indicate that aerial photographic interpretation is a feasible method for areas of this kind, and possibly for more heavily urbanized areas as well.

The primary objective of the Fox River Valley Study was to develop and test a synthetic approach toward obtaining O-D data, which have heretofore been obtained from expensive and time-consuming home interview surveys. Traffic movements between zones on a road network were simulated by means of a mathematical model. Predicted zonal interchanges were then checked against O-D information collected in a screenline survey of the roadside interview type. (The results of this check will be reported in another paper by the Urban Research Station.) A primary input of the model was the estimated number of trip ends generated by each zone. The trip ends were estimated from the data obtained from aerial photography. The specific kinds of data collected for this purpose were the number of dwelling units, and land area and nonresidential building floor area classified by land-use type. Research conducted by CATS has shown residential trip generation to be related to dwelling units, when other variables are taken into account. (The relationship of residential trips per dwelling unit to net residential density and to car ownership is shown in Figures 33 and 34, (1).) Floor area has been found to be a much better indicator of nonresidential trips than land area because it more closely reflects the amount of trip-generating activity.

This is probably the first time that aerial photography has been used to collect such a comprehensive array of information. There has been considerable use of aerial photography in planning surveys, particularly to collect land area data. However, there has been little use of aerial photography to collect dwelling unit and floor area data. Furthermore, the reliability of data obtained from aerial photographic interpretation had previously been untested.

This paper briefly describes the study area the data collected from photography and the methods of collection, and the checking procedures. It also includes the results of the accuracy checks, estimates of aerial survey costs, and some tentative conclusions.

SURVEY AREA

The Fox River Valley survey area is approximately 200 sq mi in size and contains a population of about 205,000 persons and 60,000 dwelling units. It is located about 45 mi west of Chicago and includes several small cities ranging in population from 2,000 to 60,000. Figure 1 shows the area and its division by screen lines into five districts; not shown is the further subdivision into 89 zones and 2,800 blocks. The average density is 3,400 dwelling units per net residential square mile, compared with average densities of 19,000 in the City of Chicago and 3,600 in the Chicago suburbs.

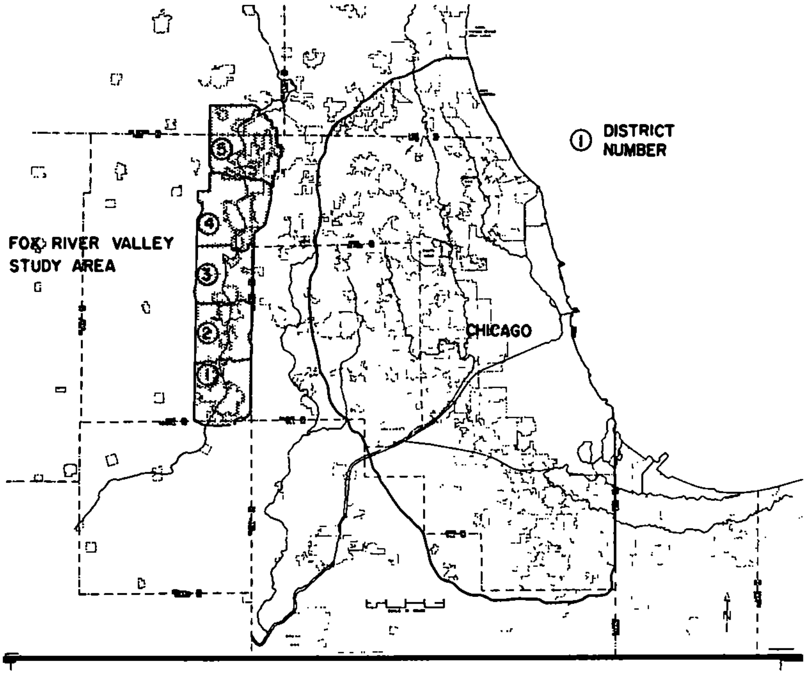


Figure 1. Fox River Valley study area.

The central business districts of towns, which account for about 10 percent of the dwelling units and 30 percent of the nonresidential floor area, were excluded from the aerial photographic survey and are therefore not represented in the data analyzed in this report. The data sources were fire insurance atlas maps and field measurements for those areas that were considered somewhat too congested for reliable interpretation from photography.

SURVEY DATA AND COLLECTION PROCEDURES

All original survey data were obtained by interpretation of photography alone, using no supplementary sources. Collection was contracted to a private firm in the Chicago area which specializes in work of this type.

The specific data collected by the contractor were

1. Floor area measurements of nonresidential buildings, identified by type of specific use. Type of use was coded to 42 detailed categories which could then be grouped to more general categories—commercial, manufacturing, public buildings, public open space, vacant, and a category including transportation, communication, and utilities.
2. Land area classified by the general nonresidential use types listed and by residential and vacant. If a building was located on a land area parcel, its classification was dependent on the land-use identification of the building.
3. Dwelling unit and residential structure counts. Dwelling units were intended to approximate the census definition. Structure counts, classified as to multiple or single family, were obtained primarily to analyze dwelling unit data.

The basic collection unit for dwelling units was the block; land area and floor area were classified by land use within block. The 'block' was either the city block or, outside cities, an area with identifiable natural boundaries. Measurements were made of each nonresidential building and land parcel from photography which was enlarged to 400 ft per in. in the developed areas and 1,000 ft per in. elsewhere. Additional low altitude oblique photographs were also used. These proved to be extremely useful in determining land-use types and the number of floors in buildings. Stereoscopic interpretation was also used to some extent for these purposes.

ACCURACY CHECKING PROCEDURES

Thorough checking was conducted by the URS (Urban Research Section). To accomplish this, separate inventories were made for sample portions of the area. These data were obtained from sources other than the aerial photography. The photography used was flown in the fall of 1959; the checking was almost concurrent, and was completed in the summer of 1960.

Check Data

Nonresidential floor area check measurements were made from fire insurance atlas maps wherever they were available, and direct measurements were made in the field elsewhere. Whenever necessary, the atlas maps were brought up to date by field checking.

Two separate checks were used for the dwelling unit counts: (a) census figures for 1960 for enumeration districts in Kane County, and (b) counts obtained directly in the field by URS. The latter were made by observation, using the number of doorbells, mailboxes, and utility meters as indications of the number of dwelling units per structure. The census data were superior to the URS field counts in that they represented complete enumeration; however, the boundaries of census districts did not correspond well with study area boundaries, and there were some parts of the area, mainly rural, which the available census data did not cover. Partly for this reason, URS made the sample field counts as an additional check. Other reasons were to obtain a check on residential structure counts, and to enable a check on the field counting methods by comparison with the census figures.

Land area checking was done by remeasuring from the original photograph. This was a different procedure than that used for floor area and dwelling units, where independent sources could be used.

Sampling Procedure

A separate systematic sample of all blocks in the aerial survey was selected for checking each type of datum. The total number of blocks sampled was 272 for dwelling unit counts, 199 for floor area measurements, (only 70 sample blocks contained floor area classified as nonresidential) and 22 clusters of blocks for land area measurements. These sample blocks accounted for about 11 percent of the total dwelling units, and for about 8 percent each of the total floor area and land area which were obtained from photography.

The sample sizes were estimated in advance on the basis of data collected from photography in a small preliminary test area, which was completed by the contractor on a trial basis before proceeding with the survey. It was assumed that the amount and variability of error in the test data, as revealed by checking, would be typical of the rest of the aerial survey. A large enough sample of blocks was then selected to yield measures of aerial survey error which would be statistically reliable, at a level specified for each type of data, and for various sizes of areal units.

Stratified sampling was employed for floor area and dwelling units. This permitted a reduction in the amount of sampling necessary to obtain reliable measures of accuracy. (The actual procedure minimized the cost of sampling rather than the number of sample items, "blocks." Within each stratum, the number of blocks sampled was directly proportional to the estimated standard deviation of the error in the aerial survey, and inversely proportional to the cost of obtaining data for each block.) The floor area strata were (a) the parts of the aerial survey area checked by atlas map measurements and (b) by field measurements. Each zone was considered a stratum for dwelling unit sampling, except for the rural zones, which were grouped as a single stratum.

Quality of Checking

An attempt was made to obtain check measurements that could be considered equivalent to true values. Extremely accurate measurements of floor area are possible from the sources which were used. Maximum accuracy was obtained by measuring each building two or more times independently, and then reconciling the differences to arrive at a final check measurement. As a test of the consistency of this procedure, comparisons were made between two sets of measurements of selected buildings, for both atlas map and field measurements. A correlation of the two sets yielded a coefficient above 0.998, and the average difference found was nearly zero. The results were about the same regardless of the source of the measurements being compared, whether map or field. Based on these results, the error in floor area introduced by checking is assumed to be negligible.

The census data, used as the final dwelling unit check, are presumed to be exact. Any error in this check would be small, and would arise from procedures of applying the check. These are discussed later.

The land area check measurements are considered to be much less accurate than the floor area or dwelling unit checks. Variation among repeated measurements from aerial photographs is comparatively great; it usually arises from difficulties in defining land-use boundaries rather than from inexactness of measurement. Lacking a reliable and independent source, these measurements can be expected to detect only the relatively large differences.

RESULTS OF ACCURACY CHECKS

By comparing the contractor's data with check data for the selected sample blocks, the accuracy level of the entire aerial survey could be estimated. The amount of error in the aerial survey is stated in the following for each type of data collected—first, for the entire area, then by smaller geographic aggregates, so as to indicate how well accuracy was maintained on a more detailed level.

Nonresidential Floor Area

In general, measurements from photography compared well with check measurements, with a tendency on the average for the photographic survey measurements to be too low. The ratio of total check to photographic survey measurements was 1.13; in other words, the check was 13 percent higher than the survey measurements for all types of nonresidential floor area taken together, in the sample or test blocks. Statistical computations establish that the error ratio, 1.13, is reliable within plus or minus 0.01. (Differences between the check and the aerial survey have been called "errors" because the check measurements are presumed to be true. The term used in this sense is not the same as "standard error," which is a statistical measure of reliability. The chances are two-thirds that the error ratio obtained in the sample, 1.13, lies within plus or minus 0.01 of the true ratio. The true error ratio would have been obtained if all aerial survey measurements had been checked.)

There was considerable variation in accruacy of the areal subdivisions. Table 1 shows error ratios (check/aerial survey)

TABLE 1

ERROR IN NONRESIDENTIAL FLOOR AREA BY DISTRICT

District	Ratio	
	Check/ Aerial Survey	Reliability[a]
1	1.08	± 0.04
2	0.92	± 0.15
3	1.57	± 0.07
4	1.34	± 0.13
5	0.96	± 0.01
Total	1.13	± 0.01[b]

[a] Two-thirds of the time, ratio obtained in sample will differ from true ratio by amount shown.

[b] Not obtained by summing districts, which would give ± 0.04; rather obtained by summing land-use reliability figures in Table 2.

for the five districts of the Fox River Valley study area, together with the reliability of each ratio. Good accuracy is indicated for Districts 1, 2, and 5, where the ratios are 1.08, 0.92, and 0.96, respectively. Furthermore, the reliability ranges for these figures indicate that the true errors could be close to zero (or, ratios of 1.00). On the other hand, Districts 3 and 4 have high error ratios, 1.57 and 1.34, which cannot be explained by sampling variability. These districts presented no unusual measurement problems. The most plausible explanation for this variation lies in the fact that different personnel performed the photographic interpretation for these areas.

Despite the errors mentioned, there was a fairly high over-all correspondence between individual blocks, as evidenced by the correlation coefficient obtained, 0.98, as shown in Figure 2, where block data are plotted. This probably can be explained as a tendency for errors in the two groups of districts to be consistently high or low.

Rates of error by generalized land-use categories for the aerial survey as a whole are given in Table 2. The figures indicate a significant understatement of floor area by the survey in the manufacturing and "other" land-use categories. By contrast, agreement is very high in the commercial and the public building categories. Manufacturing is the largest source of error, most of which is caused by building omissions.

For some purposes it may be more important to know the correct proportional distribution of floor area by land-use type rather than the absolute amounts. The aerial survey distribution is compared with the check distribution in Table 3. This is equivalent to adjusting the aerial survey floor area in each land-use class by applying a correction factor based on the average error for total floor area. (Two correction factors were actually used for Table 3, based on the average errors for each of two portions of the survey area. The wide difference between the two average errors, 32 percent as compared with 2 percent, allowed a better adjustment than the use of one over-all average.) The resulting error ratios in Table 3 show that a fairly good adjustment could be made without correcting each land use separately. Manufacturing and commerical, the largest categories, compare quite closely.

Accuracy in identifying detailed land-use types from aerial photography would be expected to be much lower. Table 4 gives the ratio of error for each of 42 detailed use categories, which are subdivisions of the generalized types previously discussed. These figures, as in Table 3, have been adjusted for the total percentage error by converting amounts of floor areas to proportions. Table 4 also gives an intermediate breakdown of the commercial category into retail, service, and wholesale; the errors

TABLE 2

ERROR IN NONRESIDENTIAL FLOOR AREA BY TYPE OF LAND USE

Land Use	Ratio	
	Check/ Aerial Survey	Reliability[a]
Manufacturing	1 26	± 0 05
Commercial	1.04	± 0 05
Public Bldgs.	1.05	± 0.03
Other	1 37	± 0.26
Total	1.13	± 0.01[b]

[a] Two-thirds of the time, ratio obtained in sample will differ from true ratio by amount shown.

[b] Obtained by weighting and summing reliabilities of types of land use.

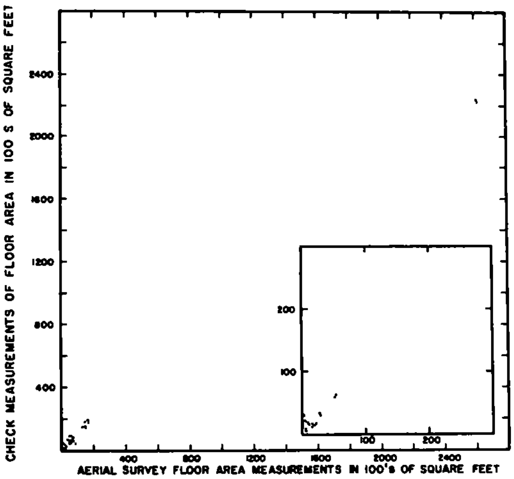


Figure 2. Aerial survey and check measurements of total nonresidential floor area by sample block.

TABLE 3

CHECK AND AERIAL SURVEY NONRESIDENTIAL FLOOR

Land Use	Check	Aerial Survey	Check/ Aerial Survey
Manufacturing	0 401	0.374	1.072
Commercial	0.362	0.367	0.986
Public Bldgs.	0 214	0.237	0 903
Other	0 023	0.022	1 045
Total	1.000	1.000	1.000

for retail and service (5 and 25 percent) show a fair ability of the photo-interpreter to distinguish between kinds of commercial activities. But most detailed types have large errors, 40 percent or more, with the exception of the public building categories. The high sampling variability of such small groupings, however, prevents a definitive statement as to detailed accuracy.

Improvements in the photographic survey procedure depend on finding out why errors occurred. Errors in nonresidential floor area have the following major components:

1. The measurements of buildings can be incorrect either because of inaccuracy in (a) the ground floor measurement or (b) the number of floors counted. The second is usually the more serious.
2. The land-use type of identification of buildings can be wrong. This reflects an inability either to distinguish nonresidential buildings from residential or to identify the particular nonresidential type.
3. Nonresidential buildings can be omitted, not because of faulty identification as residential, but because of inadequate control of building coverage. In certain cases, for example, large factory buildings were not recorded at all.

Of these three classifications, the last (building omissions) was the most important. Classification of error in floor area totals for the entire survey in order to measure the relative importance by type are given in Table 5, where net differences between check and survey totals are shown. It may be seen that of the 13 percent error, the omissions accounted for 12 percent, other types of errors adding only small amounts. This resulted because plus-and-minus errors, except for building omissions, tended to cancel for the total area; it would not be true for small areas. Thus correcting for omissions alone would have resulted in an over-all error close to zero.

The kinds of error in floor area were a result either of lack of care in obtaining data or of limitations of aerial photographic interpretation itself. More efficient control procedures probably would have solved the building omission problem to a great extent. Measurement and identification accuracy on a detailed level probably could be improved by further enlarging the photography and by using supplementary materials. If greater accuracy is needed the user of the data must decide whether the added expense would be justified.

Land Area

Remeasurements of land area for checking purposes do not have the same validity as those of floor area because no source superior to the original aerial photography itself was available. Furthermore, definitions of land-use boundaries are necessarily inexact (with the exception of gross total land area). The various nonresidential land uses, except for vacant land, were therefore treated as a group for checking purposes.

The ratios of error (check divided by aerial survey measurements) that appear in Table 6 are based on a repetition of the same process used in the original measurements, which would be likely to produce sizeable errors due to differences in land area definition. Nevertheless, the results of the comparisons were close. The aerial survey measurements of gross totals which include all land area within sample blocks, and net totals, which include everything except streets, each differed by a negligible amount from the check measurements. Vacant land area also showed a negligible difference, probably because most of it is found in large, unbroken areas. Original survey mea-

TABLE 4

CHECK AND AERIAL SURVEY NONRESIDENTIAL FLOOR AREA PROPORTIONS COMPARED BY DETAILED LAND-USE CATEGORY

Land Use	Check	Aerial Survey	Ratio of Check to Aerial Survey[a]
Commercial retail or service, type unknown	--	0.007	NC
Commercial retail			
Type unknown	0.226	0.244	0.926
Food and drugs	0.007	0.004	1.750
Eating and drinking places	0.019	0.012	1.583
Department stores, furniture, and appliances	0.006	0.003	2.000
Other	0.051	0.030	1.700
Total	0.309	0.294	1.051
Commercial services			
Type unknown	--	0.018	NC
Finance, insurance, real estate	--	--	NC
Personal services	0.003	0.005	0.600
Medical, dental, legal	0.003	0.005	0.600
Offices, general	0.002	--	NC
Other[b]	0.039	0.035	1.114
Total	0.047	0.063	0.746
Commercial, heavy			
Type unknown	--	--	NC
Wholesalers, distributors	--	0.002	NC
Junk and salvage yards, used car lots	0.003	0.001	3.000
Other heavy commercial[c]	0.003	--	NC
Total	0.006	0.003	2.000
Manufacturing			
Type unknown	--	0.091	NC
Primary metals	--	--	NC
Other	0.400	0.283	1.413
Total	0.400	0.374	1.070
Transportation, utilities, communications, and other non-manufacturing industrial			
Type unknown	--	--	NC
Trucking terminals, warehouses	0.017	0.004	4.250
R. R. stations and bus depots	0.001	--	NC
R. R. right-of-way	--	--	NC
Airports	--	--	NC
Mines, quarries, oil wells, etc.	--	--	NC
Other utilities, transportation, and sanitary services	--	--	NC
Total	0.018	0.004	4.500
Public Buildings			
Type unknown	--	--	NC
Government and public buildings	0.004	0.006	0.667
Schools	0.145	0.180	0.806
Hospitals and sanitariums	0.021	0.027	0.778
Military installations	--	--	NC
Other public buildings	0.044	0.024	1.833
Total	0.214	0.237	0.903
Public Open Space			
Type unknown	--	--	NC
Parks and beaches	0.001	0.016	0.063
Golf courses	--	--	NC
Cemeteries	--	--	NC
Other[d]	--	--	NC
Total	0.001	0.016	0.063
Vacant land and floor area			
Vacant usable land	--	--	NC
Vacant unusable land, and water	--	--	NC
Vacant floor area	0.005	0.002	2.500
Parking lots	--	--	NC
Total	0.005	0.002	2.500
Total floor area	1.000	1.000	1.000

[a] NC = ratio not computed, either check or aerial survey, or both, had no floor area in category.

[b] Including other professional services, repair, indoor recreation, indoor nonprofit organizations.

[c] Including new construction.

[d] Including outdoor theatres, racetracks, stadiums, zoos, and all other outdoor recreational services.

TABLE 5

TOTAL NET DIFFERENCE BETWEEN CHECK AND AERIAL SURVEY, NONRESIDENTIAL FLOOR AREA BY TYPE OF ERROR

Error	Difference	
	Aerial Survey Less Check	Percentage of Total Aerial Survey
Measurement:		
Ground floor	-402[a]	-3.5
No. of floors	98	0.8
Identification[b]	199	1.7
Omission	-1,368	-11.9
Total	-1,473	-12.8

[a] In hundreds of square feet.

[b] Of residential as nonresidential. Errors by generalized nonresidential type of use (manufacturing, commercial, etc.) not included. These errors were very small, indicating identification as to generalized type was accurate.

surements for nonresidential land in use exceeded check measurements by a small amount, whereas they were slightly low for residential land, the error ratios being 1.08 and 0.93, respectively. (The latter figure agrees closely with previous checking on fire insurance atlas maps in the pretest area and is likely to be nearly correct.)

Not all this error was the contractor's. By performing two or more check measurements and measuring the variation between them, the amount of checking error for land area was approximated; this indicated that on the average about 20 percent of the differences between check and survey measurements could be considered an error in checking.

Dwelling Units and Residential Structures

Census data for 1960 were the basis of final dwelling unit count comparisons for accuracy checking. Comparisons were made with (a) original aerial survey counts and (b) corrected aerial survey counts. (The latter are equivalent to the field sample counts made by the URS, weighted by the total number of dwelling units in each zone.) Inasmuch as census data can be assumed to be accurate, a direct check could then be made of the sampling procedures and of the accuracy of field-counting methods used to obtain factors. Census comparisons were made for the total survey area, for each of the five districts, and for 84 of the 89 zones outside the central business districts where counts were obtained from photography.

Because census counts were available in units no smaller than enumeration district, a direct comparison of blocks in the field sample could not be made. Instead, a procedure was followed that allowed a comparison of census, original survey, and corrected survey counts by a common unit—the zone. It was recognized that census counts by zone resulting from this procedure, having been arrived at by applying successive factors, would vary from the true totals, but these discrepancies were thought insignificant, especially where comparisons were made by units larger than the zone.

The total corrected aerial survey dwelling unit count for the area where photography was used differed from the census count by only 0.4 percent. This percentage difference is negligible and is reliable within 1.0 percent. (Statistical reliability for dwelling units has the same meaning, as for floor area, described earlier.) Because any problems arising from noncomparable Fox River Valley and census areal units become extremely minor at this scale, this comparison should be considered adequate evidence of high accuracy. The results demonstrate that dwelling units as defined by the census can be counted accurately in the field using methods described earlier, and therefore that sample field counts can provide reliable correction factors on an overall basis.

The original aerial survey counts, on the other hand, were about 10 percent less than census counts for the total area. This is to be interpreted as a necessary shortcoming of photography itself as a source rather than as deficient workmanship, because dwelling unit counts from photography are estimates based on the size of residential structures, character of the area, etc., and cannot be made exact by the exercise of greater care.

Table 7 shows the variation in accuracy of both types of counts by district, where

TABLE 6

ERROR IN LAND AREA MEASUREMENTS BY LAND-USE TYPE

Land Use	Ratio of Check to Aerial Survey
Total:	
Gross (including streets)	1.00
Net (excluding streets)	1.00
Nonresidential in use	1.08
Residential in use	0.93
Vacant or unusable	1.00

TABLE 7

RATIO OF CENSUS TO FRV SURVEY OCCUPIED, DWELLING UNIT COUNTS BY DISTRICT

District	Ratio	
	Census to Corrected Aer. Survey	Census to Uncorrected Aer. Survey
1	1.02	1.15
2	1.01	1.07
3	1.00	1.03
4	0.99	1.20
5	0.99	1.01
Total	1.004	1.120

error is again expressed as the ratio of census counts per survey count. The table shows that, although corrected districts were in error by very small amounts, 1 to 2 percent, census counts were higher than uncorrected counts by amounts which varied from -1.0 to +17.0 percent. Districts 1 and 4, which contain cities with populations of 53,000 and 64,000, large enough to have a large number of multi-family structures where estimation is difficult, had errors of 12 and 17 percent. The other districts are predominantly single-family and had small errors.

Zones, as much smaller units (the average size is about 600 dwelling units), had correspondingly larger errors. Even so, the frequency distributions of zone errors which appear in Table 8 show that the accuracy of corrected zones was more than adequate, 86 percent being within ± 5 percent of the census counts. This compares with only 21 percent within this range for the uncorrected zones. These data are presented in graphic form in Figures 3 and 4 in which the degree of correspondence with census counts may be compared for both sets of survey counts.

Accuracy of unfactored dwelling unit counts from photography was quite high in single-family home areas, but low in multiple-family structure areas. Table 9 shows the relationship of dwelling unit count error to dwelling units (families) per residential structure, demonstrating the regular increase in percentage error from 5 to

TABLE 8

FREQUENCY DISTRIBUTION OF ZONES BY PERCENTAGE ERROR FOR CORRECTED AND UNCORRECTED AERIAL SURVEY DWELLING UNIT COUNTS

Plus or Minus Error as Percent of Census DU's	Percentage Frequency Distribution of Zones	
	Corrected Aerial Survey	Uncorrected Aerial Survey
0 to 5	85.7	21.4
6 to 10	8.3	42.9
11 to 15	4.8	10.7
16 to 20	--	9.5
21 and over	1.2	15.5
Total	100.0	100.0

TABLE 9

RATIO OF CENSUS TO UNCORRECTED AERIAL SURVEY, OCCUPIED DWELLING UNIT COUNTS BY DWELLING UNITS PER STRUCTURE

Dwelling Units Per Structure[a]	Ratio of Census to Uncorrected DU Counts
1.14 or less	1.05
1.15 to 1.24	1.27
1.25 to 1.34	1.31
1.35 to 1.44	1.31
1.45 and over	1.55

[a] Obtained in field sample.

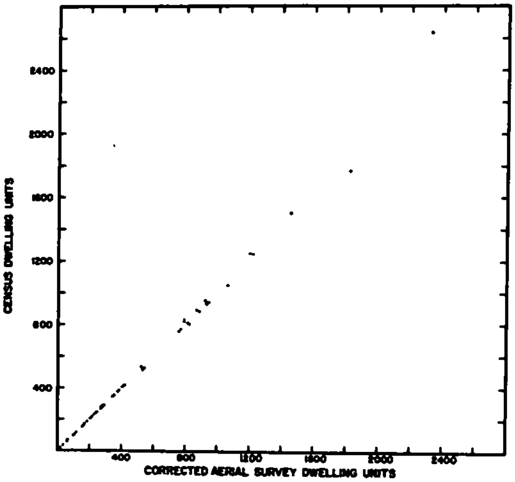


Figure 3. Census and corrected aerial survey dwelling units by zone.

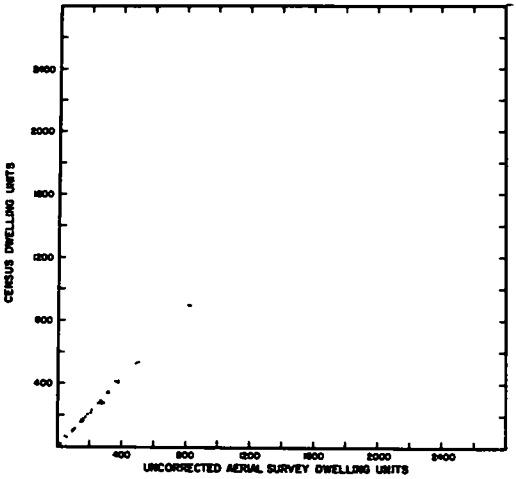


Figure 4. Census and uncorrected aerial survey dwelling units by zone.

55 percent in areas where dwelling unit structures were less than 1.15 and more than 1.44, respectively. Also, the variation in error among individual zones was comparatively small in areas with low dwelling unit per structure rates, where most zones were within ± 5 percent of the 5 percent mean error rate. Where the mean error rate was high, individual zone errors differed widely; one-half the zones varied by more than 25 percent from the mean error in areas with dwelling units per structure rates of 1.45 and over. These areas, therefore, require much heavier sampling than do areas of single-family homes to obtain equally reliable correction factors.

SURVEY COSTS

The approximate total cost of data collection, including both the aerial survey data and the data used for checking, was $10,000. Expressed in unit costs this is about $0.18 per dwelling unit, or $51 per sq mi. (Central business districts are not included.) These figures represent only costs directly concerned with data collection itself, and exclude the cost of planning the project, designing the sampling, analyzing, and tabulating data, etc. The costs are itemized in Table 10 by type of data and checking method where possible. Unfortunately, a breakdown by type of data of the cost of the original photographic work, which was done by the contractor, was not available.

TABLE 10

COST OF DATA COLLECTION

Type of Data	Cost ($)
Aerial survey	7,000
Check	2,850
Dwelling units (field counts)	900
Floor area measurements:	
Field	1,300
Atlas map:	
Measurements	400
Rental	200
Land area (photo measurement)	50
Total	9,850

CONCLUSIONS

An evaluation of the accuracy achieved depends on the use made of the data. The FRV study required sufficient accuracy to make trip estimates by areal subdivision. In general, these standards were met, but only after correction factors obtained by independent sample checking had been applied. The over-all errors of 12 and 13 percent for uncorrected dwelling units and floor area, and especially the large variation by district and by zone, prevented the use of these data as they came from the contractor.

The most important data for trip generation purposes in this study were dwelling unit counts and commercial floor area, which typically generate 55 and 25 percent, respectively, of total vehicle trips. Accuracy (after corrections) was high for both these items, especially for dwelling units, by areal subdivision as well as for the totals. The other floor area data were adequate, as were land area measurements used. It is estimated that trips generated by the average zone (about 4, 000 vehicle trips) would be in error due to data inaccuracy by about 15 percent or less, two-thirds of the time. Districts would have much smaller errors—about 3 percent.

Essential Procedures and Indicated Improvements

Careful workmanship is the main element necessary in aerial photographic interpretation. Much greater care is required than when data are obtained from other sources, such as fire insurance atlas maps or from direct field surveys. This is particularly true for floor area data. On the whole, the quality of work from photographs in the FRV survey appeared to be good, and much of the error found was probably due to limitations in the technique itself.

An important finding of the study is that sample checking is essential to obtain measures of accuracy and correction factors, for all types of data. Because of the variation in error possible, a preliminary testing should be done, from which sample sizes can be estimated large enough to produce statistically reliable measures. The FRV sample sizes that were estimated by this method proved to be large enough to produce adequate correction factors. Dwelling units in fact were oversampled; one-third the number of blocks checked would have given a standard error for the total of 3 percent. Sampling should be stratified by areal unit, by land-use type, etc., because of the different rates of error which are likely among the groupings.

Certain improvements are possible in dwelling unit sampling. As was shown previously, single-family homes were counted from photography within 5 percent of census counts. Sample sizes should therefore be very small in areas of this type and much larger where the dwelling unit per residential structure ratio is high. This would allow a reduction in total sample size.

Controls on procedure proved to be important. These include setting up forms for recording data, lists of blocks to be covered, etc., so as to insure completeness of coverage and prevent duplications. The building omissions problem discussed, which accounted for most of the error in total floor area, might have been controlled by better procedures; each building could have been numbered on the photographs, recorded on forms, and then rechecked for coverage. Forms were also designed to allow checking on computations, illogical entries, and other clerical errors. Some zones were thus corrected by 20 percent or more as a result of checks made for these contingencies.

Oblique photography was found necessary for floor area data, to determine the number of floors and to aid in land-use identification. It also made much better identification of land area possible. Other supplementary sources would also be desirable.

Comparison with Other Methods

Based on the experience in this study and elsewhere (the Chicago Area Transportation Study used atlas maps to collect floor area and land area data), aerial photography as a source of floor area and land area data still appears to be definitely inferior to fire insurance atlas maps. Better accuracy can be obtained more easily from atlas maps, especially for detailed land-use identification, at roughly one-half the cost.

Comparative costs and accuracy for dwelling unit counts by field survey and counts from photography are closer. Although it is true that field surveys can be as accurate as desired, the FRV photo counts, corrected by field sampling, are also accurate enough for most purposes. The accuracy of field surveys is not necessarily higher than uncorrected photo counts. For instance, it was necessary to correct for an 8 percent error in the field survey of dwelling units made for the Pittsburgh Area Transportation Study (2). At high densities, all types of surveys are more difficult. Experience in this study has shown that costs for field surveys would be about the same as the FRV combination photo and field sample method, and might be considerably more in areas of single-family homes.

General Applicability

Whether to use aerial photography as a data source depends on the type of area in which data are to be collected, type of data needed, accuracy needs, availability of other source materials, capability of personnel, and other factors such as cost limitations.

Aerial photography is best suited for areas of relatively low density—suburban areas, small cities, or rural areas. No other source is usually available for either floor area or land area data in these areas except sometimes in central business districts. Densities in the Fox River Valley, for instance, range from 1,000 to 10,000 dwelling units per square mile of residential land in use, excluding central business districts. These densities are also typical of Chicago suburban densities. Such areas have a predominance of single-family homes where dwelling unit counts may be made most accurately. Land-use identification of floor area and land area is also most feasible at low densities because land-use types are usually not mixed in a structure. However, measurement of total floor area without identification probably would be as accurate at high densities. In these areas, a technique combining photographic measurement with identification in the field would probably produce good results, but, of course, would add to the cost.

Where other sources are available for floor or land area data (such as fire insurance atlas maps) aerial photography should not be used, even if the other source covers only part of the area. Increasing the accuracy of measurements from photography beyond that obtained in the FRV study would probably result in sharply increased costs.

In conclusion, the FRV study shows that aerial photography can provide satisfactory data if used where it is best adapted and if proper precautions are taken. Although the testing summarized in this report was thorough, applications in other types of areas and with changes in techniques would add useful information.

REFERENCES

1. "Final Report." Chicago Area Transportation Study, Vol. 1 (1959).
2. Wegener, B.H., "Home Interview Sample Selection." Pittsburgh Area Transportation Study Research Letter, p. 5 (May 1959).

Impact of Industrial Development on Traffic Generation in Rural Areas of North Carolina

JOHN W. HORN, Technical Director, Department of Civil Engineering, North Carolina State College, Raleigh

• THE CHANGING character of rural North Carolina in recent years has produced new problems for rural traffic planners. Increasing industrial employment of rural dwellers and a general rise in vehicle ownership by such persons have brought new functions and added new traffic to rural secondary roads. Routes that once carried primarily farm-to-market traffic now have a large percentage of industrial work trips. It is the task of the traffic planner of today to evaluate and predict traffic trends in order to plan adequately for future road needs.

To understand the importance of the home-to-work trip, one need only imagine how many people work in North Carolina and how these people get to work. The State Highway Commission in North Carolina has complete responsibility for the maintenance and improvement of 13,000 miles of primary highway and 57,000 miles of secondary road that provide service to nearly 3 million rural inhabitants. Travel on North Carolina highways has nearly tripled during the past 15 years and now totals approximately 17 billion vehicle-miles per year. The home-to-work or work-to-home trip amounts to approximately 27 percent of the trips made and 38 percent of the mileage traveled by the rural inhabitants of North Carolina.

There are significant reasons for the extensive system of secondary roads in North Carolina. Economically, the State has always been dependent on agriculture. Only in recent years has industrial development begun to make inroads into the economic structure of the State.

During the past decade nearly 2,000 new industries began operation in North Carolina and the expanded use and ownership of the automobile have provided the major mode of travel for extensive growth and development of residential, commercial, and industrial areas.

Even though North Carolina has become more and more industrialized and the cities have continued to expand, the majority of the State remains rural. In 1950, 66 percent of the State's population was classified by the Bureau of the Census as rural, compared with 51 percent in the South and 36 percent for the nation. The rural population in North Carolina is growing almost as fast as the urban population, inasmuch as so many nonfarm families are electing to live in the uncrowded rural areas surrounding the major cities. During 1958, when a total of 180 new industries began operation in the State, 26 percent of these industries located in rural areas.

The demand for new and improved roads in rural areas is increasing faster than the roads can be built. Because the rural population is much more dispersed than the urban population, more individual persons tend to drive to work, putting many additional vehicles on the roads during the peak traffic hours. The superimposed graph of the growth in industrial employment and motor vehicles in Figure 1 shows the paralleling growth of industrialization and the number of motor vehicles. Also, one-third of the State's population residing in rural areas now consists of nonfarmers. Figure 2 shows the general economic and geographical areas of the State.

In June 1958 the Department of Engineering Research at North Carolina State College began work on a statewide rural traffic generation study with the following objectives: (a) to investigate and interpret the characteristics of traffic generated in open rural areas of North Carolina and (b) to investigate and analyze the basic characteristics of traffic generated by manufacturing industries and the relative importance of variables affecting work trips in North Carolina. The project was sponsored

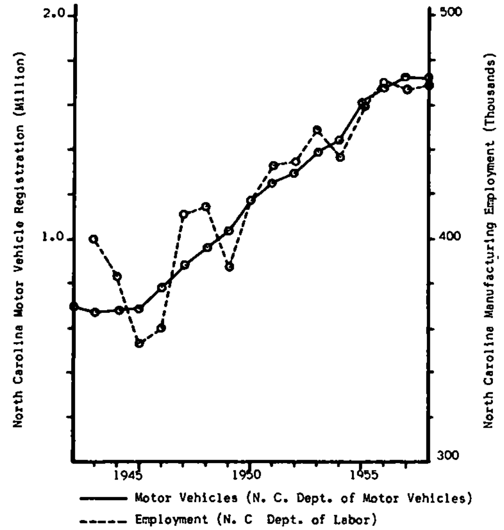


Figure 1. Growth in motor vehicle registration and manufacturing employment.

jointly by the North Carolina State Highway Commission and the U. S. Bureau of Public Roads.

Following a small pilot study from which techniques were determined and refined, a statewide personal interview survey of the occupants of 5,300 rural dwelling units was conducted. Data pertaining to location, date, type of access road, residents, number of vehicles, number of licensed drivers, length of residence, vocation of family, and daily trips by mode, purpose, driver, and length were collected. To facilitate the random selection of dwelling units, highway planning survey maps for the entire State, consisting of 100 counties, were superimposed with ½-mile squares. Each grid square that included a segment of road in a rural area was numbered consecutively in serpentine order. Using only the open rural areas outside city and town limits, a table of random numbers was used to select four samples for each 200 numbered grid squares (Fig. 3). Interviews were conducted in each county during both the summer months and the winter months.

Concurrent with the home interview survey, procedures were developed by which the work trip characteristics of over 44,000 employees of 257 different manufacturing firms were collected. Data pertaining to resident address, living area, race, sex, distance, and mode of travel were collected by providing special forms to each firm for each employee to complete. The firms consisted of twenty types or classifications of industry and eight sizes of industry.

With the combination of data from both the home origins and the industrial work destinations, a multitude of correlations for the travel of rural dwellers were easily obtained with the assistance of punch cards and computer analysis. Tabulated results and plotted relationships filled hundreds of pages; however, a few of the most important relationships are summarized as follows.

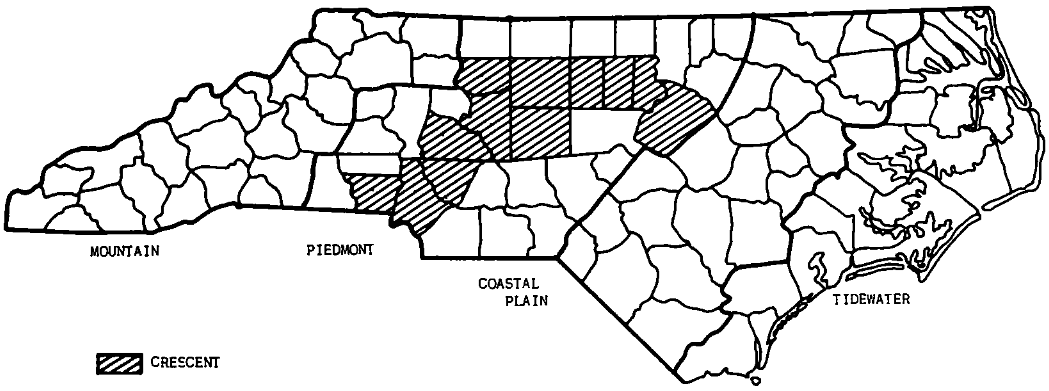


Figure 2. General economic and geographical areas in North Carolina.

Study results indicated that family vocation and race were definitely related to family travel (Table 1). The part-time farm vocational group was the most active in averaging 4.3 trips and 32.8 mi per day. Families that worked only in business or industry were second with 3.5 trips and 28.2 mi per day. In respect to race, white families with 3.6 trips and 25.6 mi per day traveled more than nonwhite families that averaged only 1.5 trips and 9.5 mi per day.

The average length of trip for the entire study was 7.1 mi (Fig. 4). Medical trips were the longest type at 14 mi, whereas shopping trips were shortest, averaging only 3.4 mi in length. Work trips, which accounted for 27.3 percent of the total trips made, averaged 10 mi in length (Fig. 5).

The over-all average numbers of trips and miles per dwelling unit per day were 3.1 and 22.1, respectively.

There seemed to be very little variation in average travel values from one area of the State to another. As previously indicated, however, there was considerable variation between vocations and races. Work trips accounted for a larger percentage of trips in the more industrialized Crescent and Piedmont areas of the State than in the Coastal Plain or Tidewater. In general, shopping trips claimed a large percentage in all areas (22.2 percent statewide).

TABLE 1

TRAVEL AND HOUSEHOLD RATIOS FOR EACH VOCATION GROUP IN EACH AREA OF STATE

State Area	Group	Pers. per DU	Veh. per DU	Trips per DU	Miles per DU	Pers. per Veh.	Trips per Veh.	Miles per Veh.
Tidewater	Farm	4.0	1.1	3.0	18.4	3.6	2.7	16.6
	Part-farm	4.3	1.3	3.8	27.0	3.3	3.0	20.9
	Ind.-bus.	4.5	1.0	2.8	22.5	4.5	2.8	22.9
	Non-work	2.4	0.4	0.8	4.0	5.8	1.9	9.6
	Total	4.1	1.1	2.9	20.2	3.9	2.8	19.1
Coastal Plain	Farm	5 0	1.0	2.7	14.6	5.3	2.9	15.4
	Part-farm	5.0	1.5	4.3	34.5	3.3	2.9	22.9
	Ind.-bus.	4.4	1.2	3.3	27.3	3.8	2.9	23.5
	Non-work	2 8	0.2	0.4	3.3	12.3	1.9	14.7
	Total	4.8	1.1	3.1	21.1	4.4	2.9	19.3
Piedmont	Farm	3.9	1.0	2.4	11.9	4.0	2.4	12.0
	Part-farm	4.6	1.6	4.6	32.4	2.8	2.8	19.8
	Ind.-bus.	4.1	1.3	3.7	28.9	3.1	2.8	21.8
	Non-work	2.4	0.4	0.7	4.5	5.8	1.7	11.1
	Total	4.1	1 3	3.4	23.4	3.2	2.7	18.7
Mountain	Farm	3.6	0.9	1.9	12.2	4.2	2.2	14.2
	Part-farm	4.7	1.5	3.5	31.8	3.1	2.4	21.2
	Ind.-bus.	4.2	1.3	3.2	28.9	3.2	2.4	21.6
	Non-work	2.3	0.3	0.7	4.7	7.1	2.1	14.4
	Total	3.9	1.1	2.6	21.8	3.5	2.3	19.4
Crescent	Farm	3.5	1.1	2.7	12.4	3.2	2.5	11.5
	Part-farm	4.5	1.6	4.6	33.0	2.7	2.8	20.1
	Ind.-bus.	4.1	1 4	3.6	29.4	3.0	2.7	21.5
	Non-work	2.3	0.6	0.7	2.6	4.1	1.2	4.8
	Total	4.0	1.3	3.6	25.4	3.0	2.7	19.1
Statewide	Farm	4.4	1.0	2.5	14.8	4.5	2.6	14.3
	Part-farm	4.7	1.6	4.3	32.8	3.1	2.8	21.2
	Ind.-bus.	4.2	1.3	3.5	28.2	3.3	2.7	22.2
	Non-work	2.4	0.4	0.6	4.3	6.8	1.9	12.1
Total		4.3	1 2	3.1	22.1	3.7	2.7	19.1

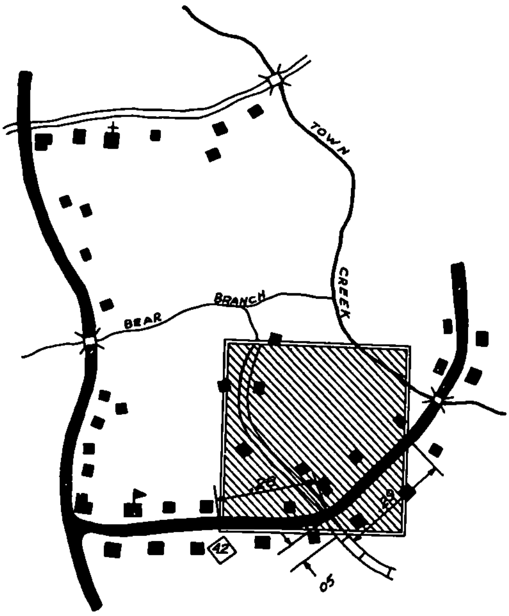


Figure 3. A typical interview section prepared for field use.

Vehicle ownership was largest in the Mountain area, where 88.8 percent of the households interviewed owned one or more motor vehicles. Vehicle ownership was also large in the Crescent (86.6 percent) and the Piedmont (80.0 percent) and was smallest in the Coastal Plain (70.0 percent). Over 92 percent of the part-time farm families owned motor vehicles, as compared to only 68.6 percent for families whose sole occupation was farming. Approximately 78 percent of all families interviewed owned motor vehicles.

Other results of the study revealed that each household interviewed had an average of 1.45 drivers.

Approximately 55 percent of the 5,294 households interviewed in this study had members of the family living at home who worked in business or industry. About two-thirds of these non-farm workers drove to work, whereas 26 percent rode as passengers with someone else driving.

Analyses indicate there is little variation in trip characteristics for rural dwellers in regard to day of the week. However, Monday, Wednesday, and Thursday did experience slightly fewer generated trips per residence than Tuesday and Friday, with all values ranging from 2.91 to 3.48 trips per dwelling unit. There seemed to be some variation in trip generation as to month of the year with values ranging from 2.28 trips per dwelling unit in January to 3.57 trips per dwelling unit in July. This monthly variation is reflected in the seasonal analysis where 2.75 trips per dwelling unit were generated in the winter months and 3.32 trips per dwelling unit were generated in the summer months.

The various agricultural employment classifications seemed to experience considerable differences in trip generation. A low of 0.83 trips per dwelling unit for daywork households and a high of 5.33 trips per dwelling unit for dairy industry households were noted from the collected data. The other classifications had corresponding values generally well dispersed in the upper levels of this range.

There appeared to be no significant difference in trip generation as related to road classification. The data show 3.06 trips per dwelling unit recorded for all paved roads as compared with 3.12 trips per dwelling unit for all unpaved roads. In part, this may be related to the fact that data were gathered only during periods of good weather. However, data were gathered only for the preceding day and therefore there was no assurance that good weather prevailed on that day.

As might be expected, there was definite indication that as the number of licensed drivers residing at a dwelling unit increased there was corresponding increase in the number of trips generated. The values varied from 2.50 trips per dwelling unit for one resident driver to 8.00 trips per dwelling unit for six resident drivers. Also, as the number of drivers increased the number of trips per driver decreased. Values ranging from 2.50 trips per driver for one resident driver households to 1.33 trips per driver for six resident driver households were observed.

An examination of the effect of the number of registered vehicles per residence indicated a similar situation. The trips generated per dwelling unit increased from 3.14 for those residences with one vehicle to 12.00 for those with six vehicles. However, there was a corresponding increase in the number of trips per driver for the same residences with values of 2.13 and 2.77, respectively, being observed.

From the industrial employee data, it was determined that 39.6 percent of all manu-

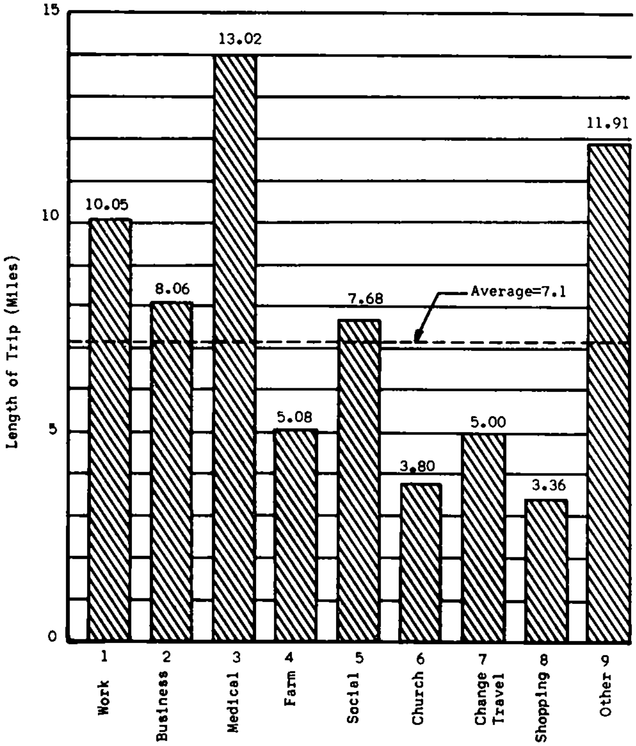


Figure 4. Average length of trip, classified according to purpose, for entire State.

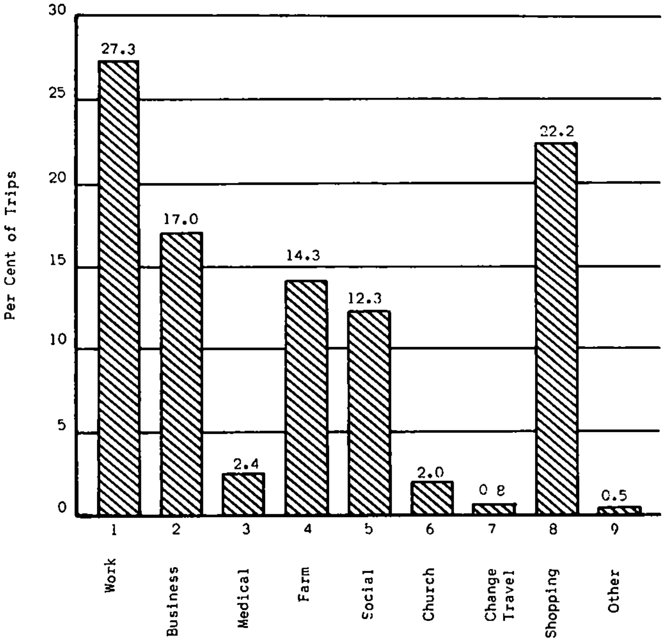


Figure 5. Percentage distribution of trips, classified according to purpose, for entire State.

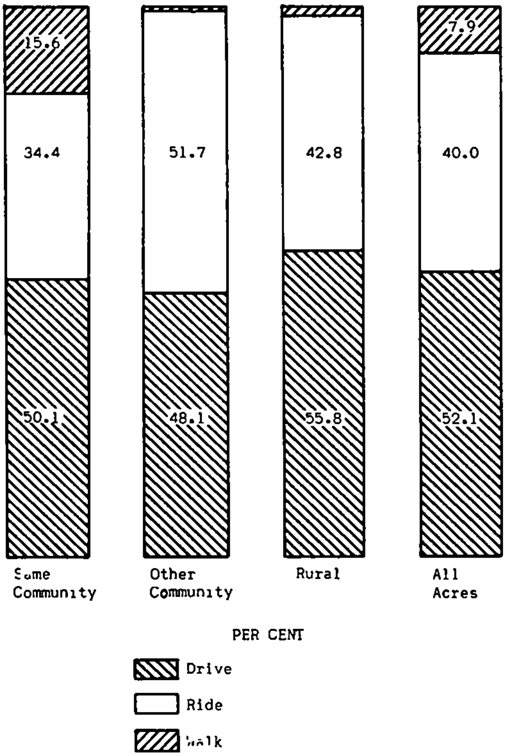


Figure 6. Living area vs mode of travel of employees.

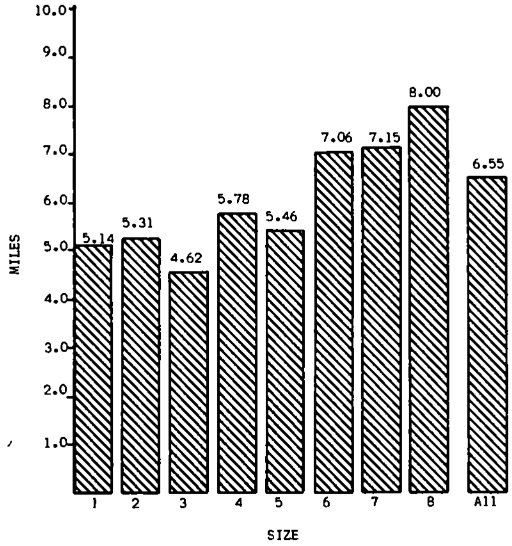


Figure 8. Average length of work trip for all employees vs size of industry.

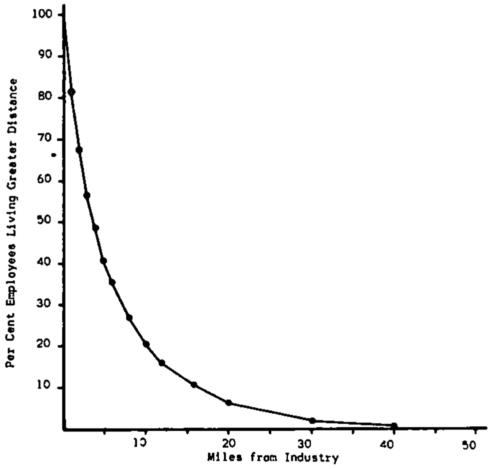


Figure 7. Distance of employee residence from place of employment.

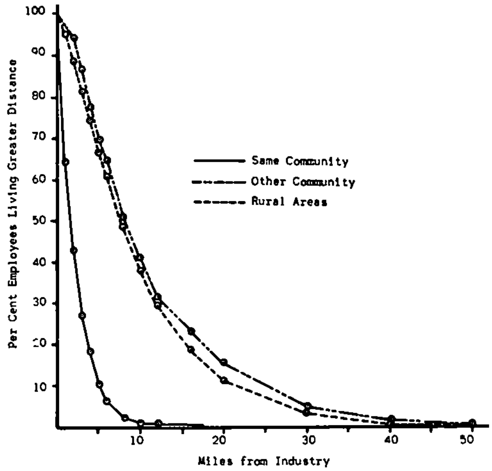


Figure 9. Distance of employee residence from place of employment, by living area.

facturing employees sampled lived in rural areas, and, correspondingly, 60.4 percent lived in urban areas. Of the 60.4 percent urban employees, 46.8 percent lived in the same community as the industry, and 13.6 percent lived in urban communities other than the town in which they worked. The percentage of male employees for all industries sampled was 64.8

Over one-half (52.1 percent) of the employees drove to work, 40.0 percent

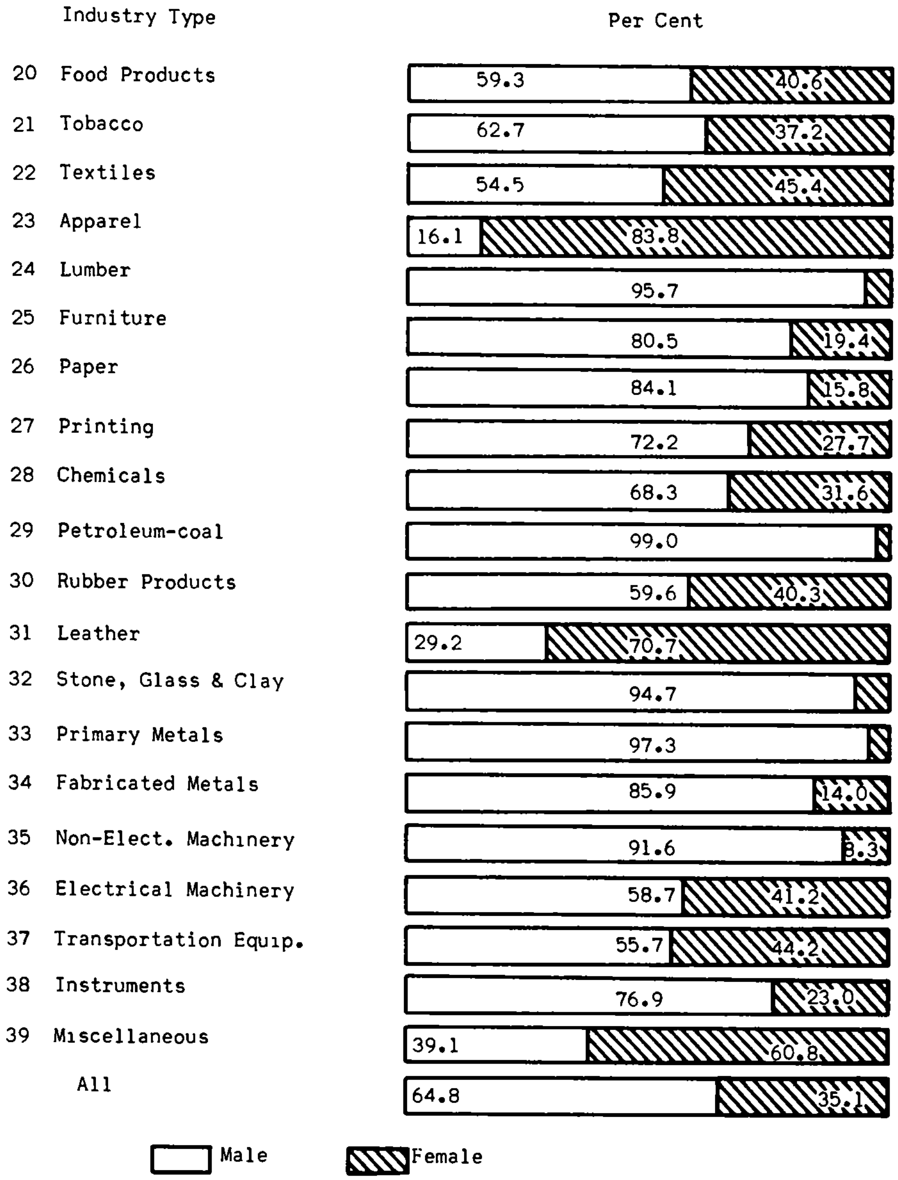


Figure 10. Sex of employees vs type of industry.

rode to work, and only 7.9 percent walked (Fig. 6). The large percentage of employees driving to work indicates the importance of the automobile in the manufacturing employment of North Carolina.

The average distance that manufacturing employees lived from their work was 6.55 mi (Fig. 7). It was determined that over 50.0 percent of all manufacturing employees sampled lived within 4 mi of where they worked, and only 20.0 percent lived more than 10 mi from their employment. The average distance employees walked to work was 0.60 mi; average driver distance was 6.28 mi; and average rider distance, excluding driver, was 8.10 mi.

There seemed to be some difference in the travel and employee characteristics of industries as related to the area of the State in which the industry was located (Fig. 8). This difference in travel characteristics is manifest in the employee distribution curves for each area and the persons per vehicle curves for each area. Also, some difference may be noted in regard to employee characteristics such as race and living area (Fig. 9). However, no appreciable difference was noticed in the sex ratio for each area (Fig. 10).

The collected data also indicated a difference in employee distribution and persons per vehicle between rural and urban companies. Employees of urban companies tend to live closer to the industry than those of rural companies (Fig. 11). Also, rural companies had an over-all average of 1.92 persons per vehicle as compared with 1.59 persons per vehicle for urban companies. Data indicated a decided difference in the living area of employees and a considerably lesser difference in the race and sex of employees (Figs. 12, 13).

Results of an attempt to relate travel and employee characteristics to population of the city in which an industry is located indicated a wide range of difference in distribution curves, persons per vehicle curves, race ratios, sex ratios, and living area ratios. With the exception of the latter, however, these differences did not indicate a trend related to population, but a rather erratic pattern. However, trends were in-

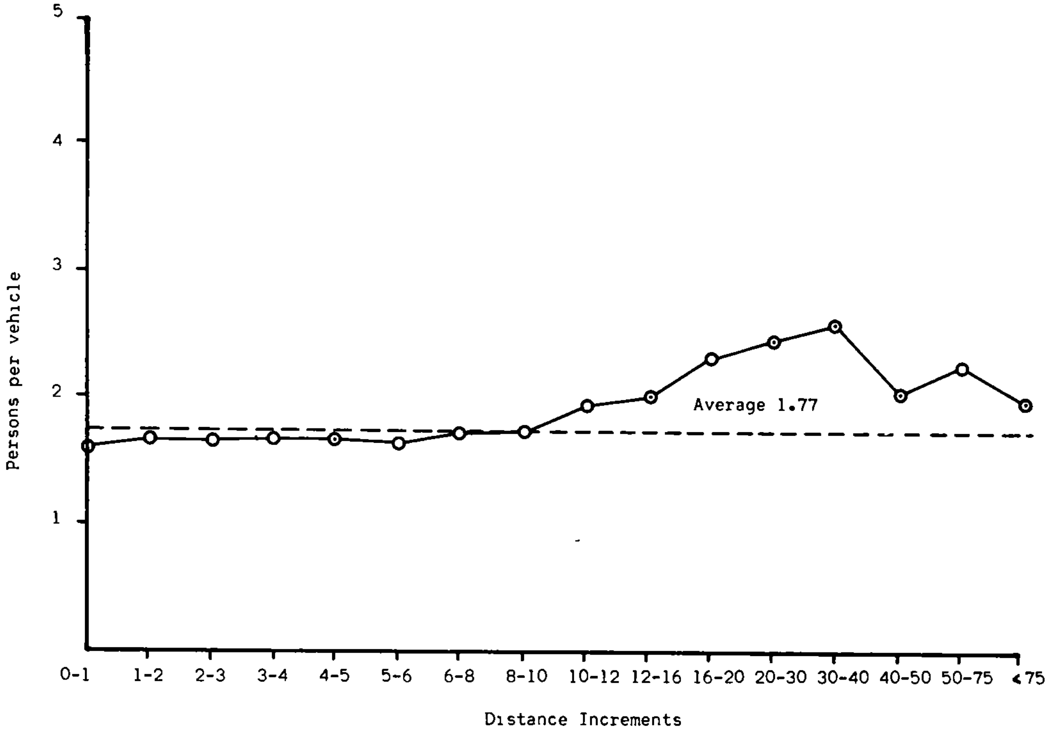


Figure 11. Persons per vehicle vs home-to-work distances for all industries.

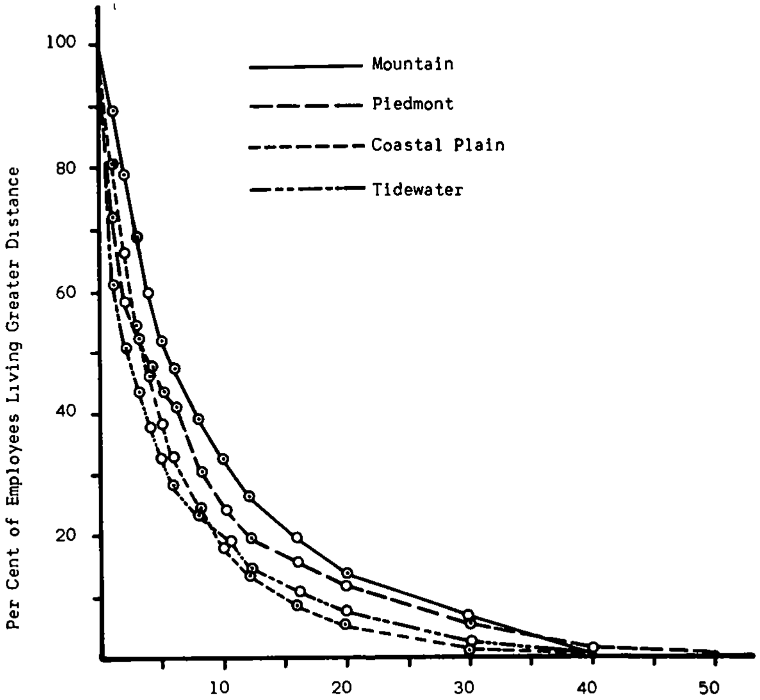


Figure 12. Percent employees living greater distance for areas of State.

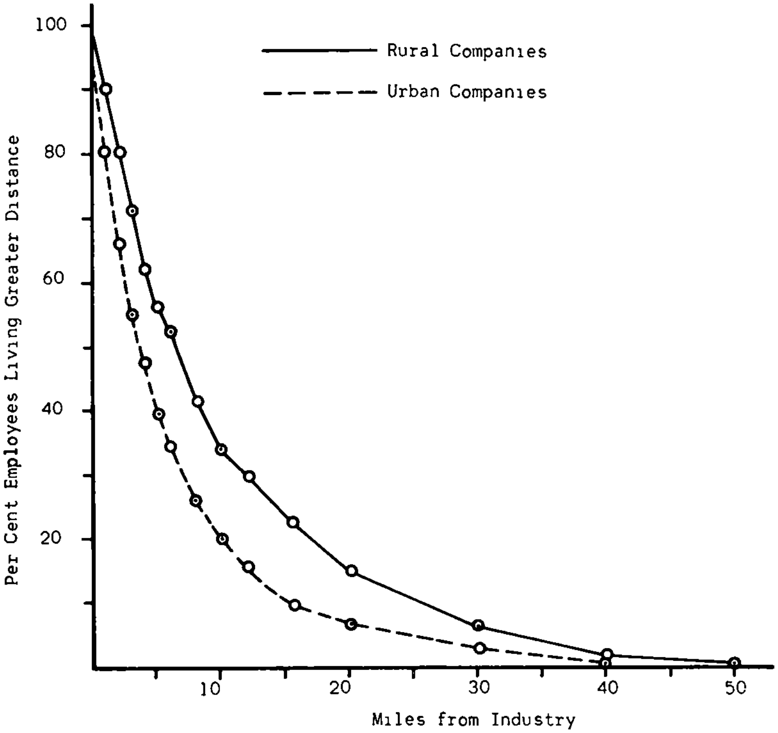


Figure 13. Percent employees living greater distance for urban and rural companies.

dicated for the living area ratios with more employees tending to reside in the same community as the industry as population increased. Correspondingly, rural residence decreased with population increase.

A third phase of the project is now being directed toward the development of predictors of the travel characteristics of the employees of North Carolina industries. The characteristics being investigated are (a) the mileage distribution of residence of employees from their place of work and (b) the percentage of employees that drive their personal automobile to work. These characteristics, when predicted, can be combined to obtain an indication of the amount of traffic generated by an industry.

An initial inspection of the industrial-interview-mileage-distribution data indicated that an exponential distribution could possibly serve as the predictor of mileage distribution of employees from an industry.

The exponential distribution was used to predict the percentages of employees from each mileage increment for each of the twenty types of industries, for each of the eight sizes of industries, and for each of a group of individual industries. The results showed that the distribution generally served as a fair approximation of the actual mileage distribution. There were, however, in several instances, significant differences between the predicted and actual mileage distributions. These differences were more pronounced when working with an individual industry than with groups of industries and also were more significant in the 0- to-1 mileage increment.

An effort is now being made to modify the exponential distribution in order to reduce these discrepancies. The new distribution will have the same basic form as the exponential, but will include at least one other parameter involving some quantitative measure of the industries' locations with respect to population or density of population.

The work on the development of the predictor of the average number of drivers in an industry is just commencing. The initial work has been attempting to determine those industrial characteristics (size, type, etc.) that significantly affect the number of employees driving to work. Ater these characteristics have been isolated, it will then be possible to determine the final form of the predictor.

A Three-Dimensional Calculus Model Of Urban Settlement

EDGAR M. HORWOOD, Associate Professor, University of Washington, Seattle

•THIS PAPER essentially has the single purpose of presenting a simplified mathematical description of urban settlement which the author believes may be a useful tool to those working on various aspects of the simulation of urban transportation demands, rent theory, and spatial interaction by analytical models.

There are two basic premises to this descriptive theory which have been verified time and again in the literature on urban analysis:

1. The density of urban settlement can be reasonably well described by a hyperbolic-parabola:

$$\rho = \frac{K}{r^n}$$

in which

ρ = density of settlement in terms of people per unit area of land;
r = distance from the focus of the urban centrality (characteristically the heart of the central business district); and
K and n = empirically derived values (see Curve A, Fig. 1).

2. The density-distance function just described is skewed by the higher density development that traditionally follows radial transportation routes (whether they be the old streetcar lines of the 1920's, the land-service arterials of the 1930's and 1940's, or the limited-access freeways of the 1950's). This point is shown by Figures 1 and 2.

The three curves of Figure 1 may be thought of as representing the density-distance relationships along three separate cross-sections of the urban area. Curve A, the lowest, represents a cut through an interstitial area of the land between major transportation radials; whereas B and C represent cuts along or adjacent to major radial transportation routes (Fig. 2, which represents the urban area in plan form).

The different shapes to curves B and C merely indicate two possibilities for increased density adjacent to well-developed radial routes—both would obviously have to be higher than curve A, reflecting the increased densities that inevitably follow transportation routes. However, only empirical evidence could ascertain whether improved transportation would simply translate the curve vertically, as in the case of curve B, or skew the slope of the curve also, as in the case of curve C.

One additional word of explanation is necessary regarding Figures 1 and 2. The curves are obviously discontinuous at the margins of the CBD core because of the relative absence of residential population in the core itself. For most American metropolises, this discontinuity occurs at about one-half mile from the point of greatest retail activity within the core.

Three assumptions are now made to keep the mathematical development simplified: (a) the exponential value of r is always 2; (b) the density-distance equation for an intensive transportation corridor is only differentiated from that of a less intensively developed sector by a higher value of K; and (c) all of the transportation intensive sec-

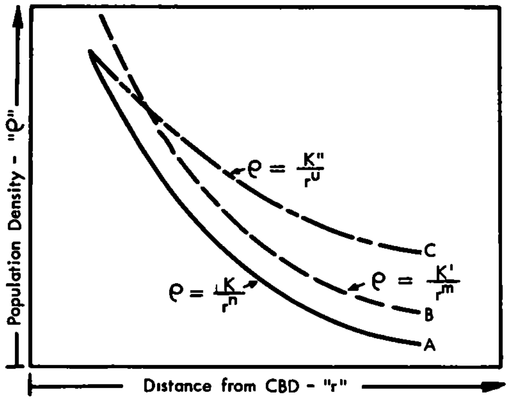


Figure 1.

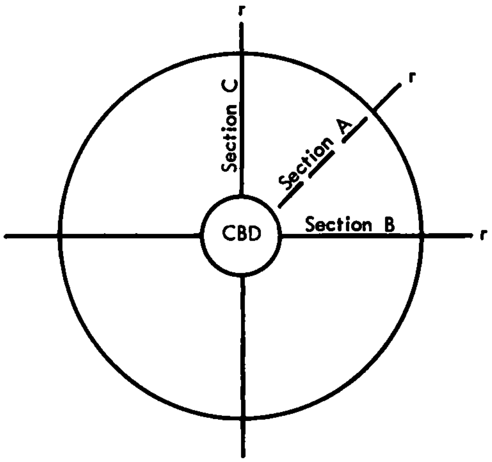


Figure 2.

tors may be characterized by one value of K, and those of the interstitial areas by another value, K'. These assumptions are shown by Figures 3 and 4. Existing knowledge of the space-density function shows all of these assumptions to be relatively valid.

It is now assumed that Figure 5 represents the plan form of an urban area with a four-radial major arterial system, with arterials along the coordinate axes. The most intensive land use of the CBD is at the origin. Distance from the origin is here represented as r.

The population residing in a small portion of the city, dA, is represented by dP, and

$$
\begin{aligned}
dP &= \rho \, \frac{\text{Persons}}{\text{unit area}} \times dA \text{ (units of Area)} \\
&= (\rho)\,(dr)\,(rd\theta) \\
&= \frac{k}{r^2}\,(dr)\,(rd\theta) \quad \text{in which k is a constant somewhere between K and K'} \\
&= \frac{k}{r^2}\,(dr)\,(d\theta) \qquad (1)
\end{aligned}
$$

To integrate the entire population of the urban area from the derivative expression it is necessary to make some assumption as to the circumferential variation of k between the arterial values of K^1 and the interstitial values of K. This variation could be represented by many functions, but to preserve a surface continuum for the urban model a cosinusoidal function will be assumed. In other words, as one would traverse the urban area in a circumferential manner within the annulus area described by dr, density would vary cosinusoidally, reaching a maximum amplitude as the circumferential route crosses the four radial arterials. This circumferential function of density is shown in Figure 6.

The significance of the expression for density as shown in Figure 6 is that it represents a method of simulating population density very readily from either known or assumed values of K', K, r, and θ. In other words, for assumed density-distance characteristics one can readily obtain density for any differentially small area of the universe of urban space.

For example, for a moderate-sized metropolitan area in the United States (say,

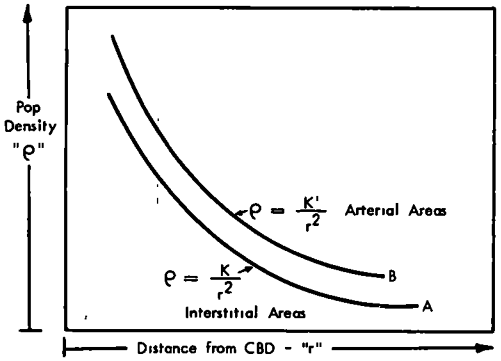


Figure 3.

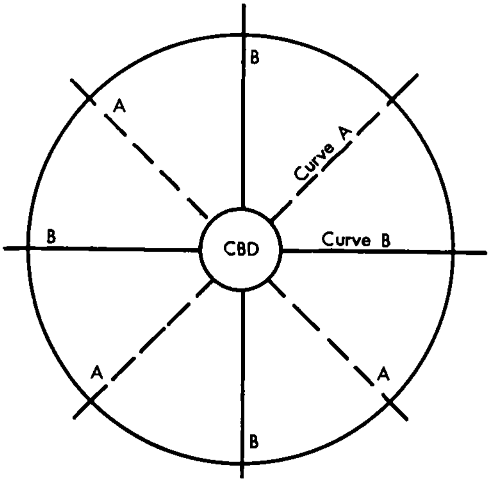


Figure 4.

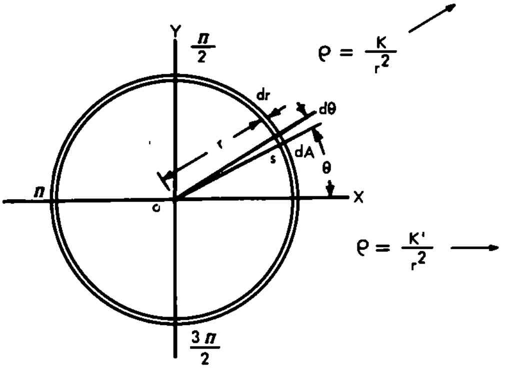
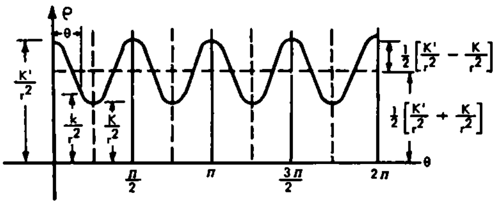


Figure 5.



Circumferential Density, ρ

$$= \frac{k}{r^2} = \frac{1}{2}\left[\frac{K'}{r^2} + \frac{K}{r^2}\right] + \left[\frac{K'}{r^2} - \frac{K}{r^2}\right] \cos 4\theta$$

$$= \frac{1}{2r^2}\left[K'(1 + \cos 4\theta) + K(1 - \cos 4\theta)\right]$$

Figure 6.

between 400,000 and 800,000 people), the constants of the density-distance curves have values of approximately 16,000 for K and 32,000 for K', when distance is expressed in miles and density in persons per square mile (ppsm). Thus, in a typical interstitial area between arterial routes at four miles distance out (r = 4, and θ = 45°, 135°, 225°, and 315°, respectively, for a four-radial model), for the smallest value of θ, as well as all other values,

$$\rho = \frac{1}{2\,(\underline{4})^2}\left[32{,}000\ (1 - \cos 180^\circ) - 16{,}000\ (1 - \cos 180^\circ)\right]$$

$$= 1{,}000 \text{ ppsm.}$$

The next significant step in the use of this theory is the evaluation of population within and segment of the urban area. If the segment is small enough so that density variation is insignificant, population can simply be obtained by multiplying density by area. Thus, in the foregoing example, the number of people on one acre of land would be the density value of 1,000 people per square mile divided by 640 acres, or approximately 1½ persons per gross acre. If, on the other hand the size of the area is significantly large so that density variance is an importance, then an integrable expression may be obtained from Eq. 1 in the following way:

$$dP = \frac{k}{r}\,(dr)\,(d\theta)$$

$$= \tfrac{1}{2}\left\{\left[\frac{K'}{r^2} + \frac{K}{r^2}\right] + \left[\frac{K'}{r^2} - \frac{K}{r^2}\right]\cos\,4\theta\right\}(dr)\,(d\theta)$$

$$= \frac{1}{2r^2}\left[(K' + K) + (K' - K)\cos\,4\theta\right](dr)\,(d\theta)$$

$$= \left[\frac{K' + K}{2}\right]\frac{dr}{r^2}\,d\theta + \left[\frac{K' - K}{2}\right]\frac{dr}{r^2}\cos\,4\theta\,d\theta$$

thus

$$P_a = \int_{R_1}^{R_2}\int_{\theta_1}^{\theta_2}\left[\frac{K' + K}{2}\right]d\theta\,\frac{dr}{r^2} + \int_{R_1}^{R_2}\int_{\theta_1}^{\theta_2}\left[\frac{K' - K}{2}\right]\cos\,4\theta\,d\theta\,\frac{dr}{r^2} \qquad (2)$$

in which P_a represents the population residing between the radial limits of R_1 and R_2, and the angular limits of θ_1 and θ_2.

In a similar fashion, a value for the entire urban population can be obtained by integrating Eq. 2 over the entire plane comprising the urban area. Assuming the radial limits of the integration to be A for the inner value and R for the outer, the entire population P is given by

$$P = \pi\left[\frac{1}{A} - \frac{1}{R}\right]\left[K' - K\right] \qquad (3)$$

The following points of significance may be attached to this model:

1. Unlike previous models involving density-distance relationships, it allows for the higher density of land development which almost universally follows alongside radial traffic arteries.
2. It describes the density-distance relationship as a continuous space function, permitting rapid calculation of density for any point on the urban surface.
3. As traffic origins and destinations can be related to population density, and as interzonal travel demand can be related to population and distance in a gravity-type model, this theory should enable rough predictions to be made for interzonal travel.
4. Stemming from the continuity of the model and the previous point, it should be relatively easy to program traffic demand by the use of a computer that could be set to integrate discreet areas and develop interzonal demand between these areas.
5. The model should give some reasonably good idea of the allocation of population growth to an urban area under varying assumptions of the density-distance relationship.
6. Subnodal concentrations should suggest of treatment in a similar way and permit simulation to be made of the compounding effect of more than one center of activity concentration in an urban area by simply adding the density ordinates.

Electronic Mapping Research and Development

EDGAR M. HORWOOD and CLARK D. ROGERS, respectively, Associate Professor of Civil Engineering and Member of the Graduate Faculty in Urban Planning, and Research Instructor of Civil Engineering and Instructor of Urban Planning

• A RECENT research and development contract between the University of Washington and the City of Spokane Urban Renewal Department is the basis for an entirely new type of research in both computer applications and urban analysis. This project involves the electronic positioning of selected information from a large universe of data stored on magnetic tape. The actual mapping of the information can be effected either through use of conventional electronic printout equipment (such as the IBM Model 717) or photographed from an image displayed on a cathode-ray tube. In either method, the data shown must be interpreted through an overlay grid or an outline map of some type that enables the viewer to interpret the positioned data in terms of a frame of reference. The superimposition of the reference screen or base map is generally effected in the photographic stage by the use of an overlay map, drawn on clear acetate, showing some features of the city. The base map or grid can also be developed by using an electronic scanner to record the base-map outline and then displaying the base map simultaneously with other desired information on the cathode-ray tube.

The construction of maps through electronic techniques is by no means new. The U.S. Weather Bureau pioneered what is known as a "printout" system for representing certain weather information collected from field stations covering a broad expanse of the earth's surface. However, most of the development of electronic mapping to date has been achieved with machines that actually plot lines. These machines generally make use of an inking head that may be directed to any spot on a plane surface by using either punched cards or taped information. The lines are constructed as vectors, and curved images are possible only by the use of a series of very short straight-line elements. The disadvantage of the ink plotter is that it is extremely slow when compared to either a printout or a cathode-ray tube display; nevertheless, it has great utility in many fields. One example of how it is being used is the contruction of "traffic trees," a series of desire lines of flow tracing the pattern of movement from any designated traffic-enumeration zone to all other zones of the system. A desire line is a straight line drawn from the point where the traveler begins his trip to his destination. Not only can these straight lines be generated to represent desires-of-flow direction, but a width band of parallel lines may also be made to represent the volume of traffic flow. This type of plotter can also stamp numbers any place on the plane surface, indicating quantities such as traffic volumes or ground elevations.

The cathode-ray tube may also be used to show desire lines of travel by the generation of the vector on the surface of the tube representing the origin and destination of the trip. In the Chicago Area Transportation Study this technology was used to record the traces of all daily trips made in the Chicago area on a typical day. A total of 2,900 one-quarter-square-mile grid units were used to define the points of origin and destination of the desire trips. Each trip showed as a lighted trace on the cathode-ray tube, and some degree of total trip volume could be comprehended from a photographic recording of the total amount of light displayed by the 400,000 trips simulated on the face of the tube. This particular job, which took 3½ hours of machine time, represented information that could never have been done by hand and that also showed many characteristics of travel never before viewed. For example, when all of the trips between 8:00 and 9:00 PM were simulated and displayed photographically, the viewer could get a fairly good idea of the trade area from which the patrons came to each of the local shopping centers. These procedures were developed in 1959.

PROJECT

The University of Washington project on electronic mapping is unique for several reasons. First, it deals with a universe of several million pieces of information representing many different types of measurements used in urban analysis. Second, it is developing a technology for mapping much of this information in symbolic form, representing an event either by a symbol on a map or by symbols indicating some scale of intensity for the events recorded. Third, by the use of bar charts and distribution curves, it shows alongside the map statistical information that enables the viewer to see at one glance not only that portion of the distribution curve he is looking at, but also where that portion of the distribution curve or data array is located in space. (These have been termed statistagraphs). Although the collection and storage of data by electronic means for urban analysis has been used for a few years, this is the first time that the automation process includes the mapping of data and the use of the new features just mentioned in the graphing of the data.

An interesting sidelight of the project is the development of a program that will translate a street address into a position on the map. In this way it is possible to show quickly any information that is recorded by an address, such as particular type of industry, a police call, or a case of illness representing a particular disease. For example, one could trace the spatial aspects of an epidemic through periodic runs of cards on which the home addresses of the diseased people were punched. The importance of this address-translation program, however, lies in the fact that it can immediately print out information from cards that have already been collected for other purposes by public agencies and private firms.

Because the client agency for the particular research and development under discussion is an urban-renewal department of government, the mapping and graphing contemplated by this project relates mainly to information significant to an urban-renewal program. In fact the mapping development is part of a larger program, the Community Renewal Program (CRP), that the City of Spokane is currently undertaking. This program, which receives two-thirds of its financial support from the Federal government, is designed to study the long-range total urban-renewal needs of a city and to set up criteria for the delimitation and scheduling of specific urban-renewal projects. The data collection for the Spokane CRP, under the general supervision of the University personnel concerned with the electronic mapping project, has involved the development of over 70,000 punched cards representing information on every piece of property in the city. This information includes the type of use of the property; the ground area of the lot; assessed valuation; floor area, age, and condition of the building; and other pieces of information relevant to urban-renewal study. Additional information punched on 25,000 other cards is fed into the storage system from census data available from the Federal government and data collected by the State of Washington through the Employment Security Department and the Tax Commission. After the punched data are recorded on cards; the information is transferred to magnetic tape from which various summaries and computations can be made in connection with the mapping process.

At the time of this writing the data-collection phase has been concluded and over 1,000 graphs and maps have been produced. An estimate indicates that for as little as between $0.03 and $0.05 apiece this method can produce maps or graphs that would cost up to $100 to produce by hand, and the machine output produces this information at the rate of between 20 and 30 maps per minute. An interesting aspect of the technology is that hundreds of maps, if not thousands, can be produced as a basis on which to develop a screening for observing conditions that may or may not be significant to examine in greater depth. In contrast, with hand-constructed maps, so much money is committed to the production of the map that certain conclusions must be drawn before it is made.

APPLICATIONS

City Planning

There is little doubt but that the city planning field is on the verge of a great revolution in methods of data handling. Although it is now almost three-quarters of a century since Holeruth first introduced his dollar-sized punched card into data collection technology, the advances of the last half-dozen years have been staggering in regard to implications for the future. Although the authors are well aware that data collection and manipulation is not a substitute for policy and programing on the planning front, nevertheless, the planning professional may soon become relieved of the tediously slow, subprofessional tasks that have absorbed the energies of the profession for so long. The land-use map, the census analysis, and the vast record keeping associated with planning administration may become the work province of subprofessionals at least as far as all the routine phases are concerned.

The beginnings of the new technology, as far as city planning is concerned, have been the rudimentary collection of data on punched cards and the application of simple accounting procedures to this store of data. As a matter of fact, some agencies kept records in some detail on punched cards for many years. The real breakthrough, however, comes in the realm of data manipulation, recall, and now plotting and mapping by electronic means. Although the development of programs and the pioneering of a new technology requires a specialist approach, there is no doubt that the product can be institutionalized to the point where almost every planning operation having at least one competent professional can automate large segments of the local planning operation. Nor will the lack of a close-by sophisticated computer inhibit automation and the newly emerging techniques by those whose fortune is not to be located near these centers. There now exists ample opportunity for both cards and tapes to be sent to computer service centers. There is no doubt that service centers will not only grow but become more specialized as time goes on and that a library of programs will become developed for use by city planners and urban researchers.

The question may be raised whether these sophisticated techniques are not beyond local authority to make a large initial investment. There is no doubt that there are some birth pangs in breaking into a new technology on any level. Planners have to readjust their thinking, and there is a backlog of information to be put on punch cards. Particularly, planners in small cities may wonder as to the practibility of data automation for their cities as well as its cost. However, apart from developing a system that will be refined to the extent of using individual property cards, the planner for a city of 40,000 or 50,000 people can put all of its census enumeration district information on cards and construct perhaps 1,000 charts and graphs for as little as one month's salary for the typical draftsman. The payoff really comes over a period of time, as data are gradually added to a growing reservoir or as data are updated. Conceive of the ability to call for a time series of data covering ten or fifteen years of events of a particular category by merely placing a call to a computer service center where tapes of the particular city are kept and where the produce can be returned within 24 hours.

A look into the future, judging by the present demonstrated results in electronic mapping and plotting, indicates the following as just a few of the possibilities:

1. Studies of the Urban Structure for Long-Range Planning.
    a. The development of residential density-distance curves for various points in time and their automatic extrapolation to a planning target date. (These plot density as the ordinate and usually time-distance as the abscissa.)
    b. The development of models showing variation in rents with distance from the central business district, by means of which an automatic screening can be made of those areas of the city that are significantly underdeveloped in terms of either use or investment potential (as measured by rents which deviate substantially from the model).
    c. The allocation of population to various subareas of the city, down to a neighborhood level by automatic means and based on area-wide historical trends, subarea growth models and other parameters of data amenable to machine processing.
    d. The delineation of nonresidential functional use areas in which different activities cluster are determined by the automatic mapping of establishments of different types.

2. Studies Relative to Short-Range Planning.
    - a. The automation of building permit records to show at a glance by electronic mapping and graphing a running account of land consumption, investment in building, housing demand, and locations of high developmental demand.
    - b. Floor-area ratio accounting to show at a glance and keep a running tab on the relationship of building to ground area in terms of the preservation of site amenity (also population density studies).
    - c. The automation of all growth indexes and graphs of socio-economic data normally used as part of the economic base study.
    - d. Automation of the U.S. Census data, as they become available, for rapid plotting and graphing.

3. The Automation of Planning Administration Records.
    - a. The recording of all zoning adjustment cases for instantaneous recall by both written description of the case and map location by which to compare the case at hand with others of similar nature.
    - b. The recall and plotting of all known functional or legal nonconforming uses related to zoning adjustment applications.
    - c. The storage of information on tape for printout of all official records, notices, and filing purposes regarding zoning adjustment cases.
    - d. The immediate plotting of field land use data collected by "porta-punch" method of information relative to any particular zoning study or adjustment case.

There is almost no limit to possibilities of integrating automation in all phases of municipal planning operations. Once information has been recorded on cards there are many operations that can be handled without the use of sophisticated computers. For example, sorters, accounting machines, and printers are to be found in every metropolitan center and in many of the smaller cities as well. There are all levels of sophistication of programing, and once instructions have been written for some of the less complex machines, significant use can be made of them in terms of developing both graphs and maps. A final example in the city planning field is the use of the computer to write reports, including both text and illustrations. It is possible now to assemble information on tape and to program in its format as to margins, spacing on the page, right marginal adjustment, footnotes, and other features that will materially expedite the prepartion of reports and preclude the need for recopying most of the information from draft to draft.

In summary, regardless of whether planning follows a conceptual framework based on market processes or is based on doctrinaire schemes, it must evolve from a detailed knowledge of the present order and a knowledge of what is involved in changing the existing order. To this end, the new electronic tool can be of material benefit in giving the professional planner a true picture and far more extensive picture than ever was possible before.

Transportation Planning and Traffic Engineering

Mention has already been made of the development of the cathode-ray tube display by the Chicago Area Transportation Study in showing desire lines of travel between one traffic enumeration zone and another. In addition to showing desire lines of travel, the Cartographatron developed by CATS has been used to show such data as the origin of persons walking to suburban or elevated subway trains, the origin of persons riding to these same transportation modes, the origins of shopping trips to the CBD, the origins of work trips to the CBD, internal persons-trips of varying length, the origins of trips to shopping centers, and other data that aid in understanding transportation movements in an urban area. All of the displays shown in the Chicago study have been assembled from sample data, either collected by home interview method, post card method, or cordon counts. In all cases, the origins and destinations and trips were first coded to zone location and then tallied to give total values for that particular zone.

A somewhat different but unique application of electronic plotters is being made currently by the Penn-Jersey Transportation Study. In this case the EAI plotter, with a punch card input is being used both to plot traffic assignment trees and to register data according to coordinate locations by the registration of a positioned dot on the map. An example of the latter use is a map showing the first work trip destination of all trips. In this case, tallies are arrived at for each destination zone and represented according to graduations of scale by different colored dots. For example, destinations of certain ranges of numbers show as yellow, and the next higher stratification as green, the next as blue, and finally the heaviest concentration as black. Another example is a display of population density by a similar color variation. The results in both these examples can be read much like contour maps. Use of the EAI electronic plotter is very slow when compared with either the print-out positioning of dots using such equipment as the IBM 717, or cathode-ray tube displays such as the IBM CRT 740 or the General Dynamics SC-4020. However, if the EAI plotter is part of an equipment pool either rented or owned by the particular agency, then the fact that it takes five minutes to construct a map which otherwise would be constructed in a few seconds by other equipment may be immaterial. The slower plotter may be standing idle otherwise, and it can do things the other display instruments cannot do.

An interesting graphic display has been produced at the Penn-Jersey study by stratifying data and reproducing each range as a color scale on a chronoflex transparency. In this way, a great variation in shades or colors can be obtained, and the resulting maps can be superimposed on each other for pictorial display by the use of an opaque projector.

University of Washington studies in electronic mapping and graphing will produce transportation planning data of a considerably different nature than that previously discussed, partially because the data relate to a city and do not involve sampling. By virtue of having a street address translation program, resulting from the complete coverage of every establishment in the city in punch card coding, it will be possible to print out on a map, automatically, the home locations of workers at a plant if their addresses are coded. Most industries of any size already have the addresses of their employees recorded on punched cards. In other instances, the addresses of employees are available on cards from State employment security records. The automatic plotting of the home locations of the workers of a particular plant opens the door to a new front in the analysis of the aggregation of worker's residences with respect to any particular plant, or group of plants. Evidence is already at hand, as pointed out by Nathan Cherniak at the Highway Research Board Annual meeting of 1960, that the aggregation of employee's residences with respect to distance from the work place can be reasonably described by a model. For example, in his studies of the locations of workers employed at the New York International Airport, Chernaik found that the percentages of the total number of workers residences in the range of time-distance bands diminished with distance from the work location according to a simple exponential function. One may query here whether the time has not come for a greater use to be made of destination type surveys. If the kind of information being assembled for the city of Spokane in the University of Washington studies were readily available in most cities, as it is evident will happen within the next decade or so, then the door is open to make extensive destination type surveys at a minimum cost to cover at least the work trip portion of the urban transportation universe. This kind of a survey certainly may bring out a different picture of traffic movements than obtained by the customary Lynch origin and destination survey, or on the other hand if found to corroborate the customary O-D survey it might be used as a substitute. There is an inherent weakness, in any event, in the expansion of a small sample obtained by a home interview survey of all trips, and then taking 11 or 12 percent of the trips as representative of the peak-hour travel, as compared to a specific work-trip survey of relative complete coverage. It might be far cheaper and better to get the peak-hour travel directly and use interview techniques to gain more knowledge of recreation travel or travel for other purposes than work or recreation in arriving at a more complete picture of total urban transportation demands.

The kind of information being collected in the Spokane study will be of great value when motor vehicle license information is stored on magnetic tape. By the use of such storage and the collection of license plate data at either a cordon line or a particular location it will be possible to obtain a vast amount of information on origin and destination regarding urban trip generators. For example, license plates could be photographed by motion picture cameras at the access points to shopping centers or at various other cordons, quickly punched, and transferred to tape for matching with the master tape linking the motor vehicle license number with the address of the owner. From this point it would be an easy matter to map the home locations of the drivers represented in the count.

The street address translation program also opens the door for the immediate rendering of accident data, once these data are represented on a punched card. This would facilitate the production of accident record maps according to hour of the day, time of the year, weather conditions, and a number of other possible segregations of the data. The printout mapping technique being developed in the Washington project will also permit the rapid stamping of traffic counts at locations on a map representing the traffic counting stations.

The frequency distribution and graphing programs are particularly adaptable to selecting the 30th highest hour of traffic flow or other flow levels on which to base design or program improvements. Coupled with the recording of traffic counts on punched tape, there are any number of possibilities to automate the rapid graphic recording of most data collected by traffic engineering departments.

EMERGING SCOPE

Only a few applications of electronic mapping graphing have been given in this paper. The real importance to emerge from the development of this tool will occur as cities automate their systems of collecting, storing, and retrieving data concerning urban activities, (land values, land use, age, and condition of buildings, and all the other things referred to in preceding discussions). The research currently going on at the University of Washington is primarily designed to evolve systems not only for the storage and retrieval of data, but for its almost immediate use in graphical form. This research will continue through 1962, at least, under the sponsorship of several agencies including the National Science Foundation. Results will be reported as they become documented.

REFERENCES

1. Cameron, S.H., and Kautner, H.H., "A Hybrid Data Processor with Magnetic Tape Input and Direct Pictorial Output." Armor Research Foundation, Unpublished paper presented at Western Joint Computer Conf., (May 1958).
2. Carroll, J.D. Jr., and Jones, G.P., "The Cartographatron, High Speed Electronic Plotting of Massive O-D Data." Traffic Engineering, 30: 18-25 (April 1960).
3. Carroll, J.D., Jr., and Jones, G.P., "Interpretation of Desire Line Charts Made on a Cartographatron." HRB Bull. 253, 86-108 (1960).
4. "Design of the Perceptron." Datamation (July-Aug. 1958).
5. Duke, R.D., "Automatic Data Processing—Its Application to Urban Planning." Michigan State University (1961).
6. Simpson, S.M., Jr., "Least Squares Polynomial Fitting to Gravitational Data and Density Plotting by Digital Computers." Geophysics, 19:255 (April 1954).
7. Tobler, W.R., "Automation and Cartography." Geograph. Rev. (Oct. 1959).

Appendix

SAMPLE MAP AND GRAPHS

Three samples of early products of the electronic plotting are presented here. They are ozalid prints from photographic transparencies of the machine output. The originals can now be produced in just a few seconds, including headings and titles, and at a cost less than that of the vellum or high contrast opaque paper on which they are produced.

Figure 1 shows computed information from a deck of census tract cards. The program will print out either the basic information or derivative information computed from it, according to instructions, and place the results in the appropriate location. Although the space modules of this illustration are census tracts, they could also be enumeration districts, blocks, neighborhoods, or uniform divisions relating to a grid, depending on the way the basic data are punched. The computational results can also be shown in symbolic form, such as the dots, minuses, and pluses of Figure 3. Symbols can be programed to fill up the entire space unit, or any portion of it.

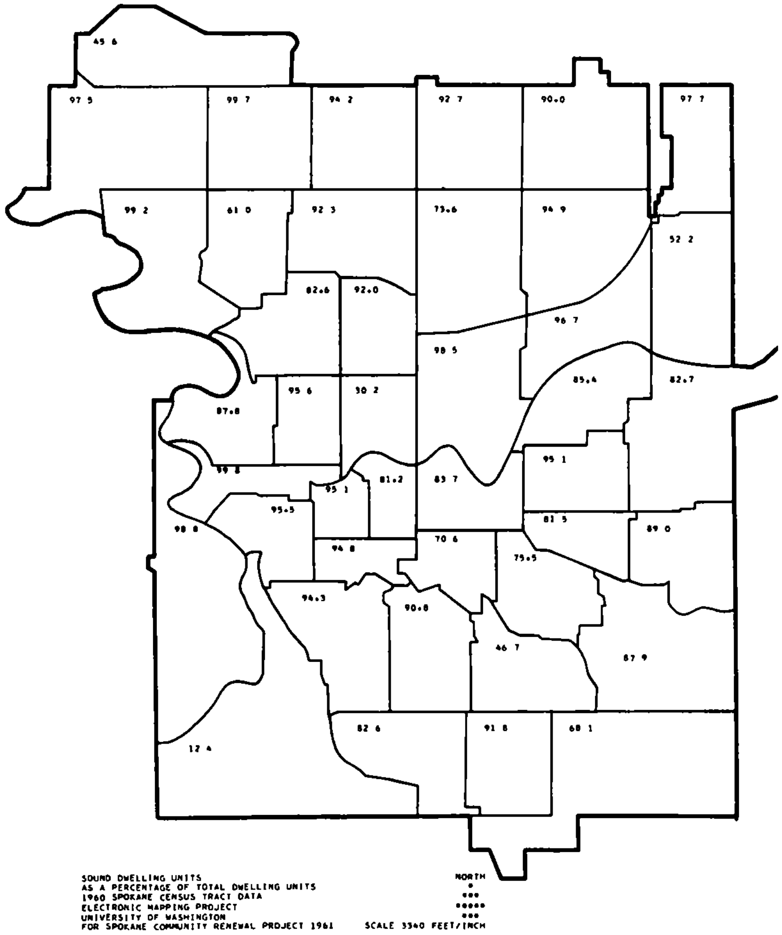


Figure 1.

Figure 2 shows a bar chart on which each census tract is shown in the array in its appropriate place. If more than 50 or 60 basic units are shown (i.e., more than a full page), they can be automatically grouped so as to form a normal distribution curve. These kinds of arrays permit one to come to tentative conclusions as to limits of normalcy. For instance, one can see at a glance just how deviant the extremes are from the normal range; say, all but the first four and last four tracts in the array. The array or distribution curve is especially valid in examining block data, where there is a large universe (say, five or ten thousand blocks) and where a Poisson-type distribution is likely to occur.

Figure 3 shows the same kind of information as Figure 2, except that the first and last quartiles were programed to print in different symbols. Actually, the breaks in the slope of the bar chart curve do not occur at the quartile points, and a plotting of the extreme octiles or deciles would have been more significant. It is expected that programs will be developed in this research to find the extreme ranges automatically. Most important, however, is that when this kind of a plot is shown alongside a map whereon the same symbols indicate the spatial location of the extremes of the array, the viewer sees at a glance both the statistical and locational significance of the data. (This combination of information in one picture is termed a "statistograph.")

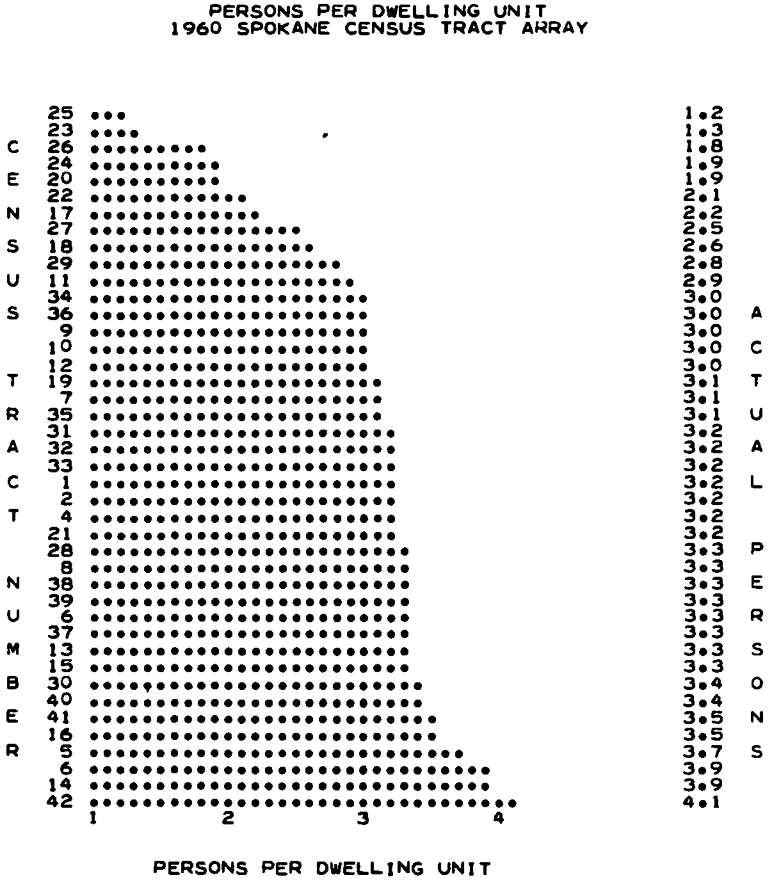


Figure 2.

MEDIAN LAND VALUE FOR
1960 SPOKANE CENSUS TRACTS

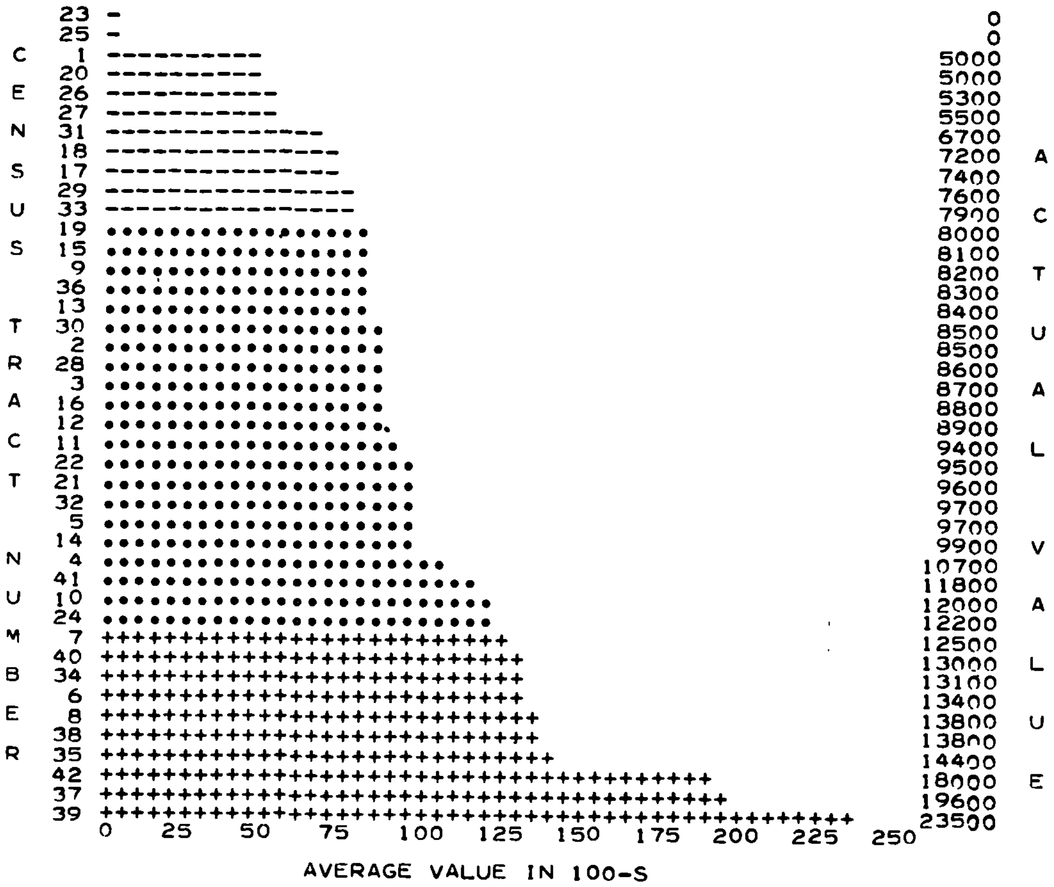


Figure 3.

A Theoretical Prediction of Work Trips in the Minneapolis-St. Paul Area

ROBERT T. HOWE, Associate Professor of Civil Engineering, University of Cincinnati

• IN DECEMBER 1960, the Twin Cities Area Transportation Study (TCATS) tested several theoretical models for predicting work trip patterns against the findings of its origin and destination survey. Among the models tested was that proposed by the writer (1, 2). The writer was furnished with a copy of the results obtained by TCATS, together with the raw data used in the calculations. This paper reports on an extensive analysis made to compare the theoretical predictions of the writer's field theory of land use and the movement of people with the findings of the O-D survey.

BASIS OF THEORETICAL PREDICTIONS

On the assumption that the pattern of movement of people between places of residence and places of employment is analogous to the potential movement of charges in an electrostatic field, Eq. 1 can be derived. (The theory is described in greater detail in 1, and the complete development is given in 2.) Solving this equation,

$$V_{P_iQ_j} = \frac{\frac{Q_j}{R_{ij}}}{\sum_{j=1}^{m} \frac{Q_j}{R_{ij}}} P_i \quad (i = 1, 2, — n) \tag{1}$$

in which

$V_{P_iQ_j}$ = number of people moving from i to j;

P_i = number of workers living at center i;

Q_j = number of jobs at job site j; and

R_{ij} = straight-line distance from i to j;

for each value of j, for a given value of i, insures that every worker at center of population i will be assigned to a job site. Solutions for all n values of i, however, do not automatically insure that the correct number of workers will be assigned to each job site, even when the restriction that $\Sigma P_i = \Sigma Q_j$ is satisfied. To achieve the necessary balance of assigning every worker to a job site and attracting the correct number of workers to every job site, a series of correcting iterations must be used, as described in the references.

In the derivation of the field theory, as stated in Eq. 1, it was assumed that the data on the distribution of workers over the field of interest would come primarily from census data, whereas the distribution of jobs over the field would come from directories of manufacturers, city directories, and similar sources of information. The resulting predictions would be one-way person-trips without regard for the mode of travel. This theory was first tested extensively in the metropolitan area of

Cincinnati, Ohio, where it had to be checked against a post card type of O-D survey which, unfortunately, covered only auto-driver trips without regard for trip purpose. Despite this handicap, the resulting predictions appeared to be at least reasonable.

CHECK OF THEORY IN TWIN CITIES

When the TCATS decided to apply the field theory to its area of interest, it tabulated all work trips, other than those by walking, originating in each zone of residence within the external cordon and ending in each zone of employment within the external cordon. This insured that the condition $\Sigma P_i = \Sigma Q_j$ would be satisfied, and also established a uniform trip purpose. The resulting O-D movements should, therefore, provide a valid base for analyzing the theoretical predictions.

Figure 1 shows the origin and destination zones of the Twin Cities. In the course of checking the theoretical predictions, it became desirable to subdivide the region into four areas: (a) zones inside the corporate limits of St. Paul, (b) zones outside the limits of St. Paul but having zone numbers less than 40, (c) zones inside the corporate limits of Minneapolis, and (d) zones outside of Minneapolis with zone numbers greater than 40.

Table 1 gives the number of workers living in each of the 64 zones of residence together with the coordinates of the centroids of population. It also gives the number of jobs filled by these workers in each of the 67 zones of employment together with the coordinates of the centroids of employment. These coordinates are in units of miles, and were established by the TCATS staff from personal knowledge of the region. For some reason no workers were assigned to live in the CBD's of St. Paul and

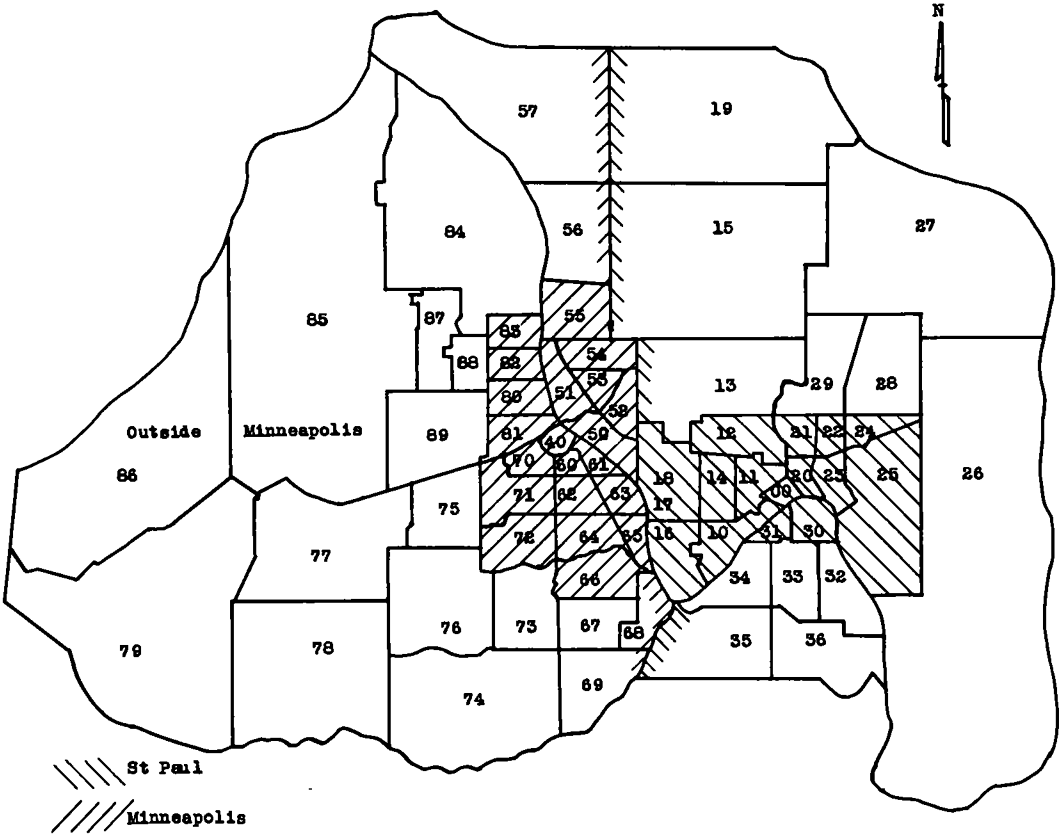


Figure 1. Minneapolis-St. Paul transportation survey, origin and destination zones.

TABLE 1

WORKER AND JOB DATA

Area	O-D Zone	No. of Workers	Center of Population		No. of Jobs	Center of Employment	
			East	North		East	North
St. Paul	00	--			37,585	55.5	49.5
	10	6,715	53.5	48.5	5,253	54.5	48.5
	11	12,833	54.0	49.5	6,996	54.5	50.5
	12	10,358	54.0	52 0	4,174	53 5	51.5
	14	11,462	53.0	50.0	6,126	52.5	50.0
	16	11,096	51.0	47.5	5,622	51.0	48.0
	17	8,126	51.5	49.5	2,659	51.0	49.5
	18	6,412	51.0	51.0	25,058	51.0	50.5
	20	1,739	56.5	50.5	5,274	56.0	50.0
	21	3,913	56.0	51.5	1,013	56.0	51.0
	22	3,876	57.0	51.5	2,584	57.0	51.0
	23	4,404	57.0	50.5	5,182	57.5	50.5
	24	3,354	59.0	52.0	733	58.5	52.0
	25	6,833	59.0	51.0	2,478	59.5	50.0
	30	3,662	56.0	48.0	4,909	56.0	49.0
	31	2,617	55.5	48.5	668	55.0	48.5
Outside St. Paul	13	7,898	52.0	54.0	5,561	52.0	53.5
	15	5,926	51.0	58.5	2,172	51.0	58.0
	19	1,732	52.5	63.5	310	50.5	64.5
	26	3,211	61.5	50.5	1,574	61.5	43.5
	27	6,114	59.0	59.0	1,728	59.5	58.0
	28	4,232	59.5	54.0	1,420	59.0	54.0
	29	2,247	57.0	54.0	527	56.0	53.5
	32	5,399	57.5	46.0	7,889	58.0	46.0
	33	3,468	56.0	47.5	1,590	55.5	46.5
	34	820	54.0	46.5	253	52.5	45.5
	35	695	52 5	44.0	199	53.0	44.0
	36	840	56.5	44.5	383	58.0	43.5
Minneapolis	40	--			63,059	46.5	52.0
	50	3,940	48.0	52.0	16,362	48.5	51.5
	51	5,453	47.0	53.5	5,189	47.0	53.0
	52	2,326	49.0	52 5	10,119	49.0	53.5
	53	5,596	48.0	54.0	4,892	48.0	53.5
	54	4,774	48.0	55.0	2,461	47.5	55.0
	55	4,907	47.5	57.0	5,650	47.0	56.5
	60	5,543	47.0	51.0	8,549	47.0	51.5
	61	3,955	47.5	51.5	4,839	48.0	51.5
	62	11,276	47.0	50.0	11,973	47.5	50.0
	63	6,519	49.0	50.0	5,221	48.5	50.0
	64	11,357	47.5	48.5	3,218	48.0	48.5
	65	3,462	49.0	48.5	938	49.5	48.0
	66	10,266	49.0	47.0	1,491	48.0	46.0
	70	8,335	46.0	51.0	9,985	46.0	51.5
	71	18,907	45.5	50.0	11,591	45.5	50.5
	72	14,663	45.5	48.0	3,531	45.5	48.5
	80	10,641	45.5	53.5	5,406	46 0	53.5
	81	6,467	44.5	52 5	14,193	45.5	52.0
	82	8,563	45.0	55.0	2,296	45.5	55.0
	83	8,563	45.0	56.0	1,132	45.5	56.0

TABLE 1 (continued)

Area	OD Zone	No. of Workers	Center of Population East	Center of Population North	No. of Jobs	Center of Employment East	Center of Employment North
Outside							
Minneapolis	56	2,685	47.5	59.5	1,008	47.0	59.5
	57	5,561	46.0	63.5	2,698	41.0	67.0
	67	3,385	47.5	45.0	4,204	49.0	45.0
	68	--			2,388	50.5	46.0
	69	2,914	48.0	42.5	586	48.0	42.0
	73	12,960	45.5	45.5	5,054	46.0	45.5
	74	7,712	46 0	42.0	4,971	45.5	42.0
	75	10,422	43.0	49.5	6,891	42.5	49.0
	76	6,627	43.0	46.5	4,057	42.5	46.0
	77	7,629	39.0	48.5	8,474	39.5	48.5
	78	554	37.0	44.0	174	38.5	43.5
	79	3,430	31.0	44.5	1,288	32.0	46.5
	84	7,415	43.0	58.5	2,322	43.0	59.0
	85	6,305	38.5	51.5	2,171	36.5	53.0
	86	5,167	28.5	48.5	2,378	29.0	50.0
	87	4,641	42.0	56.0	1,839	42.0	55.5
	88	5,913	43.5	55.0	2,277	44.0	55.0
	89	5,198	42.0	52 0	5,813	42.5	52.5

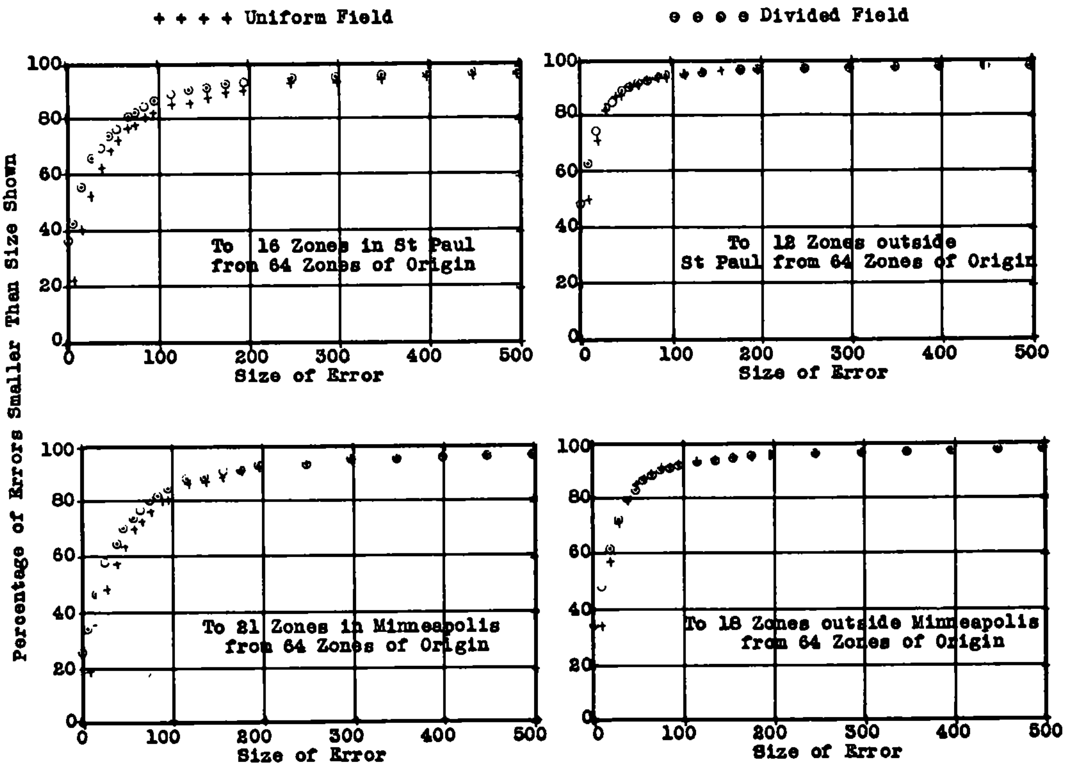


Figure 2. Cumulative percentages of errors in assignments to zones of destination.

Minneapolis, zones 00 and 40, respectively. Zone 68 is the U.S. Military Reservation, Fort Snelling, which provides civilian jobs, but contributes no workers to the field.

CALCULATIONS OF MOVEMENTS

The TCATS staff furnished the writer with a complete listing of the results it obtained by applying Eq. 1 to the entire area, together with the corresponding O-D survey findings for each movement. It was felt, nevertheless, that the predicted values should be recalculated. In this process of recalculation, three iterations of balancing were applied to the original results. The first iteration yielded results that were essentially identical to those determined by TCATS, whereas the last two iterations reduced the residual errors in total assignment essentially to zero, with a very few zones still having errors of up to 2 percent; that is,

$$2 < 100 \times \frac{\text{number of jobs in zone - number of workers assigned to zone}}{\text{number of jobs in zone}}$$

$$2 < 100 \times \frac{\text{number of workers living in zone - number assigned from zone}}{\text{number of workers living in zone}}$$

The remaining errors could have been further reduced by additional iterations, but the benefits to be gained did not seem to warrant the additional computer time required. Henceforth, this set of calculations is referred to as those on the uniform field.

The tabulations prepared by the TCATS staff included a listing of the difference between the O-D finding and the previous theoretical prediction for each movement. A brief study of these differences revealed that the theory consistently overassigned trips across the line dividing zones numbered less than 40 from those of higher number. Indeed, the O-D survey found that no trips took place between a great many of the zones on opposite sides of this line. Because of this overassignment, interzonal movements wholly on one side or the other of this line were rather consistently underassigned by the theory. On finding that the total number of workers living on each side of the line almost exactly equalled the total number of jobs on the same side, it was decided that additional calculations should be made considering zones 00 through 36 to be a self-contained, homogeneous field, and that zones 40 through 89 should be treated similarly. Henceforth, this second set of calculations is referred to as those on the divided field.

Because 4,288 movements are involved in both the uniform field and the divided field (64 zones of origin times 67 zones of destination), this paper does not include listings of all these assignments. Instead, the balance of this paper presents a fairly detailed analysis of the discrepancies between the O-D findings, which are henceforth assumed to be the correct values, and the theoretical predictions, which are assumed to be in error.

Analysis of Discrepancies

Because each movement involves one person moving from a place of residence to a place of employment, all movements have been analyzed from the standpoint of persons going from each zone of origin to the various zones and areas of destination, as well as from the standpoint of persons arriving at each zone of destination from various zones and areas of origin.

While analyzing the results of calculations on the divided field it became apparent that the theory did a better job of predicting movements within each city than it did of predicting movements outside both. For this reason, most of the analyses were based on the four areas shown in Figure 1.

Figure 2 shows the distribution of errors in assigning workers to each zone of employment from each zone of residence. The destinations have been divided into the four areas previously mentioned. From 25 to 40 percent of the errors in the divided field are of zero magnitude. At least 75 percent of the errors in the divided field have a magnitude of 50 or less, whereas a similar percentage of errors in the uniform field have a magnitude of 70 or less. Moreover, the divided field produced smaller errors inside St. Paul and inside Minneapolis than did the uniform field, whereas in the areas outside these two cities the uniform field and divided field produced essentially the same results.

Figure 3 is similar to Figure 2 but shows the distribution of errors in the assignment of workers from each zone of residence to each job site. The zones of residence are grouped into the four areas. The results are quite comparable to those shown in Figure 2. Again the divided field produced better results within St. Paul and within Minneapolis than did the uniform field.

Table 2 gives another measure of the magnitudes of the errors. The data shown were compiled in the following manner:

1. The movements from each zone of residence to a particular zone of employment were grouped into the four areas of residence.
2. The differences between the O-D finding and the two predictions were found for each zone of origin.
3. The sums of these differences were determined for both the uniform field and the divided field for each area of origin.
4. Each of these sums was divided by the number of zones in the respective areas of origin to get the mean error in assignment from each of the four areas to the particular zone of destination.
5. The sum of all movements from the area of origin to the zone of destination, as found by the O-D survey, was divided by the number of zones in the area of origin to determine the mean assignment.

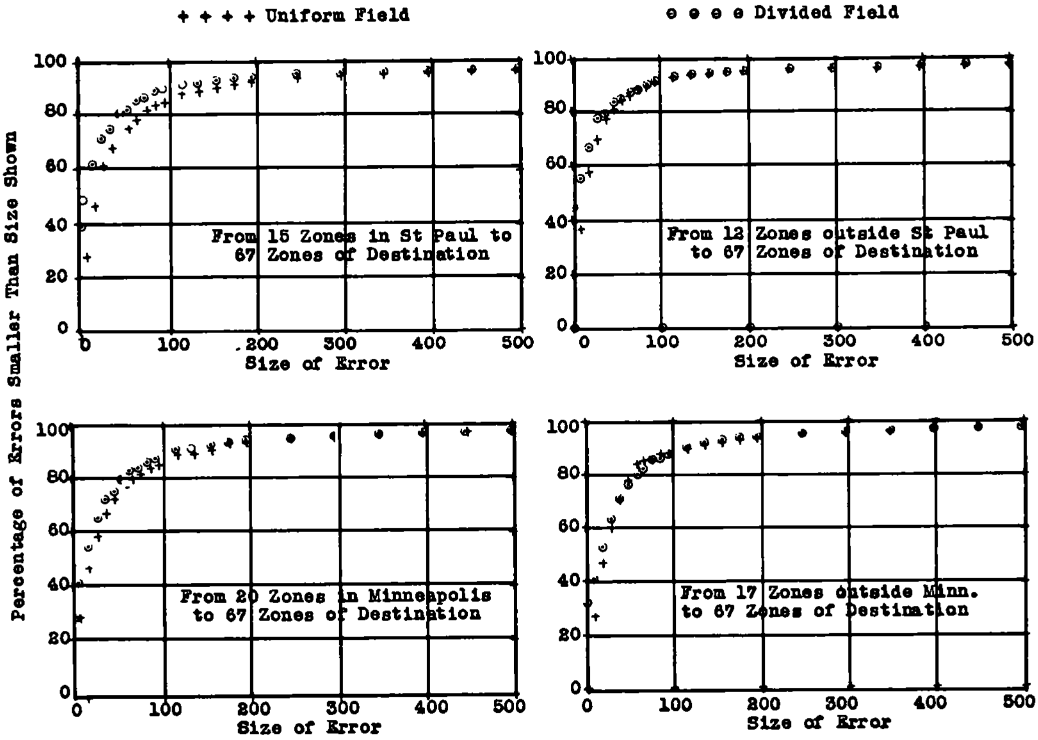


Figure 3 Cumulative percentages of errors in assignments from zones of origin.

TABLE 2

MEAN ERROR IN ASSIGNMENT AND MEAN ASSIGNMENT FROM EACH OF FOUR AREAS TO EACH ZONE OF DESTINATION

Area	To Zone	From St. Paul (15 Zones)			From Outside St. Paul (12 Zones)			From Minneapolis (20 Zones)			From Outside Minneapolis (17 Zones)		
		Mean Assignment	Mean Error		Mean Assignment	Mean Error		Mean Assignment	Mean Error		Mean Assignment	Mean Error	
			Uniform Field	Divided Field		Uniform Field	Divided Field		Uniform Field	Divided Field		Uniform Field	Divided Field
Inside St. Paul	00	1,889	661	388	607	170	236	56	293	56	49	289	49
	10	290	120	92	50	26	56	12	42	12	4	44	4
	11	331	100	75	97	50	60	30	38	30	15	49	15
	12	222	91	65	57	24	41	5	38	5	4	36	4
	14	309	159	15	73	43	54	19	45	19	14	38	14
	16	241	92	164	65	35	36	32	52	32	35	30	35
	17	134	57	45	19	22	29	21	26	21	0	27	0
	18	932	297	416	357	154	135	229	168	229	130	130	130
	20	236	64	74	116	57	40	8	41	8	11	42	11
	21	49	29	28	19	13	10	1	9	1	1	7	1
	22	120	64	66	58	36	35	2	20	2	3	20	3
	23	216	63	57	142	81	60	9	36	9	3	39	3
	24	33	17	16	16	14	16	2	6	2	1	6	1
	25	96	44	43	74	49	42	7	19	7	1	22	1
	30	203	70	57	108	44	42	19	34	19	10	37	10
	31	25	24	28	21	22	22	2	7	2	0	6	0
	Means	327	147	102	112	46	57	28	42	28	18	39	18
Outside St. Paul	13	149	71	68	152	42	130	52	34	52	27	31	27
	15	19	15	20	98	39	52	21	25	21	18	15	18
	19	1	4	7	16	17	15	4	6	4	1	7	1
	26	37	17	24	78	58	58	2	17	2	3	20	3
	27	15	18	22	125	72	46	1	14	1	0	18	0
	28	18	18	23	91	59	48	3	9	3	0	12	0
	29	12	10	14	29	23	20	0	5	0	0	5	0
	32	211	113	142	372	178	159	7	63	7	6	72	6
	33	40	32	46	74	64	75	5	15	5	0	18	0
	34	8	11	14	11	13	16	0	4	0	0	3	0
	35	3	5	7	10	10	11	1	3	1	1	4	1
	36	9	11	15	21	22	23	0	4	0	1	6	1

Minneapolis	40	195	375	195	83	312	83	2,017	449	364	1,109	284	299
	50	80	132	80	98	62	98	526	135	138	204	54	107
	51	11	40	11	20	17	20	174	59	54	77	35	44
	52	26	106	26	98	61	98	308	95	82	142	56	86
	53	7	44	7	27	28	27	174	71	63	59	28	36
	54	2	20	2	7	15	7	919	46	44	30	19	24
	55	9	42	9	40	41	40	1,707	58	48	96	56	63
	60	20	59	20	25	36	25	286	105	91	128	58	58
	61	15	40	15	12	32	12	168	75	69	69	40	46
	62	25	91	25	21	46	21	397	139	114	196	68	50
	63	14	52	14	8	26	8	186	60	43	71	40	38
	64	10	24	10	8	15	8	111	44	47	44	23	24
	65	7	10	7	4	7	4	28	23	26	14	14	14
	66	7	13	7	4	9	4	55	31	25	14	22	30
	70	30	51	30	9	48	9	282	87	91	225	99	77
	71	22	56	22	22	31	22	366	167	166	217	87	80
	72	1	22	1	0	15	0	116	46	48	70	49	48
	80	5	36	5	3	29	3	174	69	80	107	65	69
	81	23	92	23	24	66	24	467	135	122	248	66	82
	82	2	15	2	2	12	2	63	28	36	57	47	47
	83	5	8	5	2	9	2	31	16	18	25	23	25
	Means	25	63	25	25	44	25	360	92	84	178	59	64
Outside Minneapolis	56	7	6	7	4	8	4	9	12	15	39	26	22
	57	1	27	1	6	25	6	11	32	44	140	125	136
	67	36	28	36	25	22	25	89	45	42	93	50	59
	68	39	34	39	11	14	11	52	22	33	36	23	29
	69	0	6	0	2	5	2	15	12	13	14	15	18
	73	11	26	11	6	16	6	92	46	46	176	73	94
	74	5	33	5	4	25	4	73	41	42	199	72	93
	75	11	36	11	4	29	4	98	46	58	278	104	88
	76	4	26	4	0	21	0	76	51	51	145	71	73
	77	6	46	6	3	35	3	115	51	51	354	105	94
	78	0	2	0	0	1	0	1	3	3	9	12	13
	79	0	10	0	0	8	0	8	10	12	66	53	54
	84	3	13	3	4	11	4	30	27	28	97	29	22
	85	4	15	4	3	13	3	15	24	29	105	82	86
	86	2	15	2	0	14	0	6	18	21	131	93	91
	87	2	11	2	0	10	0	24	20	23	79	52	50
	88	0	14	0	2	11	2	38	22	29	88	56	57
	89	7	35	7	2	31	2	111	44	49	204	83	93
	Means	8	21	8	4	17	4	51	29	33	132	63	65

Because the divided field had no assignments across the line separating zones numbered less than 40 from those numbered 40 or more, the mean error in the divided field for each movement across this line is equal to the mean assignment. Whereas the uniform field yielded a smaller error in 11 of the 134 movements across this line, the divided field contained substantially smaller errors on the whole. Of the 268 movements listed, the uniform field produced 27 errors exceeding 100 in magnitude, and the divided field produced 20 errors of this size. Several of the mean errors exceed the corresponding mean assignments, but the only values that might be considered "wild" are some of the movements across the dividing line in the calculations based on the uniform field.

Figure 4 shows the data of Table 2 in graph form. The cumulative percentages of mean errors are plotted against corresponding sizes of errors. The upper curves are based on movements from each of the 64 zones of residence to each of the four areas of employment, or 256 movements. The lower curves are based on movements to each of the 67 zones of employment from each of the four areas of residence, or 268 movements. The divided field gives consistently better results than does the uniform field.

Figure 5 shows the composite mean errors in movement between the four areas. The errors shown are the means of all errors in interzonal movements within the respective areas, as shown on the lines labeled "Means" in Table 2.

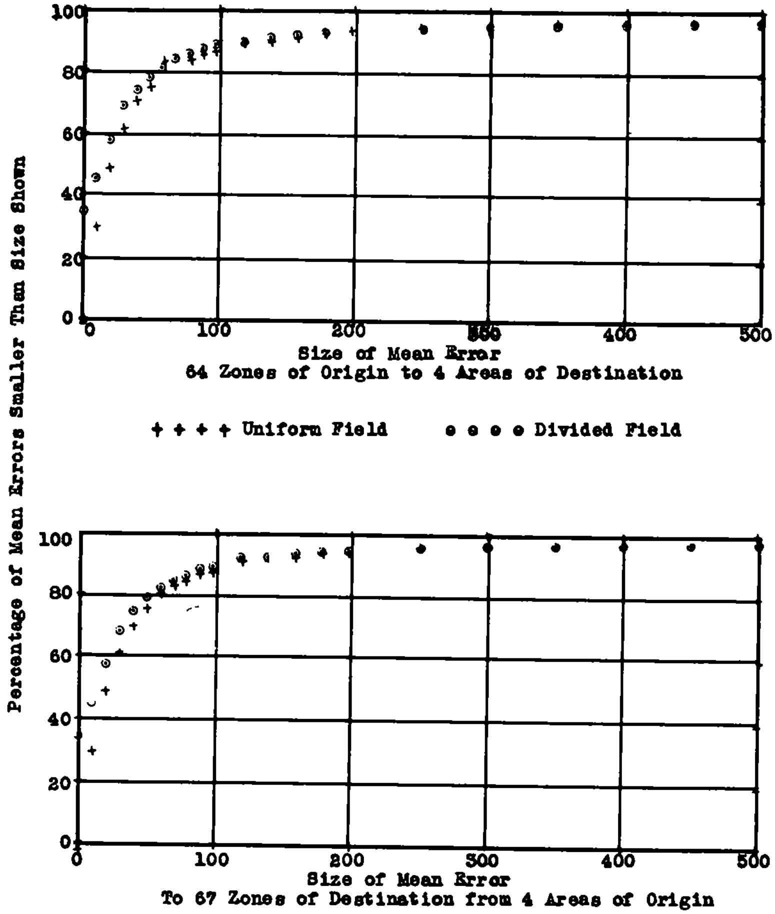


Figure 4. Cumulative percentages of mean errors in assignments.

The balance of this analysis deals with percentages of error. Because the O-D findings are considered correct, and many of these movements are of zero magnitude, it is not possible to determine percentages of error on individual zone-to-zone movements. For this reason, all the analyses of percentage error that follow are based on movements to the four areas of employment from the 64 zones of residence, and to the 67 zones of employment from the four areas of residence.

Table 3 gives the percentage distribution of workers from each zone of residence to each of the areas of employment, as determined by the O-D survey and by the two theoretical predictions. To illustrate the purpose of this table, of the 6,715 workers living in zone 10, 89.0 percent work in St. Paul according to the O-D survey, but the calculations based on the uniform field predicted that 57.5 percent work in St. Paul and those based on the divided field predicted that 89.7 percent work in this area.

Table 4 for each zone of employment gives the percentage distribution of jobs held by workers living in each of the four areas. For example, the O-D survey found that 72.5 percent of the 37,585 jobs in zone 00 are held by persons living in St. Paul, whereas the theory based on a uniform field predicted that 50.5 percent of these jobs are held by persons living in St. Paul, and the calculations based on the divided field predicted 73.0 percent.

Tables 1, 3, and 4 illustrate the statement made earlier, that the calculations based on the uniform field consistently overassigned movements across the dividing line between Minneapolis and St. Paul. They also show that the assumption of zero

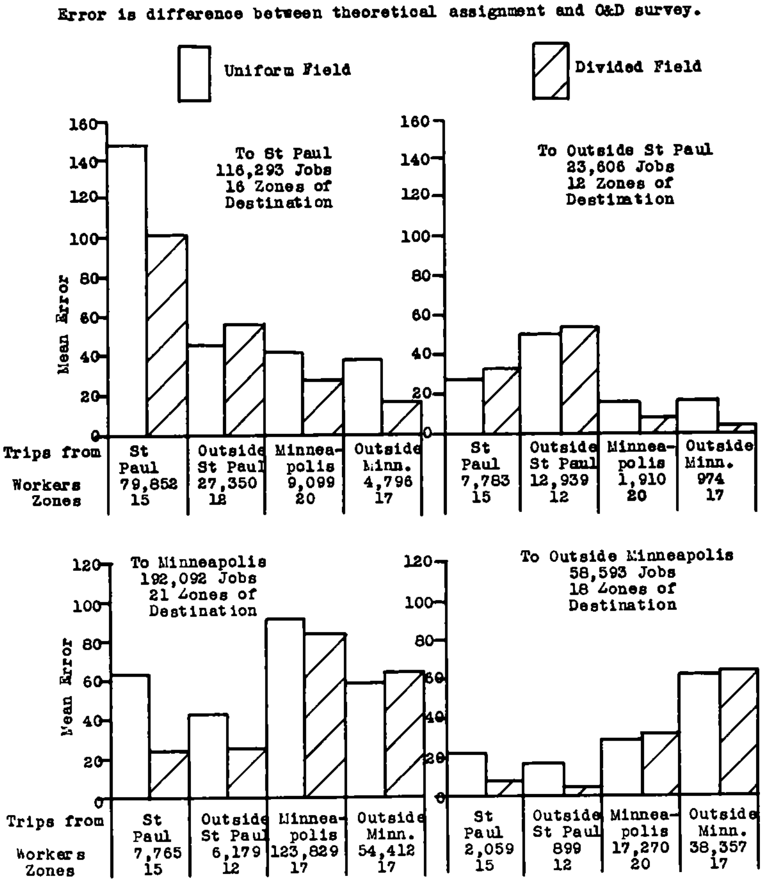


Figure 5 Mean errors in assignments to four areas from all zones of origin. Error is movement according to O-D survey minus theoretical assignment.

TABLE 3

ASSIGNMENT OF WORKERS LIVING IN EACH ZONE TO ALL JOB SITES IN FOUR AREAS BY O-D SURVEY AND BY TWO THEORETICAL PATTERNS

Job Area	Zone	No. of Workers Living in Zone	Workers Assigned to Jobs (%)		
			By O-D Survey	By Theory	
				Uniform Field	Divided Field
St. Paul	10	6,715	89.0	57.5	89.7
	11	12,833	83.9	64.0	91.6
	12	10,358	82.2	54.4	87.7
	14	11,462	82.2	59.1	91.4
	16	11,096	76.5	45.6	89.4
	17	8,126	76.6	53.7	92.3
	18	6,412	72.0	56.4	93.8
	20	1,739	87.8	70.0	91.7
	21	3,913	85.9	62.2	89.4
	22	3,876	91.6	62.5	89.0
	23	4,404	90.0	69.3	91.0
	24	3,354	86.8	53.6	83.5
	25	6,833	88.1	56.5	85.0
	30	3,662	65.6	63.0	91.5
	31	2,031	77.7	70.8	91.5
	13	7,898	60.8	31.3	63.4
	15	5,926	35.0	25.4	62.6
	19	1,732	31.7	28.9	75.0
	26	3,211	60.0	48.0	79.7
	27	6,114	59.1	34.7	69.6
	28	4,232	66.0	42.5	72.4
	29	2,247	76.9	46.5	80.7
	32	5,399	32.3	35.0	48.0
	33	3,468	64.1	57.4	82.2
	34	820	54.5	48.8	82.0
	35	695	54.8	37.5	77.9
	36	840	34.3	41.5	69.0
	50	3,940	14.9	13.7	0.0
	51	5,453	7.0	12.5	0.0
	52	2,326	10.2	19.9	0.0
	53	5,596	4.4	15.6	0.0
	54	4,774	6.4	17.6	0.0
	55	4,907	7.2	18.6	0.0
	60	5,543	9.6	11.4	0.0
	61	3,955	5.5	11.6	0.0
	62	11,276	8.8	14.6	0.0
	63	6,519	11.0	25.8	0.0
	64	11,357	5.9	21.2	0.0
	65	3,462	9.5	29.3	0.0
	66	10,266	8.6	29.8	0.0
	70	8,335	4.0	9.8	0.0
	71	18,907	4.0	13.0	0.0
	72	14,663	3.6	18.3	0.0
	80	10,641	2.8	11.9	0.0
	81	6,467	4.8	12.3	0.0
	82	8,563	3.2	14.8	0.0
	83	5,158	2.7	16.3	0.0
	56	2,685	9.9	21.7	0.0
	57	5,561	4.5	24.1	0.0
	67	3,385	15.0	24.9	0.0
	69	2,914	12.2	22.7	0.0
	73	12,960	7.0	20.2	0.0

TABLE 3 (continued)

Job Area	Zone	No. of Workers Living in Zone	Workers Assigned to Jobs (%)		
			By O-D Survey	By Theory	
				Uniform Field	Divided Field
St. Paul (continued)	74	7,712	5.6	20.8	0.0
	75	10,422	2.3	15.0	0.0
	76	6,627	5.4	17.9	0.0
	77	7,629	2.9	13.4	0.0
	78	554	0.0	21.5	0.0
	79	3,430	2.6	21.6	0.0
	84	7,415	3.6	17.8	0.0
	85	6,305	4.3	17.9	0.0
	86	5,167	1.9	19.5	0.0
	87	4,641	2.0	16.7	0.0
	88	5,913	4.0	15.4	0.0
	89	5,198	4.1	14.5	0.0
Outside St. Paul	10	6,715	4.1	6.8	10.3
	11	12,833	8.4	5.8	8.4
	12	10,358	11.4	7.6	12.3
	14	11,463	5.6	5.6	8.6
	16	11,096	4.7	5.5	10.6
	17	8,126	4.3	4.8	7.7
	18	6,412	9.9	4.2	6.2
	20	1,739	11.0	6.2	8.3
	21	3,913	7.0	7.2	10.6
	22	3,876	6.6	7.7	11.0
	23	4,404	5.4	6.5	9.0
	24	3,354	7.4	10.5	16.5
	25	6,833	6.8	9.9	15.0
	30	3,662	26.7	9.5	13.5
	31	2,617	17.3	6.4	8.5
	13	7,898	17.3	18.9	36.6
	15	5,926	23.7	16.6	37.4
	19	1,732	16.7	9.7	25.0
	26	3,211	35.0	12.0	20.3
	27	6,114	30.1	16.5	30.4
	28	4,232	27.9	17.4	27.6
	29	2,247	13.1	11.4	19.3
	32	5,399	64.1	37.4	52.0
	33	3,468	30.1	12.2	17.8
	34	820	29.3	10.3	18.0
	35	695	23.6	10.2	22.1
	36	840	63.9	18.2	31.0
	50	3,940	1.2	2.5	0.0
	51	5,453	1.7	2.8	0.0
	52	2,326	14.3	3.9	0.0
	53	5,596	2.4	3.6	0.0
	54	4,774	2.5	4.5	0.0
	55	4,907	4.0	5.2	0.0
	60	5,543	0.8	2.0	0.0
	61	3,955	0.0	2.2	0.0
	62	11,276	1.1	2.6	0.0
	63	6,519	0.5	3.6	0.0
	64	11,357	0.9	3.7	0.0
	65	3,462	3.0	4.4	0.0
	66	10,266	2.1	5.0	0.0

TABLE 3 (continued)

Job Area	Zone	No. of Workers Living in Zone	Workers Assigned to Jobs (%)		
			By O-D Survey	By Theory	
				Uniform Field	Divided Field
Outside St. Paul (continued)	70	8,335	1.6	1.9	0.0
	71	18,907	0.7	2.6	0.0
	72	14,663	6.8	3.6	0.0
	80	10,641	0.5	2.7	0.0
	81	6,467	0.6	2.7	0.0
	82	8,563	1.0	3.6	0.0
	83	5,158	1.4	4.1	0.0
	56	2,685	0.6	6.6	0.0
	57	5,561	2.7	4.9	0.0
	67	3,385	1.2	5.0	0.0
	69	2,914	1.1	5.2	0.0
	73	12,960	0.7	4.3	0.0
	74	7,712	1.3	4.8	0.0
	75	10,422	0.7	3.2	0.0
	76	6,627	0.3	3.9	0.0
	77	7,629	0.2	3.1	0.0
	78	554	0.0	5.1	0.0
	79	3,430	1.4	5.4	0.0
	84	7,415	2.2	4.7	0.0
	85	6,305	1.0	4.2	0.0
	86	5,167	1.0	4.9	0.0
	87	4,641	1.5	4.1	0.0
	88	5,913	0.3	3.7	0.0
	89	5,198	0.3	3.3	0.0
Minneapolis	10	6,715	5.4	27.8	0.0
	11	12,833	5.5	23.8	0.0
	12	10,358	5.6	30.6	0.0
	14	11,462	8.0	28.4	0.0
	16	11,096	14.7	37.2	0.0
	17	8,126	15.1	33.9	0.0
	18	6,412	16.6	32.5	0.0
	20	1,739	0.2	18.7	0.0
	21	3,913	7.2	24.1	0.0
	22	3,876	1.8	23.3	0.0
	23	4,404	3.3	18.9	0.0
	24	3,354	5.3	27.7	0.0
	25	6,833	4.1	26.8	0.0
	30	3,662	5.4	21.0	0.0
	31	2,617	4.4	17.6	0.0
	13	7,898	19.7	41.6	0.0
	15	5,926	37.0	46.4	0.0
	19	1,732	47.8	46.2	0.0
	26	3,211	3.6	30.4	0.0
	27	6,114	9.1	37.5	0.0
	28	4,232	5.8	30.8	0.0
	29	2,247	6.3	33.1	0.0
	32	5,399	2.8	20.6	0.0
	33	3,468	5.2	23.2	0.0
	34	820	6.8	30.6	0.0
	35	695	21.6	36.8	0.0
	36	840	0.0	29.6	0.0
	50	3,940	77.3	77.7	93.4

TABLE 3 (continued)

Job Area	Zone	No. of Workers Living in Zone	Workers Assigned to Jobs (%)		
			By O-D Survey	By Theory	
				Uniform Field	Divided Field
Minneapolis (continued)	51	5,453	82.6	77.2	91.7
	52	2,326	79.0	69.3	91.4
	53	5,596	85.1	73.0	91.0
	54	4,774	85.1	68.5	85.2
	55	4,907	83.3	64.3	85.2
	60	5,543	78.5	80.3	93.0
	61	3,955	87.1	80.4	93.7
	62	11,276	79.9	74.5	90.3
	63	6,519	76.9	62.4	89.0
	64	11,357	81.8	63.1	84.4
	65	3,462	78.9	54.9	83.4
	66	10,266	75.3	48.9	75.1
	70	8,335	83.8	81.2	92.4
	71	18,907	78.9	73.6	87.7
	72	14,663	81.5	61.2	79.1
	80	10,641	88.5	75.5	89.0
	81	6,467	81.8	72.1	85.6
	82	8,563	83.9	67.0	82.7
	83	5,158	83.3	64.1	81.4
	56	2,685	73.3	52.0	73.3
	57	5,561	47.3	49.1	72.1
	67	3,385	57.5	45.5	65.9
	69	2,914	47.2	34.6	61.9
	73	12,960	61.6	44.0	60.2
	74	7,712	45.2	35.3	49.6
	75	10,422	64.9	52.4	65.5
	76	6,627	61.5	45.5	59.9
	77	7,629	36.3	34.3	43.3
	78	554	26.5	44.9	62.7
	79	3,430	43.0	42.5	60.0
	84	7,415	62.0	49.5	65.5
	85	6,305	50.6	48.2	63.5
	86	5,167	35.1	39.2	54.0
	87	4,641	61.0	52.4	67.5
	88	5,913	68.0	58.0	73.0
	89	5,198	64.2	52.4	65.3
Outside Minneapolis	10	6,715	1.5	7.9	0.0
	11	12,833	2.2	6.4	0.0
	12	10,358	0.8	7.4	0.0
	14	11,462	4.2	6.9	0.0
	16	11,096	4.1	11.7	0.0
	17	8,126	4.0	7.6	0.0
	18	6,412	8.5	5.9	0.0
	20	1,739	0.0	5.1	0.0
	21	3,913	0.9	6.5	0.0
	22	3,876	0.0	6.5	0.0
	23	4,404	1.3	5.3	0.0
	24	3,354	0.5	8.2	0.0
	25	6,833	0.0	7.8	0.0
	30	3,662	2.3	6.5	0.0
	31	2,617	0.6	5.2	0.0
	13	7,898	2.2	8.2	0.0

TABLE 3 (continued)

Job Area	Zone	No. of Workers Living in Zone	Workers Assigned to Jobs (%)		
			By O-D Survey	By Theory	
				Uniform Field	Divided Field
Outside Minneapolis (continued)	15	5,926	4.3	11.6	0.0
	19	1,732	3.8	15.2	0.0
	26	3,211	1.4	9.6	0.0
	27	6,114	1.7	11.3	0.0
	28	4,232	5.3	9.3	0.0
	29	2,247	3.7	9.0	0.0
	32	5,399	9.8	7.0	0.0
	33	3,468	0.6	7.2	0.0
	34	820	9.4	10.3	0.0
	35	695	0.0	15.5	0.0
	36	840	1.8	10.7	0.0
	50	3,940	6.6	6.1	6.6
	51	5,453	8.7	7.5	8.3
	52	2,326	2.5	6.9	8.6
	53	5,596	8.1	7.8	9.0
	54	4,774	6.0	9.4	11.3
	55	4,907	5.5	11.9	14.8
	60	5,543	11.1	6.3	7.0
	61	3,955	7.4	5.8	6.3
	62	11,276	10.2	8.3	9.7
	63	6,519	11.6	8.2	11.0
	64	11,357	11.4	12.0	15.6
	65	3,462	8.6	11.4	16.6
	66	10,266	14.0	16.3	24.9
	70	8,335	10.6	7.1	7.6
	71	18,907	16.4	10.8	12.3
	72	14,663	14.1	16.9	20.9
	80	10,641	8.2	9.9	11.0
	81	6,467	12.8	12.9	14.4
	82	8,563	11.9	14.6	17.3
	83	5,158	12.6	15.5	18.6
	56	2,685	16.2	19.7	26.7
	57	5,561	45.5	19.9	27.9
	67	3,385	26.3	24.6	34.1
	69	2,914	39.5	22.5	38.1
	73	12,960	30.7	31.5	39.8
	74	7,712	47.9	39.1	50.4
	75	10,422	32 1	29.4	34.5
	76	6,627	32.8	32.7	40.1
	77	7,629	60.6	48.2	56.7
	78	554	73.5	28.5	37.3
	79	3,430	53.0	30.5	40.0
	84	7,415	32.2	28.0	34.5
	85	6,305	44.1	29.7	36.5
	86	5,167	62.0	36.2	46.0
	87	4,641	35.5	26.8	32.5
	88	5,913	27.7	22.9	27.0
	89	5,198	31.4	29.8	34.7

TABLE 4

ASSIGNMENT OF WORKERS FROM FOUR AREAS TO EACH JOB SITE BY O-D SURVEY AND BY TWO THEORETICAL PATTERNS

Living Area	Zone	Total Jobs in Zone	Jobs Held by Workers (%)		
				By Theory	
			By O-D Survey	Uniform Field	Divided Field
St. Paul	00	37,585	75.2	50.5	73.0
	10	5,250	83.0	51.4	75.7
	11	6,996	71.0	52.5	76.1
	12	4,174	79.6	51.1	75.8
	14	6,126	75.6	54.6	81.8
	16	5,622	64.3	46.7	83.5
	17	2,659	75.5	44.2	80.0
	18	25,053	55.1	41.8	76.5
	20	5,274	67.0	51.0	72.6
	21	1,013	72.8	54.2	75.0
	22	2,582	69.5	56.9	75.2
	23	5,172	62.4	53.8	72.7
	24	733	66.6	52.6	69.5
	25	2,477	57.9	46.0	64.5
	30	4,909	62.1	49.0	70.5
	31	668	55.7	50.5	73.5
	13	5,561	40.2	26.2	40.2
	15	2,172	13.7	15.5	21.0
	19	310	5.5	17.2	35.8
	26	1,574	35.0	30.4	55.5
	27	1,728	12.1	21.5	28.0
	28	1,420	18.6	29.2	37.8
	29	527	34.3	38.8	57.3
	32	7,889	40.1	28.8	43.6
	33	1,590	37.9	37.6	60.2
	34	253	47.8	33.2	67.5
	35	199	22.6	38.6	57.6
	36	383	27.1	30.5	55.0
	40	63,035	4.6	13.6	0.0
	50	16,362	7.2	19.4	0.0
	51	5,188	3.2	13.8	0.0
	52	10,119	3.8	19.5	0.0
	53	4,892	2.3	15.5	0.0
	54	2,461	1.4	13.7	0.0
	55	5,650	2.4	13.2	0.0
	60	8,549	3.5	13.8	0.0
	61	4,879	4.6	16.8	0.0
	62	11,972	3.2	14.6	0.0
	63	5,221	4.0	19.0	0.0
	64	3,218	4.6	15.8	0.0
	65	938	11.2	25.7	0.0
	66	1,491	7.0	17.9	0.0
	70	10,027	4.5	12.1	0.0
	71	11,591	3.8	10.1	0.0
	72	3,531	0.6	10.1	0.0
	80	5,406	1.3	11.4	0.0
	81	14,194	2.5	12.2	0.0
	82	2,296	1.6	10.3	0.0
	83	1,140	6.1	10.7	0.0
	56	1,008	11.1	10.2	0.0

TABLE 4 (continued)

Living Area	Zone	Total Jobs in Zone	Jobs Held by Workers (%)		
				By Theory	
			By O-D Survey	Uniform Field	Divided Field
St. Paul (continued)	57	2,698	0.8	13.9	0.0
	67	4,204	12.8	21.3	0.0
	68	2,388	24.6	30.2	0.0
	69	565	0.0	16.2	0.0
	73	5,054	3.3	10.8	0.0
	74	4,973	1.4	11.5	0.0
	75	6,891	2.3	10.2	0.0
	76	4,057	1.5	11.2	0.0
	77	8,474	1.1	9.1	0.0
	78	174	0.0	13.8	0.0
	79	1,288	0.0	11.7	0.0
	84	2,333	2.0	9.2	0.0
	85	2,171	2.7	12.3	0.0
	86	2,378	1.0	10.4	0.0
	87	1,839	1.3	9.7	0.0
	88	2,277	0.0	9.4	0.0
	89	5,813	1.7	10.7	0.0
Outside St. Paul	00	37,585	19.5	15.7	27.0
	10	5,250	11.5	14.2	24.3
	11	6,996	16.7	13.6	23.9
	12	4,174	16.4	13.3	24.2
	14	6,126	14.2	10.1	18.2
	16	5,622	13.8	8.5	16.5
	17	2,659	8.6	9.4	20.0
	18	25,053	17.0	10.5	23.5
	20	5,274	26.4	16.0	22.4
	21	1,013	22.5	15.0	25.0
	22	2,582	27.0	15.2	24.8
	23	5,172	33.0	16.7	27.3
	24	733	26.2	19.4	30.5
	25	2,477	35.9	21.7	35.5
	30	4,909	26.4	17.4	29.5
	31	668	38.0	15.6	26.5
	13	5,561	32.9	30.8	59.8
	15	2,172	54.4	39.5	79.0
	19	310	62.9	22.1	64.2
	26	1,574	59.6	21.0	44 5
	27	1,728	86.7	43.2	72.0
	28	1,420	77.2	41.3	62.2
	29	527	65.7	23.6	42.7
	32	7,889	56.7	36.6	56.4
	33	1,590	56.1	22.5	39.8
	34	253	52.2	14.2	32.5
	35	199	57.4	18.1	41.4
	36	383	67.1	22.5	45.0
	40	63,035	1.7	7.5	0.0
	50	16,362	7.2	9.2	0.0
	51	5,188	4.6	8.2	0.0
	52	10,119	11.6	12.3	0.0
	53	4,892	6.7	9.6	0.0
	54	2,461	3.5	10.0	0.0
	55	5,650	8.5	10.7	0.0

TABLE 4 (continued)

Living Area	Zone	Total Jobs in Zone	Jobs Held by Workers (%)		
				By Theory	
			By O-D Survey	Uniform Field	Divided Field
Outside St. Paul (continued)	60	8,549	3.5	7.2	0.0
	61	4,879	2.8	8.2	0.0
	62	11,972	2.0	6.5	0.0
	63	5,221	1.8	7.7	0.0
	64	3,218	2.8	6.3	0.0
	65	938	4.5	8.0	0.0
	66	1,491	3.1	7.5	0.0
	70	10,027	1.0	6.6	0.0
	71	11,591	2.2	5.2	0.0
	72	3,531	0.0	5.0	0.0
	80	5,406	0.7	7.1	0.0
	81	14,194	2.0	7.0	0.0
	82	2,296	1.0	7.1	0.0
	83	1,140	1.8	8.1	0.0
	56	1,008	4.3	12.6	0.0
	57	2,698	2.6	13.5	0.0
	67	4,204	7.2	8.9	0.0
	68	2,388	5.7	10.0	0.0
	69	565	3.7	8.1	0.0
	73	5,054	1.4	5.2	0.0
	74	4,973	0.9	6.1	0.0
	75	6,891	0.8	5.8	0.0
	76	4,057	0.0	6.1	0.0
	77	8,474	0.5	5.4	0.0
	78	174	0.0	8.0	0.0
	79	1,288	0.0	7.5	0.0
	84	2,333	1.9	7.3	0.0
	85	2,171	1.8	8.2	0.0
	86	2,378	0.0	7.0	0.0
	87	1,839	0.0	6.8	0.0
	88	2,277	0.7	6.5	0.0
	89	5,813	0.3	6.7	0.0
Minneapolis	00	37,585	3.0	18.6	0.0
	10	5,250	4.4	19.0	0.0
	11	6,996	8.6	19.1	0.0
	12	4,174	2.3	20.5	0.0
	14	6,126	6.3	21.0	0.0
	16	5,622	11.5	27.6	0.0
	17	2,659	15.9	29.3	0.0
	18	25,053	18.3	30.0	0.0
	20	5,274	3.3	18.0	0.0
	21	1,013	2.6	16.7	0.0
	22	2,582	1.5	14.9	0.0
	23	5,172	3.4	15.7	0.0
	24	733	4.3	14.6	0.0
	25	2,477	5.5	16.8	0.0
	30	4,909	7.8	18.2	0.0
	31	668	6.3	18.6	0.0
	13	5,561	18.7	24 9	0.0
	15	2,172	18.9	24.1	0.0
	19	310	23.9	26.3	0.0
	26	1,574	2.4	23.9	0.0

TABLE 4 (continued)

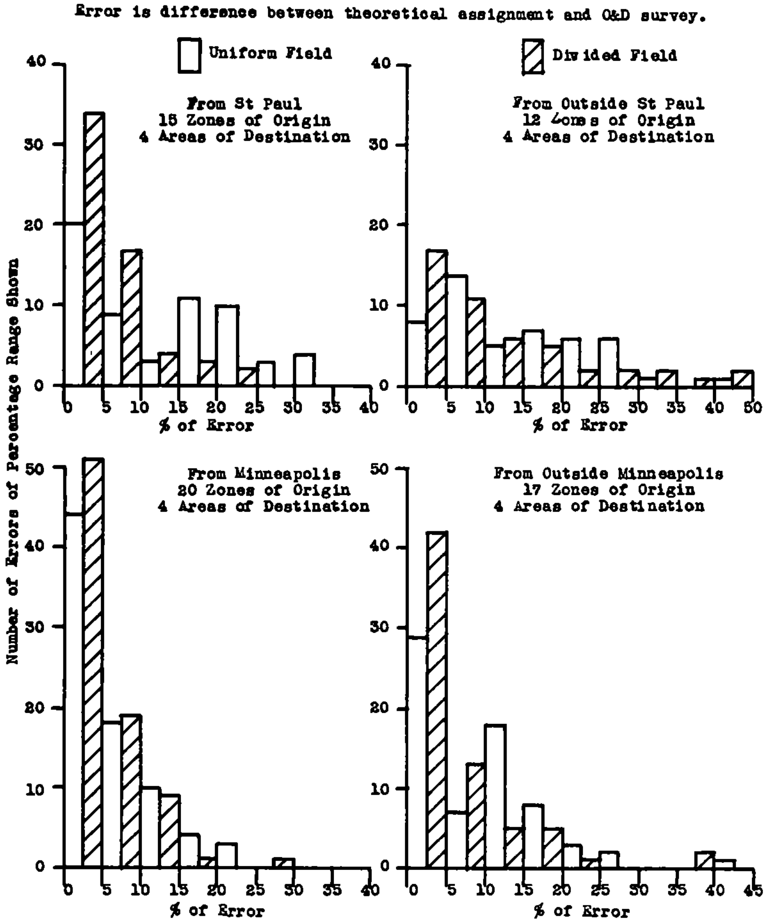
Living Area	Zone	Total Jobs in Zone	Jobs Held by Workers (%)		
				By Theory	
			By O-D Survey	Uniform Field	Divided Field
Minneapolis (continued)	27	1,728	1.2	17.8	0.0
	28	1,420	4.2	15.3	0.0
	29	527	0.0	20.4	0.0
	32	7,889	1.9	17.8	0.0
	33	1,590	6.0	21.1	0.0
	34	253	0.0	28.0	0.0
	35	199	10.0	26.6	0.0
	36	383	0.0	23.3	0.0
	40	63,035	63.7	54.4	67.5
	50	16,362	64.5	49.8	68.7
	51	5,188	67.0	54.8	68.8
	52	10,119	60.7	45.6	65.5
	53	4,892	71.1	53.0	69.5
	54	2,461	74.7	52.6	67.8
	55	5,650	60.4	48.5	62.5
	60	8,549	67.5	57.0	70.7
	61	4,879	68.6	53.6	70.5
	62	11,972	66.4	58.3	72.9
	63	5,221	71.1	52.8	71.5
	64	3,218	69.0	57.0	72.7
	65	938	59.5	45.3	68.5
	66	1,491	73.9	40.4	53.6
	70	10,027	56.2	57.0	68.7
	71	11,591	63.2	61.9	71.8
	72	3,531	65.9	59.7	69.5
	80	5,406	64.2	57.6	69.2
	81	14,194	65.7	53.8	65.0
	82	2,296	55.3	56.6	67.3
	83	1,140	54.1	52.9	63.8
	56	1,008	18.3	29.7	38.2
	57	2,698	8.3	28.4	38.8
	67	4,204	42.5	35.4	50.1
	68	2,388	43.8	34.6	57.5
	69	565	53.5	25.2	30.4
	73	5,054	36.3	26.8	31.0
	74	4,973	29.3	20.6	23.8
	75	6,891	28.4	32.2	37.5
	76	4,057	37.5	28.6	33.8
	77	8,474	27.2	22.7	26.0
	78	174	9.8	28.2	35.0
	79	1,288	12.6	22.5	26.7
	84	2,333	25.5	23.1	26.6
	85	2,171	13.5	28.1	34.4
	86	22,778	5.0	19.6	22.6
	87	1,839	25.8	29.5	34.6
	88	2,277	33.7	41.5	48.5
	89	5,813	38.3	25.2	42.9
Outside Minneapolis	00	37,585	2.3	15.2	0.0
	10	5,250	1.1	15.4	0.0
	11	6,996	3.7	14.8	0.0
	12	4,174	1.7	15.1	0.0
	14	6,126	3.9	14.3	0.0
	16	5,622	10.4	17.2	0.0

TABLE 4 (continued)

Living Area	Zone	Total Jobs in Zone	Jobs Held by Workers (%)		
				By Theory	
			By O-D Survey	Uniform Field	Divided Field
Outside Minneapolis (continued)	17	2,659	0.0	17.1	0.0
	18	25,053	8.6	17.7	0.0
	20	5,274	3.4	15.0	0.0
	21	1,013	2.1	13.9	0.0
	22	2,582	2.0	13.0	0.0
	23	5,172	1.2	13.8	0.0
	24	733	2.7	13.2	0.0
	25	2,477	0.7	15.5	0.0
	30	4,909	3.7	15.4	0.0
	31	668	0.0	15.3	0.0
	13	5,561	8.2	17.1	0.0
	15	2,172	14.0	20.9	0.0
	19	310	7.7	34.4	0.0
	26	1,574	3.0	24.7	0.0
	27	1,728	0.0	17.5	0.0
	28	1,420	0.0	14.2	0.0
	29	527	0.0	17.2	0.0
	32	7,889	1.3	16.8	0.0
	33	1,590	0.0	18.8	0.0
	34	253	0.0	23.6	0.0
	35	199	10.0	25.7	0.0
	36	383	5.8	23.7	0.0
	40	63,035	30.0	24.5	32.5
	50	16,362	21.1	21.6	31.3
	51	5,188	25.2	23.2	31.2
	52	10,119	23.9	22.6	34.5
	53	4,892	19.9	21.9	30.5
	54	2,461	20.4	23.7	32.2
	55	5,650	28.7	27.6	37.5
	60	8,549	25.5	22.0	29.5
	61	4,879	24.0	21.3	29.5
	62	11,972	28.4	20.6	27.1
	63	5,221	23.1	20.5	28.5
	64	3,218	23.6	20.9	27.3
	65	938	24.8	22.0	31.5
	66	1,491	16.1	34.2	46.4
	70	10,027	38.3	24.3	31.3
	71	11,591	31.8	22.8	28.2
	72	3,531	33.5	25.2	30.5
	80	5,406	33.8	23.9	30.8
	81	14,194	29.8	27.0	35.0
	82	2,296	42.1	26.0	32.7
	83	1,140	38.0	28.4	36.2
	56	1,008	66.3	44.5	61.8
	57	2,698	88.3	42.2	61.3
	67	4,204	37.5	34.4	49.9
	68	2,388	25.9	25.2	42.5
	69	565	42.8	53.6	69.6
	73	5,054	59.0	57.2	69.0
	74	4,973	79.4	61.8	76.2
	75	6,891	68.5	51.8	62.5
	76	4,057	61.0	54.1	66.2
	77	8,474	71.2	62.8	74.0

TABLE 4 (continued)

Living Area	Zone	Total Jobs in Zone	Jobs Held by Workers (%)		
			By O-D Survey	By Theory	
				Uniform Field	Divided Field
Outside Minneapolis (continued)	78	174	90.2	49.0	64.4
	79	1,288	87.4	58.3	73.3
	84	2,333	70.6	60.4	73.4
	85	2,171	82.0	51.4	65.6
	86	2,378	94 0	63.0	77.4
	87	1,341	72.9	54.0	65.4
	88	2,277	65.6	42.6	51.5
	89	5,813	59.7	46.4	57.1



Error is difference between theoretical assignment and O&D survey.

From St Paul
15 Zones of Origin
4 Areas of Destination

From Outside St Paul
12 Zones of Origin
4 Areas of Destination

From Minneapolis
20 Zones of Origin
4 Areas of Destination

From Outside Minneapolis
17 Zones of Origin
4 Areas of Destination

Figure 6. Distribution of percent of error from each zone of origin in area noted (based on Table 3). Error is movement according to O-D survey minus theoretical assignment.

movement across this line, as used in the divided field calculations, gives smaller percentages of error than does the assumption that the entire area is homogeneous. The writer can only speculate that there is some political or sociological reason for this phenomenon.

Figure 6 summarizes the data in Table 3 by showing the discrepancies between the percentage assignments as found by the O-D survey and the percentages predicted by the theory, the discrepancies being arranged in groups of 5 percentiles. This figure shows, for example, that 20 of the 60 movements from the individual zones of origin inside St. Paul to the four areas of destination are in error by 5 percent, or less, on the uniform field, and 34 of these same movements are in error by 5 percent, or less on the divided field. There are very few errors as great as 25 percent in these lumped movements, and the divided field gives appreciably better results than does the uniform field.

Figure 7 is similar to Figure 6, but summarizes the data in Table 4. Both Figures 6 and 7 show predictions of movement to and from areas outside the two major cities are more erratic than those within the cities.

Figure 8 summarizes Figures 6 and 7, and shows that well over 75 percent of all the composite movements between the individual zones and the four areas are in error by not more than 10 percent.

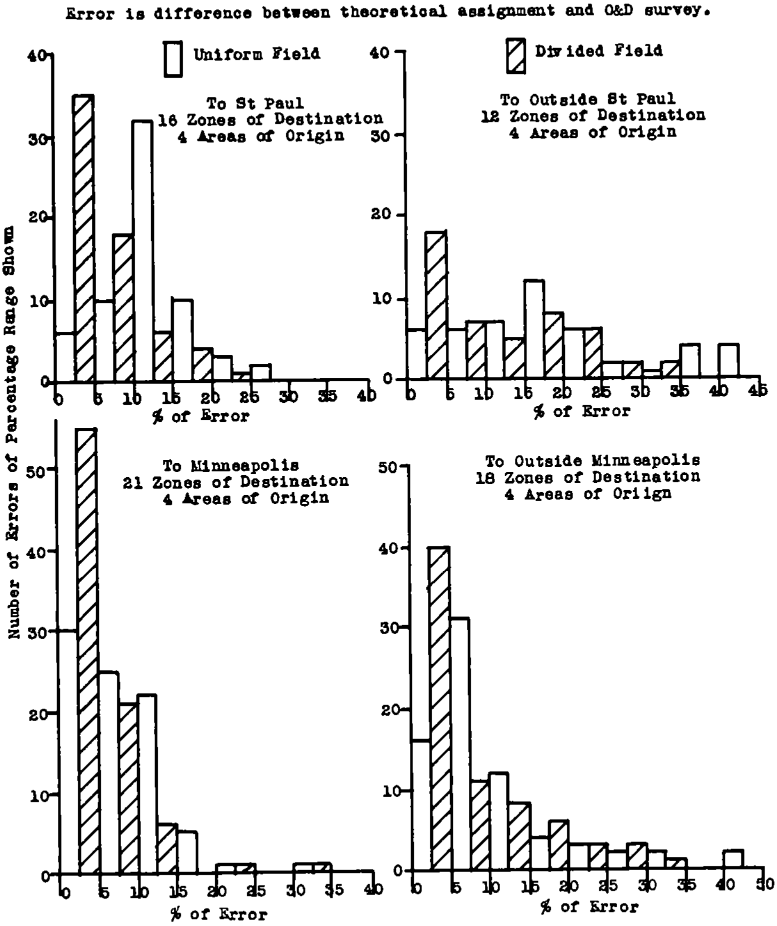


Figure 7 Distribution of percent of error in assignment from four areas of origin to each zone of destination in area noted (based on Table 4). Error is movement according to O-D survey minus theoretical assignment.

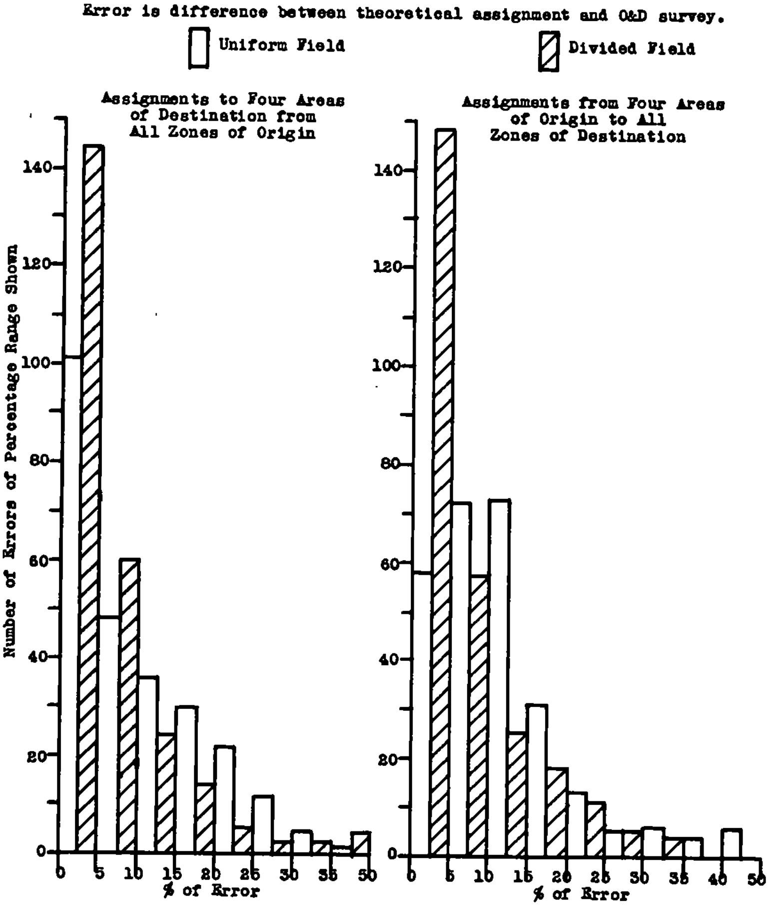


Figure 8. Distribution of percent of error. Error is movement according to O-D survey minus theoretical assignment.

Coefficients of correlation were run for the work trips originating in and destined for each zone on the assumption that the first theoretical movements, first on the uniform field and then on the divided field, were identical to the movements found by the O-D survey. The values of these coefficients are summarized in Figure 9 and given completely in Table 5. With only two exceptions (zones 57 and 69), the coefficients with values less than 0.60 occur in zones having fewer than 1,000 workers or jobs.

CONCLUSIONS

This paper has presented a comparison of the work-trip pattern found by the origin and destination survey of the Twin Cities Area Transportation Study and the pattern predicted by a field theory of movement as expressed in Eq. 1. So far as the writer knows, there are no discrepancies between the basic assumptions of the theory and the reality of the data for the Twin Cities, other than that of the apparently divided field. One cannot hope to predict theoretically patterns of movement with complete accuracy, for not even an origin and destination survey can achieve this goal, but it must be left to others to decide whether the theory has given a reasonable degree of precision in this case. Because the theory does not depend in any way on the existing pattern of movement, if it can be accepted as predicting the existing pattern, it can be used as the basis for predicting future patterns given the future distribution of places of residence and of employment.

TABLE 5

COEFFICIENTS OF CORRELATION FOR EACH ZONE, HYPOTHESIS–THEORETICAL PREDICTIONS EQUAL O-D SURVEY FINDINGS

Zone	No. of Workers Living in Zone	Coef of Correl. from Zones of Origin		No. of Jobs in Zone	Coef. of Correl. to Zones of Destination	
		Uniform	Divided		Uniform	Divided
00	--			37,585	0.67	0.95
10	6,715	0.92	0 97	5,253	0.86	0.91
11	12,833	0.96	0.99	6,996	0.94	0.97
12	10,358	0.89	0.98	4,174	0.93	0.95
13	7,898	0.78	0.89	5,561	0.88	0 89
14	11,462	0.89	0 93	6,126	0.75	0.80
15	5,926	0.80	0.81	2,172	0.97	0.97
16	11,096	0.79	0.82	5,622	0.87	0.90
17	8,126	0.87	0.86	2,659	0.86	0.92
18	6,412	0.93	0.90	25,058	0.83	0.90
19	1,732	0.58	0.46	310	0.47	0 75
20	1,739	0.94	0.96	5,274	0.82	0.91
21	3,913	0.95	0.98	1,013	0.83	0.84
22	3,876	0.94	0.99	2,584	0.68	0.77
23	4,404	0.94	0.96	5,182	0.85	0.92
24	3,354	0.89	0.96	733	0.87	0.88
25	6,833	0.92	0 98	2,478	0.84	0.86
26	3,211	0.69	0.82	1,574	0.44	0.60
27	6,114	0.74	0.92	1,728	0 98	0.99
28	4,232	0.83	0.94	1,420	0.96	0 96
29	2,247	0.76	0.92	527	0 60	0 68
30	3,662	0.83	0.85	4,909	0.86	0.91
31	2,617	0.95	0.97	668	0.44	0 46
32	5,399	0.97	0.98	7,889	0.96	0.95
33	3,468	0.79	0.83	1,590	0.56	0.54
34	820	0.75	0.83	253	0.86	0.20
35	695	0.62	0.59	199	0.47	0.56
36	840	0.57	0.67	383	0.47	0.49
40	---			63,059	0.93	0.95
50	3,940	0.90	0.90	16,362	0.84	0.86
51	5,453	0.92	0.92	5,189	0.85	0.87
52	2,326	0.93	0.93	10,119	0.78	0.78
53	5,596	0.93	0.95	4,892	0.88	0.88
54	4,774	0.90	0.93	2,461	0.82	0.83
55	4,907	0.92	0.93	5,650	0.91	0.89
56	2,685	0.78	0.83	1,008	0.85	0.84
57	5,561	0.51	0.58	2,698	0.73	0.73
60	5,543	0.96	0.95	8,549	0.83	0.87
61	3,955	0.94	0 95	4,839	0.74	0.81
62	11,276	0.97	0.96	11,973	0.87	0.93
63	6,519	0.93	0 95	5,221	0.90	0.95
64	11,357	0.93	0.97	3,218	0.89	0.92
65	3,462	0.86	0.95	938	0.50	0.53
66	10,266	0.83	0.95	1,491	0.76	0.80
67	3,385	0.87	0.87	4,204	0.85	0.83
68	---			2,388	0.68	0.64
69	2,914	0.58	0.63	586	0.57	0.59
70	8,335	0.97	0 97	9,985	0.82	0 86
71	18,907	0.97	0.95	11,591	0.82	0.85
72	14,663	0.93	0.97	3,531	0.90	0.91

TABLE 5 (continued)

Zone	No. of Workers Living in Zone	Coef. of Correl. from Zones of Origin		No. of Jobs in Zone	Coef. of Correl. to Zones of Destination	
		Uniform	Divided		Uniform	Divided
73	12,960	0.90	0.94	5,054	0.94	0.95
74	7,712	0.90	0.94	4,971	0.94	0.94
75	10,422	0.96	0.98	6,891	0.94	0.95
76	6,627	0.88	0.92	4,057	0.81	0.83
77	7,629	0.98	0 99	8,474	0.98	0.98
78	554	0.38	0.41	174	0.23	0.25
79	3,430	0.72	0 79	1,288	0 84	0.84
80	10,641	0.98	0.98	5,406	0.84	0.87
81	6,467	0.99	0 99	14,193	0.90	0.92
82	8,563	0.96	0.98	2,296	0.77	0.78
83	5,158	0.92	0.95	1,132	0.77	0.78
84	7,415	0.88	0.91	2,322	0.98	0.98
85	6,305	0.80	0.85	2,171	0.82	0.80
86	5,167	0.84	0 86	2,378	0.98	0.98
87	4,641	0.91	0.95	1,839	0.88	0.88
88	5,913	0.92	0 93	2,277	0.89	0.89
89	5,198	0.95	0.97	5,813	0.81	0.83

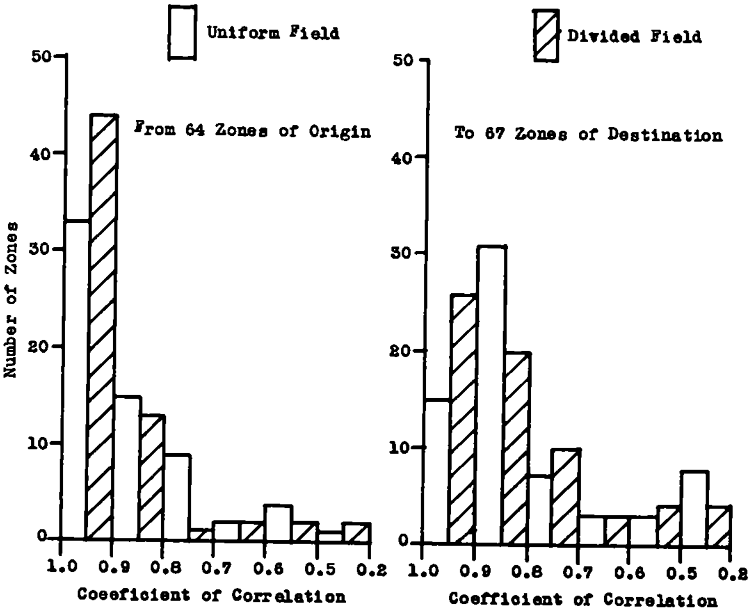


Figure 9. Distribution of coefficients of correlation.

ACKNOWLEDGMENTS

The writer wishes to thank the administration of the Twin Cities Area Transportation Study for its willingness to test his theory. In particular, he wishes to thank Leonard Wroblewski, formerly a statistician on the TCATS staff for his interest and work on this project.

REFERENCES

1. Howe, R.T., "A Theoretical Prediction of Work Trip Patterns." HRB Bull. 253, 156-165 (1960).
2. Howe, R.T., "A Field Theory of Land Use and the Movement of People." Ph.D. thesis, Purdue University (1959).

Determination of O-D Zones By Means of Land-Use Data

L.W. KERR, New York State Department of Public Works, Albany, New York

• LAND USE is the most important single factor in establishing zones for origin and destination surveys. It is essential that the demarcation of zones be undertaken only after careful study of land-use factors, because haphazard, random, or arbitrary selection of zones without consideration of land use will undoubtedly lead to difficulties in analysis and interpretation of data. Indeed, it may sometimes happen that unreflective selection of zones for O-D surveys will prohibit any significance in the survey results.

Only when O-D zones reflect adequate land-use analysis can traffic generated within those zones be measured accurately. When O-D surveys are thus rationally based, they will best show highway needs. Because the several classes of land use produce different levels of traffic generation, it is apparent that separate O-D zones in a survey should account for either one land use or a combination of land uses with similar traffic-generating capacity.

As a corollary to this point, the central business district (CBD) should consititute a single zone. If the CBD is large enough, however, a subdivision of the area may be warranted. In this case, only the CBD should be included within those zones comprising the subdivision. Multiple zones employed to show a large CBD should not be used to include peripheral areas surrounding the CBD.

Inasmuch as the analysis and interpretation of O-D zone data includes spatial considerations, among others, the physical location of the center of traffic generation in any given zone must be known.

It is necessary, therefore, to be aware of the kinds of land use in the zones and the distribution of those uses within the zone. If adequate land-use study has been made in establishing O-D zones, the investigator can determine the center of traffic generation. Without such a study, the investigator is forced to use the physical or geometric centers of the O-D zones in plotting traffic desire lines. In such cases, improper conclusions may be made as to the location of needed highway corridors. It should be acknowledged, however, that in those zones where land use is homogeneous and uniformly distributed, the geometrical center may properly be taken as coincident with the traffic generation.

MAJOR CONSIDERATIONS IN ESTABLISHING O-D ZONES

The first major consideration in establishing O-D zones is to have the land uses of similar traffic-generating capacities within a given O-D zone. The ideal situation is to have O-D zones contain but a single, homogeneous land use. This is not always possible if a multiplicity of small decrete O-D zones is to be avoided. For example, it is frequently desirable in predominately residential areas to establish zones that contain, in addition to substantial residential land use, islands of commercial land use represented by neighborhood shops and service centers.

The similarity of traffic-generating capacities of various land uses is especially important in the delineation of major commercial and industrial zones. Although refinements within commercial and industrial land-use categories are possible, and indeed desirable where the scales of traffic and land use are large, it is not usually necessary to go into much detail in defining land uses as long as their traffic-generating capacities are known to be similar.

Care must be taken in the evaluation of land-use data to determine whether major streets should be used as zone dividers. There are cases where such streets can be used legitimately; there are also cases where they should not be used. Arbitrary use of major streets as zone dividers can result in inappropriate application of survey data in the representation of the true traffic desires. This is especially true in drawn-out areas of similar land use such as long strip or shoestring development of industrial or commercial land use. When the land uses on opposite sides of the street are similar in traffic generation, the use of the street as a divider represents a major error.

A major street properly may be used as a zone divider if the areal extent of the similar land uses is great enough in a direction perpendicular to the major street to merit consideration of subdividing the area into two or more comparable zones. A major street also may be used as a zone divider if there are dissimilar land uses or traffic-generating capacities on opposite sides of the street, or where that street acts as a barrier to the development of similar land uses on opposite sides of the street.

Care should also be taken to avoid splitting a block with a zone line. Block splitting should be done only when there is some compelling reason. One of the most important reasons for so doing is to maintain the predominance of a particular land use within a zone. The best illustration of such a case is the shoestring commercial development. In such circumstances, usually it will be noted that both sides of a street are in commercial land use, but that such use does not always extend the full depth to the next parallel street. Commercial land use may be back to back with residential land use down the centerline of a block. To insure accuracy in an O-D survey in such conditions, it is desirable to create ribbon-like O-D zones along that street to separate the commercial shoestring from surrounding areas in other land uses. The split block technique will more accurately show the effects of both the commercial and the industrial land uses.

Another major consideration in establishing O-D zones is the coordination of those zones with the U.S. Census tracts. Census reports are major sources of information concerning population, housing, and other economic factors. If these data are to be used effectively in an O-D survey, it becomes necessary to coordinate the various units of areal distribution; O-D zones (as a unit or as a combination of units) should coincide with the census tracts. The importance of such coordination increases in the more complex industrial zones and in the CBD. If O-D results are to be correlated with other sources that may use census tracts as their grid, the need for conformity of O-D zones with census tracts becomes critical.

These principles of similarity in traffic-generating characteristics in O-D zones, and of coordination of such zones with census tracts, represent ideal conditions for establishing O-D zones. A certain amount of compromise however, will be necessary in practice. Value judgments, enhanced by a working knowledge of land use, will have to be used in establishing practical and workable units for survey purposes.

FIELD WORK AND PLANNING

As soon as it is determined that an O-D survey is to be undertaken, the preceding principles should be implemented systematically by (a) office planning, first stage, (b) field work, and (c) office planning, second stage.

First stage office planning should consist of the compilation of primary and secondary source material. The availability and usefulness of maps, aerial photographs, and census data should be ascertained, as well as whether previous studies of the area, particularly those involving land use mapping, have been made available. These data should be analyzed for validity, completeness, currentness of data, and usefulness to the project at hand. If the area has been subdivided into census tracts, maps of those tracts should be obtained.

Field work should then be undertaken to implement data gathered in the first stage, to check those data for validity and completeness and "fill-in" the blank areas. The first step would be the consultation with area officials at all levels of government to enlist their cooperation and their data. Regional, county, town and village planning and zoning officials can be important sources at this stage. Federal officials should be contacted, such as those connected with the Housing and Home Finance Agency (HHFA) which through the 701 Program participates in the preparation of land use maps as one element of master plans.

If the study is to be multipurposed (i.e., for both existing and future traffic desires), information should be obtained as to which urban renewal, suburban development, private housing, industrial and commercial projects have reasonable chances of fruition, and as to what their probable effects on traffic generation will be.

Reconnaissance field survey will be used to resolve discrepancies in data, their incompleteness, their validity, and their currency. Because of the nature of the material to be examined, this survey should be undertaken by a geographer. A properly planned reconnaissance of land use in an area would not provide full detail; its results, however, could be incorporated into a full study at a later date. Such reconnaissance would facilitate planning a complete survey for (a) analysis of traffic desires, (b) highway inadequacy studies, and (c) expansion factors used in predicting future traffic desires.

Second stage office planning would consist of the compilation of data gathered previously and presented cartographically in accordance with the principles defined in the first part of this paper. Such presentation would provide the basis for the following:

1. The establishment of O-D zone systems so as to provide more accurate and detailed information consistent with the detailed requirements of the O-D survey. The CBD limits of the subject area and the logical grouping of industrial and commercial land uses within homogeneous zones will also be facilitated by such a presentation.
2. Planning future and more comprehensive land-use studies when required.

DEFINITION OF THE CBD

So that a block be included in a CBD, it is necessary that a minimum of 70 to 75 percent of the floor space within the block be devoted to the urban land uses listed in the next paragraph as belonging in the CBD. Although a given block may not include all these functions, it should have a core of commercial A land use. In some cases, such as a block of public and quasi-public land use surrounded by other blocks in the CBD, a block without commercial A land use may be taken to be a part of the district. In making the judgment as to whether a block is part of the CBD, it should be borne in mind that the CBD bases much of its attraction on the exclusiveness of the specialized goods and services offered there. The CBD is not only a shopping place but also a very important employment center.

A number of land uses may be included in the CBD:

1. Commercial A:—Retail outlets and service centers, including their parking lots.
2. Commercial B:—Wholesale outlets and warehouses. A block devoted to these purposes may be left out of the CBD if not contiguous to the remainder of the CBD. If it is on the outskirts of the CBD, it should probably be left out of the CBD—a value judgment will have to be made in each individual case.
3. Office:—Business offices of all types, including banking establishments.
4. Professional:—Establishments of lawyers, doctors, dentists, engineers, and other professional people.
5. Public and quasi-public: —Buildings utilized by all levels of government and such quasi-public institutions as churches, and civic and fraternal clubs. Another case for value judgment—if the block is an intregal part of the CBD, include it in that area.
6. Recreational:—Facilities, such as theatres, bowling alleys, and skating rinks, offering recreation to the public.
7. Transportation:—In relation to the CBD, this land use is important only when considering the transportation terminal facilities.

In line with these points, reference is made to the definition of the CBD made by the U.S. Bureau of the Census in its "Census Tract Report," 1958: "The CBD may be generally described as an area of very high land valuation, an area characterized by high concentration of theatres, hotels and service businesses, and an area of high traffic flow. Wholesale business, so far as possible, should be generally excluded."

Use of Pre-Interview Trip Cards in Developing a Traffic Model for the Hamilton Area Transportation Study

WALTER KUDLICK and EWEN S. FISHER, respectively,
Traffic and Planning Engineer and Assistant Traffic Engineer, C. C. Parker & Parsons, Brinckerhoff Ltd., Hamilton, Ontario

A traffic model analysis of origin-destination patterns is being made as part of a comprehensive transportation study for the City of Hamilton, Ontario. This paper describes the use of a small-scale home interview survey in the development of the model and relates the experiences encountered in the use of pre-interview trip cards in conducting the home interviews.

It was found that 59 percent of the persons making trips used the cards and that they accounted for 61 percent of the total trips. The average number of trips reported by card users was 3.4, whereas non-card users made an average of 3.1 trips. This difference was statistically significant at the 1 percent level using the t-test, and the Wilcoxon test indicated that this difference was distributed throughout the areas interviewed.

The authors conclude that the use of pre-interview trip cards in the Hamilton Area resulted in the reporting of more trips and that these trips were reported more completely and more accurately than would have been likely without the use of cards. It was also concluded that the limited home interview survey constitutes such a considerable source of local data that it should be considered an indispensable part of the development of a traffic model.

• EARLY IN 1960 a technical coordinating committee was formed for a comprehensive transportation study for the City of Hamilton, Ontario. This committee has as its chairman the director of traffic, City of Hamilton, and its members consist of representatives from the Department of Highways of the Province of Ontario, the city engineer, the superintendent of operations of the transit company, and the planning directors for the several interested areas. Subsequently, the consulting firm of C. C. Parker & Parsons, Brinckerhoff Limited was employed, first, to prepare a report on the scope and procedures of the comprehensive study and, later, to assist in carrying out the study.

The Hamilton metropolitan area is located at the head of Lake Ontario, which makes it of strategic importance as a highway and rail transportation center in the Golden Horseshoe region extending from Toronto to Niagara Falls and Buffalo. With a large protected harbor on Lake Ontario and the St. Lawrence Seaway, Hamilton is an established Great Lakes port and a fast-growing ocean port. The city is the largest steel-producing center in Canada, and attendant manufacturing is extensive, varied, and rapidly expanding. The population of the region, now about 350,000, is expected to reach about 530,000 in 1985. Present traffic volumes in the area are expected to increase four-fold by 1982.

During the scope and procedures study, it was decided that a gravity model analysis of both present and future traffic patterns would form a significant portion of the comprehensive study. It was also decided that the analysis of present patterns should be based on, among other data, the results of a small-scale home interview survey. Subsequently, two papers presented at the HRB 1961 Annual Meeting were read with great interest: "Developing a Traffic Model With a Small Sample" by Davidson and "The Use of Pre-Interview Cards in Pittsburgh Research Project" by Sullivan and Pyers.

This present paper is a report on the application and extension of the findings presented in these two papers. It is hoped that it will be of interest to others seeking to develop traffic models or considering pre-interview contact and the use of trip cards.

SELECTION OF INTERVIEWEES

Once it was decided to incorporate a limited home interview program in the development of the traffic model, two further questions had to be resolved: how many interviews would be required and which homes should be interviewed. The paper by Davidson which was cited earlier states that a total sample of 1,000 families selected from the 825,000 families in the Boston area was sufficient to obtain an error of estimate of total trip production of within plus or minus 10 percent. An independent computation made by the Electronic Section of the Department of Highways, Ontario, demonstrated that in sampling for proportions a total sample of 900 interviews would be sufficient to provide relative certainty at the 99.7 percent confidence level (three standard deviations) if the total population is about 100,000. A copy of this computation is attached as Appendix A. Consequently, it was decided to select 1,200 dwelling units for interviewing in expectation that finding a normal rate of refusals and vacancies would still leave the desired number of interviews.

The choice then had to be made whether these 1,200 interviews should be scattered throughout the city at random or whether they should be clustered in specific regions of the city. Each alternative has its advantages and disadvantages. It was felt that selecting one home in every 70 or 75 probably would provide the best data on trip length distribution because the sample would be truly random and spread throughout the entire city. The analysis of trip production characteristics, however, requires that there be, for example, a range of automobile ownership per family. A satisfactory range of ownership may not result from a scattered sample but is almost sure to occur if interviews are made in selected areas whose characteristics are known.

Perhaps more importantly, a one-in-ten interview ratio would produce data for a particular zone comparable to the data obtained in a full-scale home interview survey. Thus it could also be used at a later stage to check trip distribution for that zone as predicted by the traffic model. It was decided ultimately to follow the cluster sampling approach, using a stratified random sample.

The sample was considered random because each tenth family within a designated zone was selected from the city assessor's records without bias. The sample was considered stratified because the zones designated for interviewing were selected in proportion to their occurrence in the total population. This was done by first dividing the city into seven traffic districts based on either land-use divisions or areas bounded by topographic barriers. The total 1,200 interviews were then distributed among the seven districts in proportion to their populations. Finally, the interviews in each district were assigned to selected zones within the district:

1. Representative of the distances from the CBD and the major industrial area.
2. Representative of the economic level or levels of the resident population of the district.
3. Representative of the population distribution within the district itself.

This procedure resulted in the selection of 17 zones and a slightly less than 10 percent sample interview was carried out in each zone. During the analysis phase, it was found desirable to combine any zone in which fewer than 30 families were interviewed with a similar zone. This was done wherever possible to provide greater stability. The characteristics of the resulting twelve areas are given in Table 1.

METHOD

The interviewing staff was made up almost equally of university students on summer vacation and women who recently had completed assignments as census takers. A

TABLE 1

CHARACTERISTICS OF INTERVIEW AREAS

Area	Total No. of Families	No. of Families Interviewed	Autos Housed per Family	Economic Level	Distance to CBD (mi)	Distance to Center of Major Industry (mi)
1	320	30	0.50	Low	0.0	3.2
2	735	64	0.70	Low	3.2	1.5
3	1,389	127	0.74	Low	1.3	1.9
4	1,084	99	0.81	Low	0.9	4.0
5	679	55	0.84	Medium	0.9	4.0
6	1,075	99	0.87	Medium	3.1	6.4
7	927	81	0.89	Medium	1.9	1.7
8	812	77	0.92	Medium	5.3	2.4
9	1,316	124	0.96	Medium	1.9	4.3
10	888	88	1.03	High	3.2	3.0
11	1,064	104	1.03	Medium	4.5	3.6
12	973	94	1.11	High	2.5	5.7
Total	11,262	1,042	0.89	--	2.5	3.4

number of the permanent study staff also served as part-time interviewers when required as translators or to check refusals. On being hired each interviewer was given about three days of instruction and practice.

One editor was assigned to every three interviewers, on the average, and a survey chief was in over-all charge of the interviewing. Almost all verifications and inquires concerning omitted information were made by telephone.

All samples were selected and recorded before the start of the interviewing, which began in late July and continued until early September. Interviews generally were made between 10 AM and 8 PM, at the discretion of the interviewer, Mondays through Fridays. Each interviewer initially was assigned eight sets of trip cards to deliver each day and told to pick up eight sets of completed cards each day. It was stressed, however, that accuracy and completeness were more important than quantity. The average interviewer was dropping off and picking up somewhere between six and seven sets of cards a day by the end of the survey.

Pre-Interview Contact

The transportation study was given a good amount of publicity in the newspaper and on the local television and radio stations immediately before the start of the home interviewing. About one week before the household was scheduled to be visited, a letter was sent over the Mayor's signature telling of the interviewer's impending visit and asking for cooperation.

The interview began with the interviewer's obtaining the data required for the dwelling unit summary form. This form was printed on the outside of a 9- by 12-in. manila envelope, and thereafter all trip cards and other material pertaining to the household were kept inside this envelope. A copy of this form is given in Appendix B. The interviewer then distributed a trip card and a letter of instruction for completing the card to every member of the household over five years of age. Both of these forms are almost identical to those used in the Pittsburgh study and are shown in Appendix B. The interviewer then spent about fifteen minutes explaining how the cards were to be completed. This was done primarily by referring to the examples contained in the instruction letter. The family was asked to keep a record of their travel on the day following the interviewer's visit (except if the interviewer called on a Friday, in which case Monday was designated as the travel day) and an appointment was made for the interviewer to come back after the travel day and collect all completed cards. If one or more of the adult members of the family were on vacation at the time the interviewer called, the interview was rescheduled to a day when all members would be back to their normal travel patterns.

If no one was at home at the time of the first call, the interviewers were instructed to return at least twice more at different times of day. If no one was found at home after repeated visits or if the persons at home refused to cooperate or if there was a language difficulty, the interview was reassigned to a permanent member of the study staff. These members succeeded in interviewing all but a negligible percentage of the selected sample. Thus for almost all households, the trip cards and letters of instructions were left personally with at least one adult member of the family.

Picking Up Completed Cards

On returning to the household after the travel day, the interviewer began by asking for the completed cards. If the cards had been filled out, the interviewer proceeded to check them for accuracy and completeness. If they had not been filled out, he tried personally to interview the person who made the trips. In many cases, this involved making an appointment to come back a third time to interview members of the family not at home when the second visit to the household was made. When a personal interview was not possible for some reason, the information was usually obtainable from another member of the family. Trips recorded by the interviewer and not by the respondent were listed on a marked trip card.

The interviewers were given a set checking procedure for examining trip cards or trips obtained by interviewing. They were told first to try to make sure that all trips made the previous day were recorded. This was done by asking the type of trips a person normally could be expected to make. Thus, for example, an employed person who reported only one trip from home to work and one trip from work to home was asked. where he normally ate lunch and did he go out to a movie or to visit friends after work. The interviewer then made sure that all information was complete and had been recorded in accordance with the instructions on the back of the cards. After the interviewer had reviewed or filled out a trip card for each member of the household, all cards were placed inside the manila envelope and turned in to the study office for editing and coding.

EVALUATION OF CARD USE

Rate of Card Use

The extent to which the trip record forms were used is given in Table 2. Of the 2,015 people making trips, 59.4 percent used the cards to record most of the details of their trips. This group accounted for 61.1 percent of the total number of trips reported.

In the twelve areas in which interviews were conducted, the rate of card use ranged from 42.9 to 79.3 percent, and only one area had a card usage of less than 50 percent. The extent to which the cards were used was slightly greater in the six areas where the rate of car ownership was higher. In the areas of lower car ownership, an average of 56.4 percent of the respondents made use of the cards as opposed to an average of 61.3 percent in the higher car-ownership areas.

Number of Trips Reported

In eight of the twelve interview areas given in Table 2, the average number of trips per person was greater for the card-user group than for the non-card users. Of the four areas where card users reported fewer trips, two are classified as low economic level, and two are medium economic level. It is felt that these results might be due to chance alone, the card users in these areas being people who made fewer trips, and to other factors unrelated to the use of trip cards. Considering all twelve areas, the card

TABLE 2

EXTENT OF CARD USE

Area	Persons Using Cards		Persons Not Using Cards		No. of Trips Reported		Trips per Person		Difference Between Users and Non-Users
	No.	Percent	No.	Percent	Users	Non-Users	Users	Non-Users	
1	12	42.9	16	57.1	51	42	4.25	2.63	+1.62
2	57	53.3	50	46.7	161	163	2.82	3.26	-0.44
3	103	50.5	101	49.5	300	299	2.91	2.96	-0.05
4	97	53.0	86	47.0	271	208	2.79	2.42	+0.37
5	69	79.3	18	20.7	241	48	3.49	2.67	+0.82
6	104	59.4	71	40.6	367	218	3.53	3.07	+0.46
7	99	59.6	67	40.4	340	197	3.43	2.94	+0.51
8	93	57.4	69	42.6	290	222	3.12	3.22	-0.10
9	190	69.9	82	30.1	660	231	3.47	2.82	+0.65
10	110	55.0	90	45.0	388	313	3.53	3.48	+0.05
11	143	63.0	84	37.0	481	299	3.36	3.56	-0.20
12	119	58.3	85	41.7	505	331	4.24	3.89	+0.35
Total	1,196	59.4	819	40.6	4,055	2,571	3.39	3.14	+0.25

users reported 0.25 more trips per person on the average. This increase in total trip reporting for the survey as a whole, an apparent increase of 300 trips, was felt to be the important factor, particularly because the increase applied in some measure to all economic levels and consequently did not introduce any bias to the study.

Two statistical tests were employed to determine if the increased reporting of trips by card users could be attributed to chance.

The Wilcoxon matched-pairs signed-ranks test was used to determine whether the trip frequency of the card users was generally greater than that of the non-card users for the range of socio-economic levels that the interview areas represented. The total difference in trip reporting was tested for significance through the use of the t-test. Both of these tests proved to be significant; the Wilcoxon test being significant at the 5 percent level and the t-test at the 1 percent level. The details of these analyses are given in Appendix C.

These results, of course, cannot be interpreted as complete proof that the pre-interview contact technique increases trip reporting, although they do constitute strong evidence that this is so. The results obtained in the Hamilton survey show that the card users reported a significantly greater number of trips than the non-card users. Possibly some of the difference observed can be attributed to a greater sense of civic responsibility on the part of the card users; these same people might have reported the greater number of trips had the usual form of interview been conducted. An ideal experimental design for testing the effectiveness of trip cards would be to conduct a series of regular interviews in parallel with the pre-interview contact technique and compare the difference thus obtained.

Accuracy of Information Obtained

A respondent who is an automobile driver and who makes four trips on the travel day is expected to furnish an interviewer with 48 items of information concerning his travel. This fact alone would seem to make a pre-interview contact mandatory. It appears unreasonable to expect a person to provide such extensive data without having been briefed thoroughly as to what is expected of him. It was found that many of those persons who did not use the cards had a good recollection of the details of their travel when questioned by the interviewer. This can be attributed, at least partially, to the fact that they had been personally given oral and/or written descriptions of the data required.

Those families that completed trip cards enabled the interviewer to function more as an editor than as a reporter. That is, the interviewer was able to devote his entire attention to making sure that no trips were overlooked and that all required details of the trips had been given. The opportunity to check data on the site when the memory of the travel day was still fresh in the respondent's mind was a considerable asset.

APPLICATION OF HOME INTERVIEW DATA

The basic intent from the start of the study was to approach the development of the traffic model without any fixed commitment regarding the form the model should take. The reported findings of many researchers, of course, were studied with interest, and some of these are listed in the references. It was decided, however, that an independent check or derivation of all relationships should be made wherever possible using Hamilton area data. Consequently, more than 60 tabulations were prepared from the home interviews and dwelling unit questionnaires. Analysis of these tabulations is being carried out with the primary objective of studying the following:

1. Trip production.
2. Distribution of trip lengths.
3. Trip attraction factors.
4. Other travel characteristics and patterns.

Analysis of Trip Production

Five different forms of equations were initially fitted to 32 sets of data to determine what relationships, if any, existed between such things as total trips per family and automobiles per family, and work trips per family and persons per family. This phase of the study is shown by Figure 1.

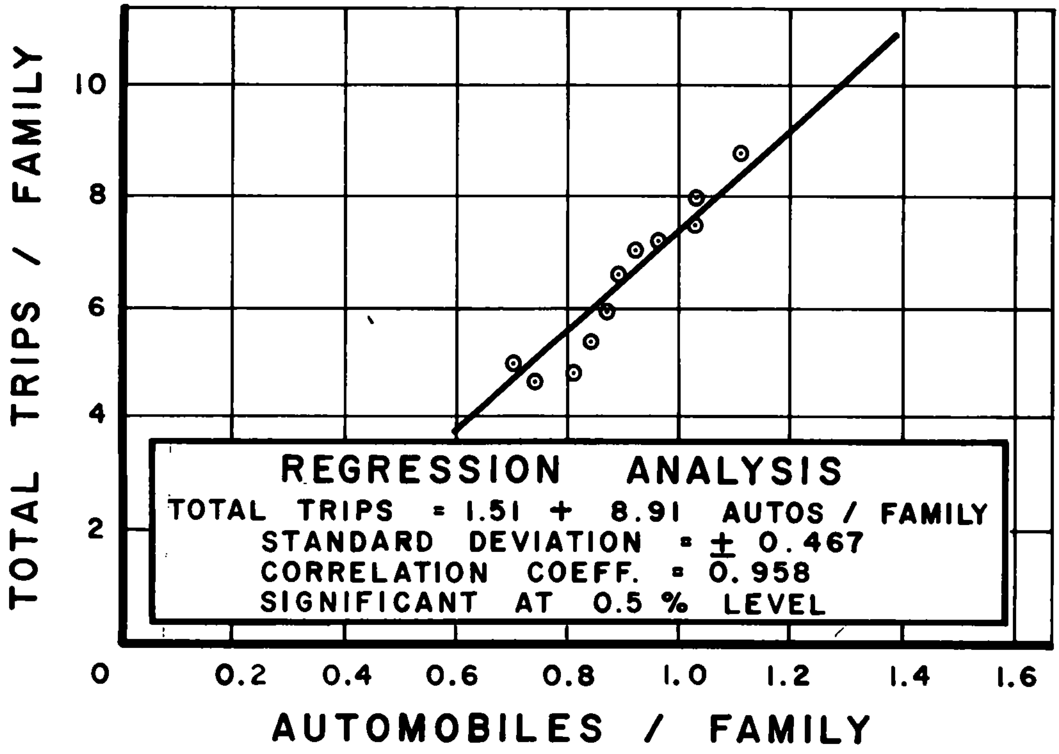


Figure 1. Analysis of trip production.

A review of the initial results, along with a study of the trip length distributions, suggested that a number of trip purposes be combined. This was done, and additional regression analyses were made on the grouped data. Among the many useful relationships developed were the following:

Work trips = 0.429 + 0.219 (persons/family).
Correlation coefficient = 0.829, standard deviation = ± 0.084.
Other home-based trips = -0.882 + 2.718 (autos/family).
Correlation coefficient = 0.931, standard deviation = ± 0.187.
Non-home-based trips = -1.042 + 2.218 (autos/family).
Correlation coefficient = 0.815, standard deviation = ± 0.276.
Auto driver trips = 2.917 + 7.000 (autos/family).
Correlation coefficient = 0.941, standard deviation = ± 0.440.
Auto passenger trips = -0.652 + 2.663 (autos/family).
Correlation coefficient = 0.807, standard deviation = ± 0.341.

Distribution of Trip Lengths

The distribution of trip lengths is being studied in conjunction with trip production equations to determine how many different trip purposes need to be included in the model. At the present time, it is felt that three purposes (work, other home-based, and non-home based) will be required to define adequately present and future travel in the Hamilton area. These trip length distributions are shown in Figure 2.

The distribution of trip lengths obtained by interviewing also will be used in computing trip frequency factors for each trip purpose. This will be done by setting the frequency factors equal to unity on the first pass through the model. The ratios between the trip length distributions thus obtained and the distributions measured in the survey being by definition the required trip frequency factors.

Analysis of Attraction Factors

The home interviews furnished a description of the type of land use at the destination of each trip. Nine categories of land use were coded initially, but these have been combined into major groupings, as required. To illustrate how attraction factors will be developed for each trip prupose, it is assumed that the model incoporates the three purposes and four land-use groupings shown in Figure 3. The attraction factor for other home-based trips, for example, will reflect the fact that 23 percent of these trips can be related to population and 52 percent can be associated with retail and service employment. An additional 20 percent can be related to retail and service employment indirectly using known relationships between that category of employment and employment in public and quasi-public functions. Thus, the attraction factor for non-home-based trips can be expressed simply as a function of population and retail and service employment.

Additional Travel Characteristics and Patterns

The home interviews, besides being a source of local data for the development of a traffic model, are furnishing an extensive variety of information concerning travel habits in the area. This information is proving to be quite valuable as basic planning data for a comprehensive transportation study. It includes such things as purpose distributions by various travel modes, variation of trip purposes and mode of travel by time of day, blocks walked at the origin and destination of transit and automobile trips, parking type and fees paid, vehicle occupancy, variation of trip purposes and mode of travel by day of the week. The distribution of reported trips by grouped trip purposes by time of day is shown in Figure 4 as an example of data that, although not being incorporated directly as part of the traffic model, are still extremely useful.

OTHER SOURCE MATERIAL FOR TRAFFIC MODEL

The home interviews are being supplemented as a source of data for the traffic model in two ways: (a) supporting traffic studies are being carried out as part of the

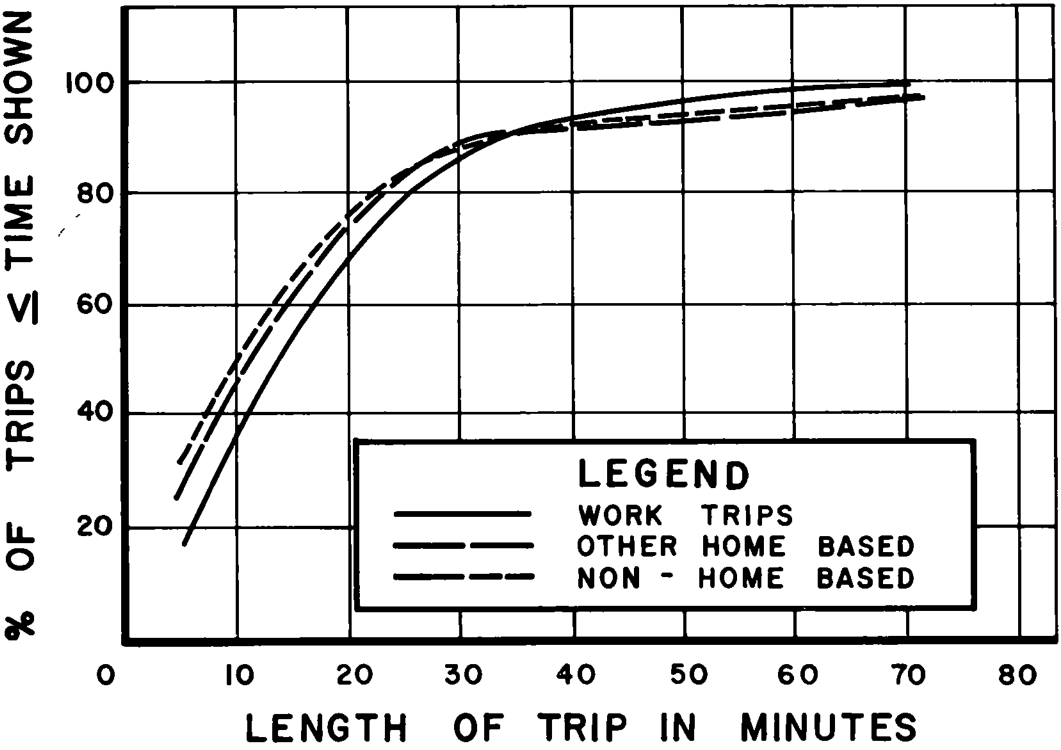


Figure 2. Trip length distribution.

present comprehensive transportation study, and (b) data obtained from previous studies made in the area are being utilized as much as possible. The supporting traffic studies currently underway include the following:

1. Roadside motorist interviews along an external cordon line and internal screen line.
2. A volume-counting program along arterial streets and highways and at internal cordon lines.
3. An operating speed study for most major streets and highways within the study area.
4. Interviewing of employers to determine employment by categories within each traffic zone.
5. Interviewing a selected number of truck owners regarding the operation of commercial vehicles.
6. Making a physical inventory of the existing street system.
7. Other studies designed to furnish data on land use, transit operation, accident history, and other items related to transportation planning.

Important data obtained from past studies include roadside motorist interviews and a postcard survey of transit riders made at a cordon around the core area of the central business district in 1956; roadside motorist interviews made on internal cordon and screenlines in 1956; land-use and population distribution estimates; an inventory of major highways in the area; and transit patronage and inventory of facilities and material developed from location studies for isolated routes or improvements.

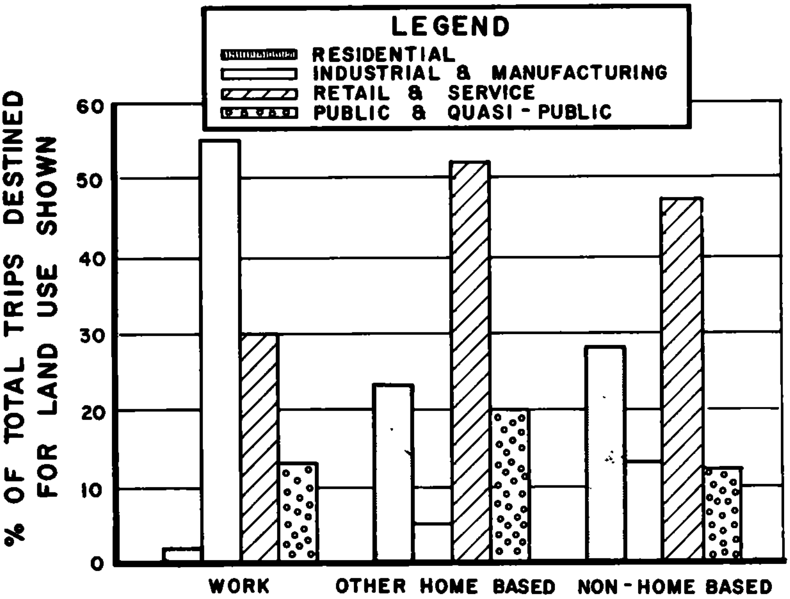


Figure 3. Analysis of attraction factors

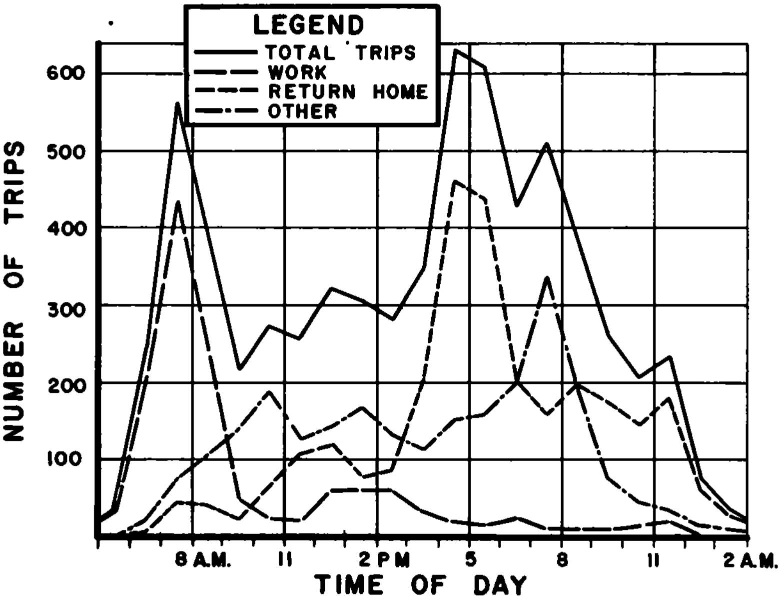


Figure 4. Travel characteristics.

CONCLUSIONS

The results obtained to date in the Hamilton Area Transportation Study have been consistent, for the most part, with what other studies have reported previously. What differences exist appear attributable to the characteristics of the study area. It is felt that this emphasizes the importance of having local data as a basis for such things as trip production equations, trip length distributions, and, computations of attraction factors.

A limited home interview survey of about 1,000 families selected on a stratified random sampling basis appears to be a most suitable source of the kind of local data required. Indeed, so much valuable information is obtainable from this kind of survey that the authors conclude that it should be considered an indispensable part of the development of a traffic model.

The pre-interview contact is considered a necessity for the type of home interview survey under discussion because of the large amount of data the respondents are asked to furnish. The experience with this technique was considered satisfactory by all concerned, and it is felt that it increased both the number of trips reported and the accuracy and completeness of this reporting.

ACKNOWLEDGMENTS

The authors would like to acknowledge their indebtedness to the many organizations and individuals who have provided assistance and information. Among these are the staff of the Electronic Section, Department of Highways, Ontario, who developed the necessary computer programs and who provided the computation of required sample size, Appendix A, and Alan M. Voorhees, who was consulted regarding the basic concept and approach.

Appendix A

COMPUTATION OF REQUIRED SAMPLE SIZE

Sampling for Proportions

In a simple random sample the sample size, n, is given by

$$n = \frac{t^2 \, pq/d^2}{1 + \frac{1}{N}\left(t^2 \frac{pq}{d^2} - 1\right)} \qquad (1)$$

in which

p = proportion in group of interest;

q = 1 - p;

N = population size;

t = abscissa of normal curve corresponding to confidence level; and

$\pm d$ = range of accuracy.

If

$$n_o = \frac{t^2 \, pq}{d^2} \qquad (2)$$

then,

$$n = \frac{n_o}{1 + \frac{n_o - 1}{N}} \quad \text{Approx.} = \frac{n_o}{1 + \frac{n_o}{N}} \quad \text{for large N} \qquad (3)$$

n_o is maximum when $p = q = \frac{1}{2}$.

This can easily be shown by calculus:

$$y = pq$$
$$= p(1 - p) = p - p^2$$
$$\frac{dy}{dp} = 1 - 2p = o$$

Therefore,

$$p = \frac{1}{2} = q$$

Using this maximum value, and letting N = 100,000 and range of accuracy = ± 5 percent, at the 95 percent confidence level, then t = 2

Therefore from Eq. 2

$$n_o = \frac{4 \times 0.5 \times 0.5}{0.0025} = 400$$

Therefore from Eq. 3

$$n = \frac{400}{1 + \frac{400}{100,000}} \doteq 400$$

Thus, a sample of 400 would be required.

For relative certainty at the 99.7 percent level (3 standard deviations)

$$n_o = \frac{9 \times 0.5 \times 0.5}{0.0025} = 900$$

and

$$n = \frac{900}{1 + \frac{900}{100,000}} \quad \text{Approx.} = \underline{\underline{900}}$$

It is apparent that for large N, $n_o = n$ approximately.

HAMILTON AREA TRANSPORTATION STUDY

DWELLING UNIT SUMMARY

Preceeding number ______ Card ☐

Interview address ______ Sample No. ☐☐☐

Succeeding number ______ Block No. ☐☐

Type of Dwelling Unit ______ ☐ Zone No. ☐☐☐

Day and Date of Travel ______

A. How many passenger cars are owned by persons living at this address? ______ ☐☐

B. How many persons live here ? ______ ☐☐

C. How many are 5 years of age or older ? ______ ☐☐

D. Household information:

Person No.	✓ if interviewed	Person Identification	Code		Occupation and Industry	Trips	
						Yes	No
01							
02							
03							
04							
05							
06							
07							
08							
09							
10							

E. Total number of trips reported at this address ______ ☐☐

1. Number of persons 5 years of age or older making trips ______ ☐☐
2. Number of persons 5 years of age or older making no trips ______ ☐☐
3. Number of persons 5 years of age or older with trips unknown ______ ☐

F. Comments and reason if complete information was not obtainable ______

______

G. Factor ______ ☐☐☐

C. C. Parker and Parsons, Brinckerhoff Limited

Administrative Record

Interviewer ______

CALLS

	Date	Time
(1)		
(2)		
(3)		
(4)		

REPORT SUBMITTED INCOMPLETE

Date ______

Reason ______

______

______

______

______

Supervisor's comment ______

______

______

______

Remarks ______

______

______

______

Report completed by ______

Date ______

Interviews checked by ______

Coded by ______

HAMILTON AREA TRANSPORTATION STUDY

TRIP RECORD FORM

ZONE__________ SAMPLE__________ PERSON____________________

SEE BACK FOR INSTRUCTIONS

BEGINNING OF TRIP (ORIGIN)	END OF TRIP (DESTINATION)	PURPOSE OF TRIP	ESTABLISHMENT AT DESTINATION	TIME OF		BLOCKS WALKED		MODE OF TRAVEL	AUTO DRIVERS ONLY		
				START	END	ORIGIN	DEST		PERSONS IN CAR	PARKING	
										TYPE	RATE

Trip Card Front

INSTRUCTIONS

A TRIP IS THE ONE-WAY MOVEMENT OF A PERSON BETWEEN TWO POINTS BY A SINGLE MODE OF TRAVEL IF YOU ARE EMPLOYED AS AN OPERATOR OF A VEHICLE (bus, taxi, truck driver) DO NOT INCLUDE TRIPS MADE WHILE ON DUTY

TRIP ORIGINS AND DESTINATIONS Record actual street address, for example 795 Main Street West, or record nearest intersection, for example Main Street West and Longwood Road Names of prominent buildings are satisfactory The word "home" is sufficient when the trip begins or ends at your place of residence.

PURPOSE OF TRIP· Describe why you made the trip, for example. to go to work, return home, buy a box of candy, catch bus, pay a bill, to eat lunch, go to doctor, pick up son

ESTABLISHMENT AT DESTINATION. Give a description of the type of establishment at the destination end of the trip, for example high school, grocery store department store, park, insurance office, bank, steel mill, fabricating plant, gas station, house or dwelling Note whether the store is a wholesale or retail store and the kind of office or plant

TIME OF START AND END Record to the nearest minute the time you begin and end a trip. INCLUDE THE TIME IT TAKES TO PARK CAR AND WALK TO YOUR ACTUAL DESTINATION.

BLOCKS WALKED Record the number of blocks walked at each end of the trip (such as home to bus or auto, at origin of trip, and from the location parked to your destination at the end of the trip)

MODE OF TRAVEL Use the abbreviation for one of the following classifications

Auto Driver(A Dr.)	Railroad Passenger(R R)	Taxi Passenger (Taxi)	Walked to Work(W.W.)
Auto Passenger(A Pas.)	Bus, Streetcar, Pass.(Bus)	Truck Passenger(Tr.Pass)	Truck Driver(Tr Dr.)

PERSONS IN CAR If you drove, give the total number of people in the car, including yourself.

PARKING TYPE Use the abbreviation for one of the following classifications·

Street (St)	Garage (Gar.)	Residential Property (Res)	Not parked (N.P.)
Lot	Service & Repair (Serv)	Cruised (Cr.)	

PARKING RATE· Use the abbreviation for one of the following classifications

Hour (Hr)	Day (D)	Month (Mo)	Meter (Met)	Free (F)

IF YOU HAVE DIFFICULTIES IN RECORDING A PARTICULAR TRIP OR SEQUENCE OF TRIPS, MAKE A NOTE ON THE FACE OF THE FORM DESCRIBING THE SITUATION. THE INTERVIEWER WILL ASSIST YOU IN PREPARING THE FORM WHEN HE RETURNS TO COLLECT THE TRIP INFORMATION.

LEAVE THIS FORM HOME THE DAY FOLLOWING THE 24 HOUR PERIOD DURING WHICH YOU RECORDED YOUR TRIPS.

Trip Card Back

HAMILTON CANADA

DEPARTMENT OF TRAFFIC

CITY HALL

Dear Householder:

As explained in the letter Mayor Jackson recently sent you, your household is one of a number selected from which to obtain badly needed travel information in connection with the Hamilton Area Transportation Study.

Each member of your family is being asked to record, on the attached forms, the trips which he or she makes on ______________________________. Our interviewer will return to your home on the following day to collect the information contained on these trip records. We realize that this is an inconvenience, but so is the traffic problem. It is only with your co-operation that your City and Provincial Governments can take action toward solving this difficult problem.

The requested information is completely confidential and will be used for statistical purposes only.

Thank you in advance for your contribution of time and information.

Yours very truly,

(W. E. Ewens)
Director.

HAMILTON AREA TRANSPORTATION STUDY

GENERAL INSTRUCTIONS

1. Each person in this household 5 years of age or older, including maids, roomers, and out-of-town guests, should keep a separate record of his or her trips.
2. Record all trips for a 24-hour period beginning 4:00 a.m. on ________________ .
3. Record no walking trips EXCEPT walking to or from work.
4. Identify each person by his or her relationship to the head of the household, such as wife, son, mother-in-law, roomer, etc.
5. PLEASE READ INSTRUCTIONS ON THE BACK OF THE TRIP RECORD FORM.

Example: Refer to Trip Record form and instructions on back.

Mr. Jones drove to the bus stop with his wife. After reaching the city by bus, he walked two blocks to his office. At noon he took a taxi to and from lunch. He was driven home by a friend. Mrs. Jones rode with her husband to the bus stop in order that she could have the car during the day, driving the car home from the bus stop. Later she took her 4-year old son to the barber shop, waited for him, then drove to her daughter's home. From her daughter's home she drove to the grocery store and then home, her son accompanying her on these trips. Neither Mr. or Mrs. Jones made any trips the rest of the day.

ZONE 0101 SAMPLE 008 PERSON MR JONES (HEAD) SEE BACK FOR INSTRUCTIONS

BEGINNING OF TRIP (ORIGIN)	END OF TRIP (DESTINATION)	PURPOSE OF TRIP	ESTABLISHMENT AT DESTINATION	TIME OF		BLOCKS WALKED		MODE OF TRAVEL	AUTO DRIVERS ONLY		
				START	END	ORIGIN	DEST		PERSONS IN CAR	PARKING	
										TYPE	RATE
HOME	WHITNEY AVE & MERICOURT RD	CATCH BUS	BUS STOP	7 51 A·M	7 58 A M	0	0	A DR	2	NP	
WHITNEY AVE & MERICOURT RD	795 MAIN ST WEST	GO TO WORK	ENGINEERS OFFICE	8·00 A M	8·20 A·M	0	3	BUS			
795 MAIN ST WEST	ROYAL CONNAUGHT HOTEL	LUNCH	HOTEL	12·05 PM	12 21 PM	0	0	TAXI			
ROYAL CONNAUGHT HOTEL	795 MAIN ST WEST	BACK TO WORK	ENGINEERS OFFICE	1 05 PM	1·23 PM	0	0	TAXI			
795 MAIN ST WEST	HOME	HOME FROM WORK	HOME	5·15 PM	5 36 PM	0	0	A PASS			

ZONE 0101 SAMPLE 008 PERSON MRS JONES (WIFE) SEE BACK FOR INSTRUCTIONS

BEGINNING OF TRIP (ORIGIN)	END OF TRIP (DESTINATION)	PURPOSE OF TRIP	ESTABLISHMENT AT DESTINATION	TIME OF		BLOCKS WALKED		MODE OF TRAVEL	AUTO DRIVERS ONLY		
				START	END	ORIGIN	DEST		PERSONS IN CAR	PARKING	
										TYPE	RATE
HOME	WHITNEY AVE & MERICOURT RD	WENT WITH HUSBAND TO BUS STOP	BUS STOP	7·51 A·M	7 58 A·M	0	0	A PASS			
WHITNEY AVE & MERICOURT RD	HOME	RETURN HOME	HOME	7·58 A·M	8 07 A M	0	0	A DR	1	RES	FREE
HOME	KING ST & STERLING ST	TAKE SON TO BARBER	BARBER SHOP	9 35 AM	9 40 A M	0	1/2	A DR	2	ST	FREE
KING ST & STERLING ST	861 MAIN ST EAST	VISIT DAUGHTER	RESIDENCE	10:10 AM	10 26 A·M	1/2	0	A DR	2	ST	FREE
861 MAIN ST EAST	UNIVERSITY PLAZA - DUNDAS	SHOP AT DOMINION	SUPERMARKET	11:40 A·M	12 01 PM	0	0	A DR	2	LOT	FREE
UNIV· PLAZA DUNDAS	HOME	RETURN HOME	HOME	12 31 PM	12 38 P M	0	0	A DR	2	RES	FREE

Appendix C

DETAILS OF WILCOXON AND t-TESTS

Wilcoxon Test

The Wilcoxon test considers both the direction and the relative magnitude of the differences between matched pairs. In this study, the card users and the non-card users in each area were considered to be a matched pair because of their similar socio-economic backgrounds. The hypothesis tested was that the average trips per person for the control group (the non-card users) was greater than or equal to that of the experimental group (the card users). The alternative was that the experimental group had the greater trip frequency. A one-tailed test was employed because the card users were expected to have the greater trip frequency.
Thus,

H: Σ positive ranks $\leq$ Σ negative ranks
A: Σ positive ranks $>$ Σ negative ranks

For N = 12 and T = 15.5, as given in Table 3, H may be rejected at the 5 percent level of significance. It is apparent that the trip frequency is generally greater for the card users for the variety of socio-economic levels that the interview areas represented.

t-Test

The difference in trip frequency between the card users and the non-card users was analyzed by the t-test to determine whether the difference in the means was significant. Because the frequency distributions for both groups were severely skewed, a logarithmic transformation was made to reduce the skewness. The resulting distributions were still slightly skewed but the error involved in assuming normality should not be critical because of the large sample sizes. Continuity of the dependent variable was also assumed for the same reason although it was discrete. A test for homogeneity of variance was conducted and permitted the use of a pooled estimate of the population variance at the 0.01 level of significance.

H: $\bar{X}_e \leq \bar{X}_c$

A: $\bar{X}_e > \bar{X}_c$

$t = 3.76$ $\quad$ $df = 2013$

TABLE 3

AVERAGE TRIPS PER PERSON FOR CARD USERS AND NON-CARD USERS

Area	Trips per Person		d	Rank of d	Rank with Less Frequent Sign
	Control	Experimental			
1	2.63	4.25	+1.62	12	
2	3.26	2.82	-0.44	- 7	-7
3	2.96	2 91	-0.05	- 1.5	-1.5
4	2.42	2.79	+0.37	6	
5	2.67	3.49	+0.82	11	
6	3.07	3.53	+0.46	8	
7	2.94	3.43	+0.51	9	
8	3.22	3.12	-0.10	- 3	-3
9	2.82	3.47	+0.65	10	
10	3 48	3 53	+0.05	1.5	
11	3.56	3.36	-0.20	- 4	-4
12	3.89	4.24	+0.35	5	
					T = 15.5

H may be rejected at the 1 percent level of significance.

It is apparent that the average trips per person is significantly greater for the card users.

REFERENCES

1. Voorhees, A.M., "Use of Mathematical Models in Estimating Travel." ASCE Jour. Highway Division (Dec. 1959).
2. Davidson, R.G., "Developing a Traffic Model with a Small Sample." HRB Bull. 297, 106-108 (1961).
3. Sullivan, S.W., and Pyers, C.E., "Results of Use of Pre-Interview Contacts in Pittsburgh." HRB Bull. 297, 42-51 (1961).
4. Wiant, R.H., "A Simplified Method for Forecasting Urban Traffic." HRB Bull. 297, 128-145 (1961).
5. Barnes, C.F., Jr., "Integrating Land Use and Traffic Forecasting." HRB Bull. 297, 1-13 (1961).
6. Furness, K.P., "The Use of a Gravity Model in the Estimation of Traffic." Traffic Section, Department of Highways, Ontario (Oct. 1961).
7. Curran, F.B., and Stegmaier, J.T., "Travel Patterns in 50 Cities." HRB Bull. 203, 99-130 (1958).
8. Voorhees, A.M, and Morris, R., "Estimating and Forecasting Travel for Baltimore by Use of a Mathematical Model." HRB Bull. 224, 105-114 (1959).
9. "Jour. Amer. Inst. of Planners." Special issue (May 1959).
10. Siegel, S., "Nonparametric Statistics for the Behavioral Sciences." McGraw-Hill (1956).
11. Edwards, A.T., "Experimental Design in Psychological Research." Rinehart (1960).
12. Cochran, W.G., "Sampling Techniques." Wiley (1953).

The Dataplotter—A Tool for Transportation Planning

GENE LETENDRE and GEORGE V. WICKSTROM, respectively,
Assistant Supervisor, Data Processing, and Transportation Division Director,
Penn-Jersey Transportation Study, Philadelphia, Pennsylvania

• THE ADVENT of computers has allowed, if not encouraged, the gathering and processing of data at ever finer levels of detail. However, the day when computer use reaches the ultimate in sophistication (that is, when after thorough digestion of much information, it will print a one-word message, "yes" or "no") has not yet arrived. Humans must still evaluate the computer's work and make judgments on its meaning. A major problem yet to be conquered is that of visual presentation of computer and even electronic accounting machine data summaries.

Credit for the initial recognition and at least a partial solution to this problem should be given to some unnamed sales manager. Long ago he gave up fumbling with cross-indexed lists and started sticking pins on maps. Later sales managers embellished this with colored pins and finally with flags. Now, when he wants to know who the salesman is in Des Moines, the sales manager looks at the name printed on the flag at Des Moines. How are sales doing there? The gold head on the pin tells him they're doing great—time to cut down on the territory and put in another salesman.

The advantages to such a system are obvious. How to apply these and other principles to the problems of transportation data reduction are not so obvious, but possibly much more useful. One available tool that can contribute to the solution of this problem is the dataplotter or the X-Y plotter. This machine can help and, in fact, is helping.

DETAILS OF DATAPLOTTER

The dataplotter (Fig. 1) is basically a machine for drafting straight-line segments between pairs of coordinates, or plotting points at single sets of coordinates X and Y. The machine also posts values of up to four digits at points located by coordinates.

Input to the machine being used by the Penn-Jersey Transportation Study (and manufactured by Electronics Associates, Inc., Long Branch, N.J.) is via punched cards; however, tape input machines are available at higher cost. Points for either the line-drawing or symbol-plotting mode are located by eight decimal digit numbers interpreted by the plotter as coordinates (four digits X, and four digits Y). The machine recognizes negative values and, therefore, the maximum range is 20,000 counts (plus or minus 9,999) for either X or Y.

The machine traces lines, or plots symbols, on a 30- by 30-in. sheet of paper at a rate of approximately 20 line-segments per minute to approximately 50 symbols or points per minute.

Scale variations range from a maximum of about 7 counts per inch (on the plotting surface) to over 5,000 counts per inch. Changes of scale are made by means of potentiometer adjustment on the console, and both the X and Y directions are independently variable. Another feature of the machine is that of off-board parallax. This feature allows offsetting of the coordinate system center (zero point) so that all parts of quadrants can be traced on the full 30- by 30-in. plotting surface. Parallax adjustments are made similarly to those of scale factor and are done independently for X and Y.

In operation, the machine must be set before a run for either the line-drawing or the symbol-plotting mode. For line tracing, a pen-and-ink cartridge is manually fitted to the servo-arm. Various cartridges are maintained with different colored inks.

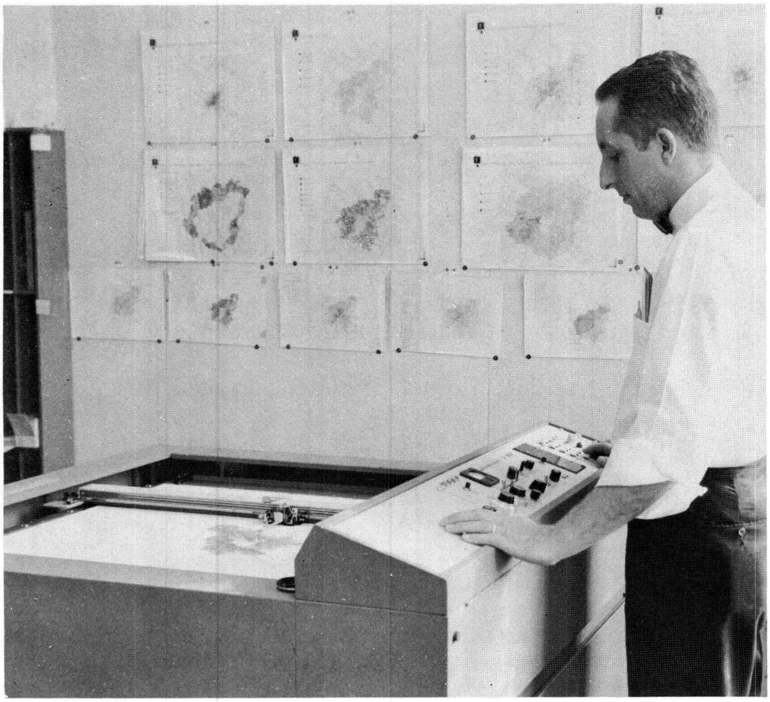


Figure 1. Dataplotter.

For symbol plotting, a symbol wheel is manually attached to the servo-arm. The symbol wheel has twelve characters, each automatically selectable by appropriate card coding. The twelve symbols are -, ., 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. The symbols may be plotted singly or in groups up to four by locating only the first symbol with a set of coordinates. Thus it is possible to indicate on the plotting surface a value of 1, 10, 100, or 1, 000 by locating only the first digit (one) by coordinates.

Input of data to the machine is by punched card which can be read serially or in parallel, depending on the type of card reader employed. For serial reading, the 024 keypunch machine is used. This machine reads the card column by column starting at column 1 and ending at column 80 and will selectively transmit some or all of the columns read to the plotter as operating codes, symbols, or coordinates, depending on the program card installed on the drum. For parallel reading, the 514 is used, and, depending on panel wiring, will transmit one field (one point or line terminal point) of information per card to the plotter.

Accuracy of the plotter is indicated by the manufacturer at 0.05 percent at full scale, plus or minus one bit of information for point plotting and 0.1 percent straight-line interpolation for lines up to 4 in. in length. The plotter will trace lines up to 15 in. in length at only slightly reduced accuracy, but it would be well to stay within the limit of approximately 15 in. where possible.

Application to Transportation Analysis

Because much of the data collected by the Penn-Jersey Study has been coded to grid coordinates, it has been possible to use the plotter for direct visual presentation of keypunched data. These applications have included use in contingency-checking data, dot map presentation, scattergrams, numerical presentation by symbol plotting, and drafting and presenting information about highway and transit networks.

Contingency Checks

The basic areal unit used by the study in the ¼-sq mi grid identified by three digits X and Y. Data coded to these units were then summarized to larger units such as traffic zones and districts or minor civil divisions. The plotter could then check the summarization of these units, and it was possible to determine miscodes or missing grids. Radical differences between adjacent grids are readily apparent on a visual basis.

Dot Map Presentation

The generation of vast amounts of socio-economic and trip data by large-scale transportation studies has defied rapid visual interpretation at a detailed level. Manual mapping techniques are limited to presenting highly summarized data. It has been found convenient to present this data at the grid level using the dataplotter. By stratifying the data summarized to grids into six groups, an effective color dot map can present information about population density, car ownership, trip density, etc. This can be increased in detail to include 10 or 100 strata or to the numeric value itself by changing to the symbol plotting mode or changing map scale. Examples of dot map presentations are shown in Figures 2 and 3.

A color dot map for the entire 1,200-sq mi study area can be completed in approximately two hours.

Scattergrams

An excellent application is the presentation of relationships between sets of data.

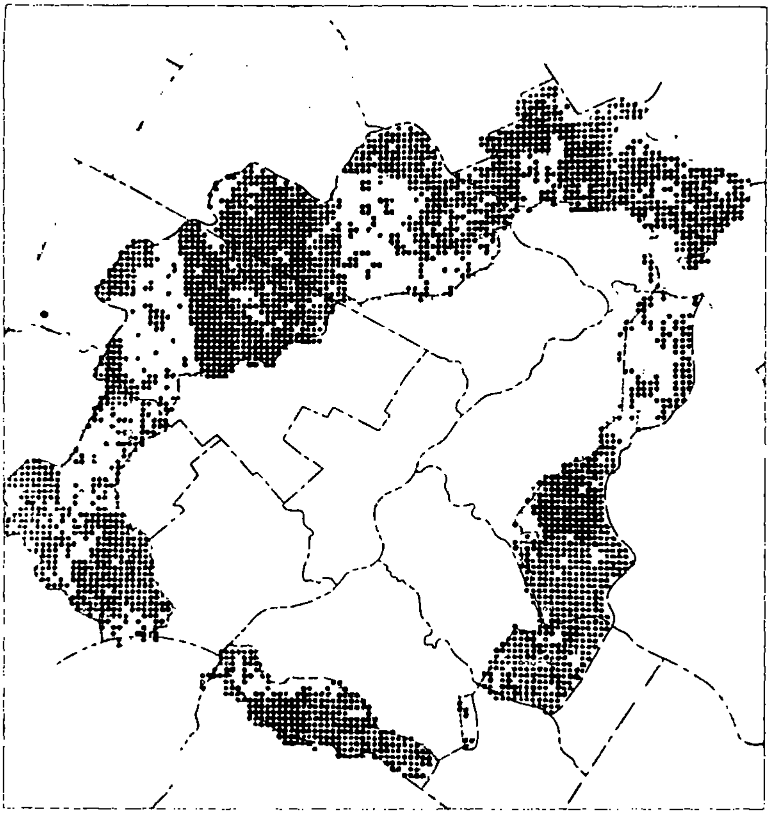


Figure 2. Character of land use outside cordon line by 1/4-sq mi grid.

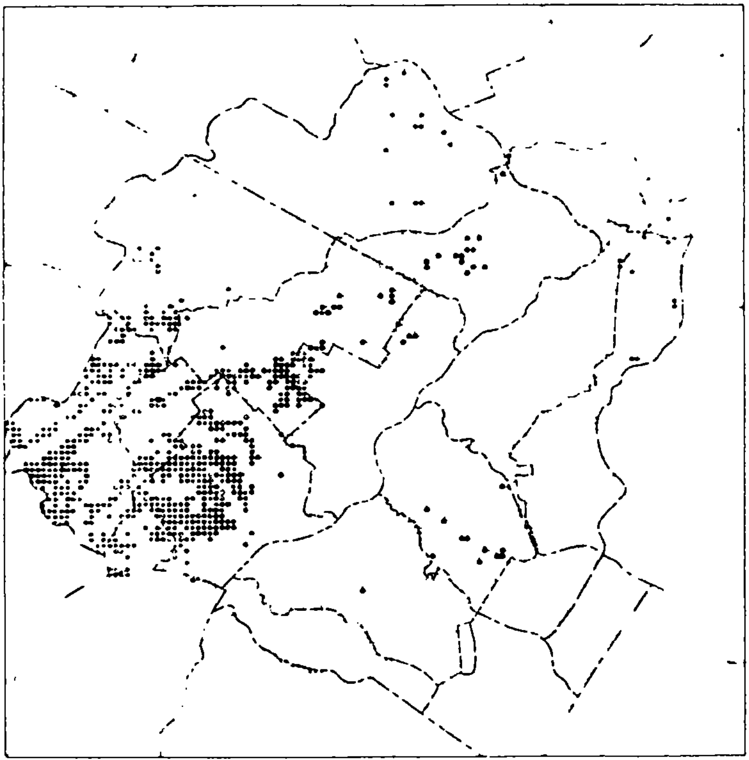


Figure 3. Slope map showing terrain character by 1/4-sq mi grid (part of Philadelphia not shown).

The plotter can produce scattergrams effectively and accurately using the point-plotting mode and data contained in two fields in a card. Scales can be varied to suit the data being related. The symbol plot can be used in conjunction so that individual points can be identified as well.

Line Plotting and Applications to Traffic Assignment

The line-plotting capabilities are put to use in checking and presenting data about highway and transit networks.

It has also been possible to check for contingencies in networks coded for computer traffic assignment. The plotter output has been used to check the keypunched network computer input data visually for missing links or incorrect identification of nodes and speeds.

Output of computer traffic assignments has also been presented. By stratifying the assigned volumes into ranges, an effective color map (similar to a flow map but the color changes representing volume ranges rather than width) of the assigned volumes can be drawn at the rate of 20 links per minute. Individual link volumes can be plotted at the midpoint of the links by subdividing the area and using the symbol printer at larger map scales. Other data about the links in a network (such as volume-capacity ratios) can be presented in this form. The minimum path "trees" traced by the computer for trip loading have also been plotted for analysis. Figure 4 shows a section of a highway network with line segments and coded speed values drawn and posted by the dataplotter.

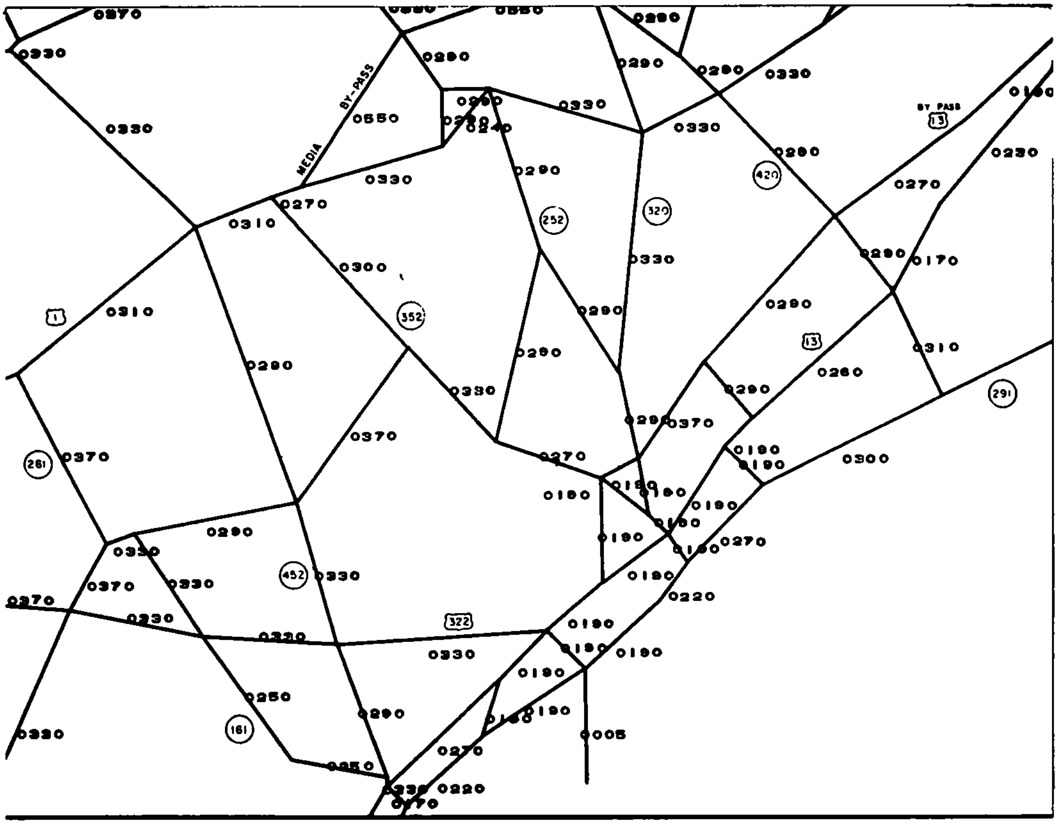


Figure 4. Example of network tracing and posting by dataplotter.

Other Applications

The presentation of desired lines of travel information has long plagued transportation planning agencies. The problem has always been to present the available data with clarity without sacrificing detail.

The first attempts were to connect each zonal pair with a straight line, varying the width of the line to represent the amount of travel between the zones. This consumed many man-hours of drafting time, and resulted in a picture approximating a blob of ink. The next attempt accumulated desire lines into broad bands termed "major desire lines." This cleaned up the map somewhat, but lost a great deal of detail and tended to show only major movements. Results also varied with the size and shape of the zones or districts considered.

The Detroit Area Transportation Study (DATS) used a contour line desire presentation, developed by the California Division of Highways. This method overcame some difficulties and introduced others. It was necessary to portray separate maps for desires in eight principal directions. Interpretation became somewhat difficult. The Chicago Area Transportation Study (CATS) then developed the cartagraphatron to present existing travel patterns in Chicago (1). Hand drafting was eliminated, and grid-to-grid movements could be presented. Trips could be rapidly stratified and studied by length, purpose, or other classification. This method has also been used by the Pittsburgh Area Transportation Study (PATS).

Figure 5 shows a technique recently developed at Penn-Jersey for the presentation of desire lines of travel via the dataplotter. The darker lines in the picture indicate higher travel demands and the lighter lines indicate lesser demand values. In practice, these lines are in color, ranging from light yellow through black, thus yielding higher resolution.

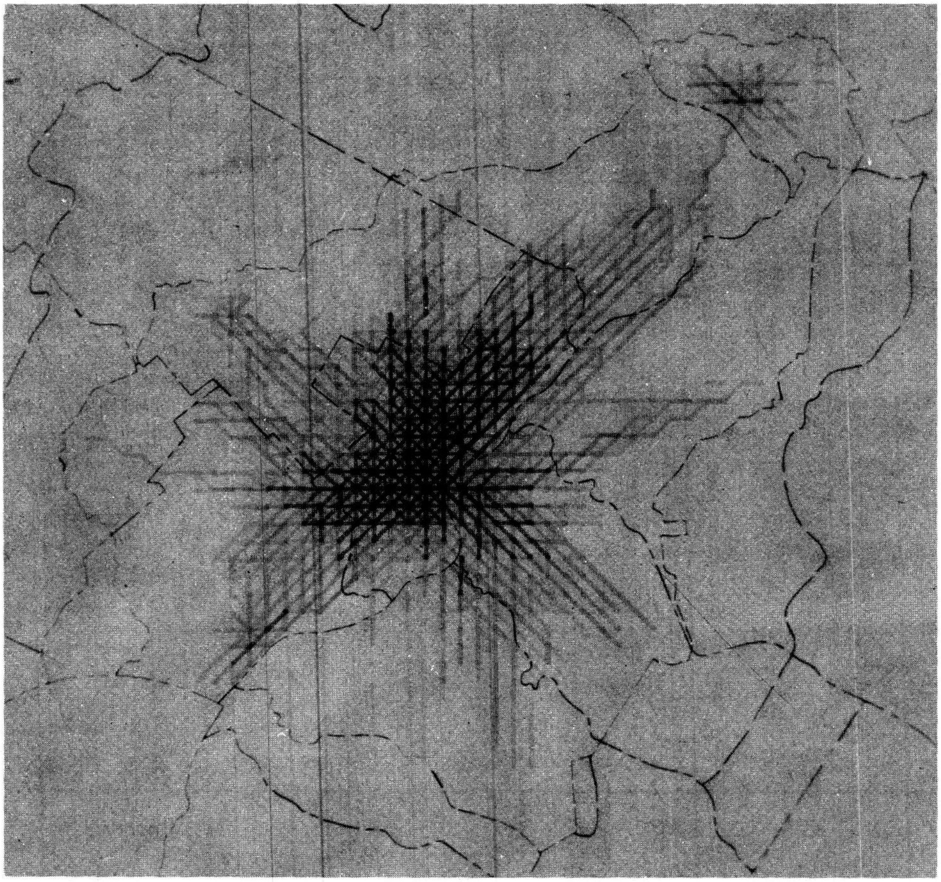


Figure 5. Desire line density map of mass transit trips.

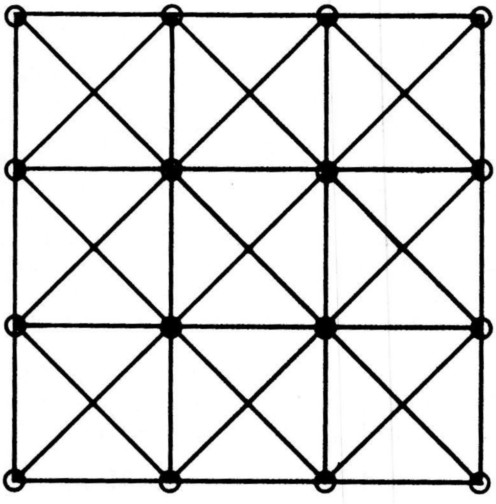


Figure 6. Abstract grid framework for desire line loading, circles indicate grid centers.

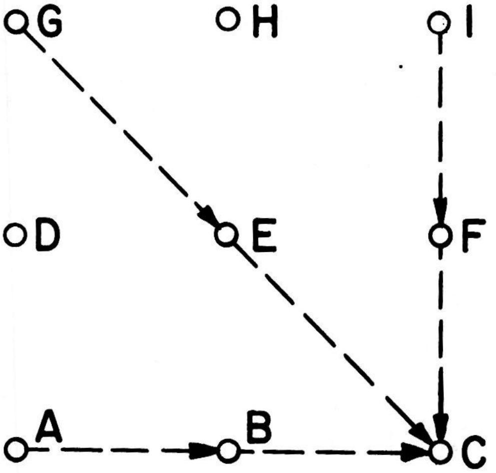


Figure 7. Trace patterns for exact east-west, north-south or 45° diagonal desires.

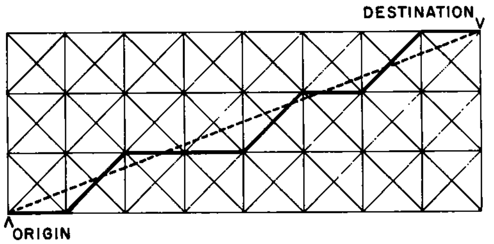


Figure 8. Broken line shows actual desired line of travel; heavy line shows routing through grid to grid interchanges.

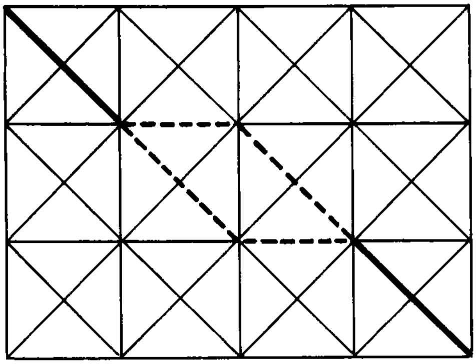


Figure 9. Equally satisfactory routing is indicated by broken line; program directs successive traces alternatively to each.

The preparation of such a map involves the loading of a network by computer. The program for this purpose operates in a manner similar in some respects to assignment programs that load abstract highway networks. Instead of highway sections, however, an abstract grid network system is used composed of some 6,400 grid centers (nodes) connected to each other via straight lines (links) as shown in Figure 6. Any movement is loaded from origin to destination only via those links comprising the shortest route, and the movement value is accumulated in each of the links involved in the route. Figure 7 shows the loading of simple, straight line movements. A movement from, say, grid G to grid C would have its value accumulated on the link from G to E and from E to C. Figure 8 shows the more complex case where the desired line of travel does not exactly match any of the inherent network directions. The routing and loading of such a movement is accomplished as shown by the heavy lines. The rule here illustrated is simply that the routing of the movement follows, as closely as possible within the limitations of the grid network a straight line from the origin grid to the destination grid. The special case where two equally satisfactory routes are available (see Fig. 9) is handled by means of alternate loading of both of the available routes.

The product of the program described is a punched-card deck containing one card for each loaded link in the loaded system. These cards are then stratified according to the grid interchange volumes indicated and each group is run on the dataplotter with a different colored pen, the lower volumes with lighter colors and the higher volumes with darker colors. The result is a map similar to that shown. It is also possible to print the actual link volumes at the grid interchange points if desired.

Some effort has been devoted toward making the computer program, which was written for the IBM 7090, as flexible as possible. The capacity of the program is a maximum of an 80- by 80-unit grid center matrix which can be made as fine or as coarse as is consistent with the maximum dimensions by the use of constants for enlargement or reduction of grid values before loading. The program was designed to accept detailed or summarized movement records for loading, and provision has been made for selective loading of records from an intact magnetic tape file.

SUMMARY

The intent of this paper was to introduce the applications of the dataplotter to transportation analysis. Although some of the applications mentioned have been illustrated, the data summarized to date by the study does not provide the best illustrations or indicate all of the techniques or refinements to be explored. For these reasons, this report should be regarded as preliminary. More data, and more experience, should provide material for a more detailed report at a later date.

REFERENCE

1. Carroll, J.D., Jr., and Jones, G.P., "Interpretation of Desire Line Charts Made on a Cartographatron." HRB Bull. 253, 86-108 (1960).

Evaluating the Requirements for a Downtown Circulation System

ROBERT L. MORRIS, Senior Transportation Planner, National Capital Downtown Committee, Washington, D.C.

• PLANNING for metropolitan area transportation systems in recent years has involved many millions of dollars and billions of words of print. Knowledge in this field has grown rapidly. Indeed, so much has been learned so quickly that today's sophisticated techniques will be too crude for tomorrow's problems. There is surely nothing lamentable about this situation; it is a sign of healthy progress. One element of the transportation system, however, that is consistently ignored or glossed over in all such studies concerns the circulation within the central business districts. Downtown's problems are inevitably lumped in with those of the rest of the city, even though the respective needs are quite at variance. Within downtown, the dominant mode of transportation is the foot. Pedestrian trips exceed all other modes combined, principally because the intense concentrations of people, with an incredibly complex system of interrelationships among the various functions of the heart of a city, require trips that are too short for existing vehicles and systems, and further require the highest degree of flexibility in transportation. If these trips must or should be made by foot, the subject is strictly an academic one. However, if a satisfactory system of facilitating this basic movement could be developed, that would provide relief for the local transportation system, increase the effectiveness of rapid transit by increasing the basic area of service of stations, provide for higher efficiency of business activity and promote retail sales, it might be well worth the expenditure of a modicum of funds and effort. In the belief that this is true, the following study is offered as a first step toward a sophisticated method of planning for downtown internal circulation systems. It was developed in conjunction with the formulation of a plan for the revitalization of downtown Washington, D.C.

BACKGROUND

The problem of determining local circulation requirements involves the same basic information as is needed in evaluating any other component of a transportation system. The kinds of trips, generations, attractions, origins and destinations, trip lengths, and volumes first had to be determined. A model was then needed that could be readily checked and then used for projection to the target year of 1980.

Four primary categories of trip purpose were tentatively defined:

1. Terminal.—trips to and from parking lots, garages and transit stops.
2. Business.—trips between and among office, bank, doctor, lawyer, government center, etc. Essentially any trip other than terminal which did not involve a purchase (either actual or potential).
3. Shopping.—trips oriented toward purchases, including personal services, eating, and drinking. A special subcategory involved lunch trips of downtown employees.
4. Miscellaneous.—a residue category that included sightseeing, trips to and from residences, hotels, etc.

Necessary limitations on the scope of the study precluded definitive findings in any of these categories, and the latter was generally ignored, then added in as an assumed lump sum percentage at the end.

Four devices were employed for the basic measurements:

1. A series of 1,314 interviews with pedestrians at selected locations within and

adjacent to downtown, including parking facilities, transit stops, office buildings, retail generators. The questions were designed to permit tracing of the entire trip of the interviewee from the time of departure from home until his return, as well as background data on age, sex, residence and employment. Interviews were conducted on a Tuesday, Thursday and Saturday in August, and repeated on a Tuesday, Thursday and Saturday in October.

2. A series of 29,000 questionnaires distributed to employees at selected office buildings to determine lunch and shopping habits, as well as age, sex, income, residence. Sixty-six percent of these questionnaires were completed and returned.

3. Manual counts of people entering and leaving two selected office buildings, with periodic interviews to determine if the entrant was an employee or a visitor. Counts and interviews were conducted on two consecutive days (Wednesday and Thursday) in November.

4. A manual all-day count of pedestrians at four key mid-block downtown locations.

MEASUREMENTS

Terminal Trips

Terminal trips were relatively easy to evaluate. Many studies have been made to determine the distances walked from such points according to purpose and length of stay (see 1). Data obtained from cities the size of Washington were applied without further verification.

Business Trips

Measurement of business trips was determined as follows: Using the counts taken at the entrance to two office buildings, referred to as Buildings A and B, on November 2 and 3, a rough determination of generation factors for office use was made. These counts were taken for periods of five minutes in the following order:
(a) totals in and out at door "I"; (b) interrogation for five minutes at door "I" of incoming and outgoing persons to determine if they worked in the building; (c) repetition of two preceding steps at door "II." This cycle was repeated without interruption, except for necessary breaks.

Comparative totals were made of the sample of those persons who worked in the building and those who did not (Table 1).

It was assumed that 80 percent of all workers would be in the building by 11:00 AM. Workers in the building were then determined as 80 percent of total employment:

Building A = 0.80 × 622 = 500
Building B = 0.80 × 941 = 750

TABLE 1

COMPARISON OF PERSONS WORKING IN BUILDING WITH THOSE NOT WORKING IN BUILDING

Persons	Building A		Building B	
	11/2	11/3	11/2	11/3
Working	133	113	466	245
Not working	91	136	156	78
% not working of Total	41	55	25	24
Weighted avg.	48		25	

TABLE 2

Distance (ft)	No. of Trips
0- 500	6
501-1,000	6
1,001-1,500	4
1,501-2,000	8
2,001-2,500	5
2,501-3,000	2
3,001-3,500	3
3,501-4,000	0
4,001-4,500	3
4,501-5,000	11
Over 5,000	4

The total sample of workers in by 11:00 AM was determined:

Date	Building A	Building B
11/2	72	186
11/3	51	83

The difference in Building B resulted from failure to alternate counts between the front and back doors on 11/2.

The total sample of all persons entering by 11:00 AM was determined:

Date	Building A	Building B
11/2	94	355
11/3	107	212

The percent sample was determined by comparing workers counted with actual number of workers:

	Percent Sample	
Date	Building A	Building B
11/2	14.5	25
11/3	10	11

The total number of persons entering the building was determined by applying the sample percentage to the sample total count:

Date	Building A	Building B
11/2	2,000	3,100
11/3	2,830	4,200
Avg.	2,415	3,650

The total persons entering who were not employed in the building was determined by subtracting 90 percent of the total employees (allowing 10 percent for absentees) multiplied by 2 (assuming each worker enters the building an average of 2 times per day) from the total count:

$$\text{Building A} = 2,415 - 0.90 \times 2 \times 622 = 1,300$$
$$\text{Building B} = 3,650 - 0.90 \times 2 \times 941 = 1,960$$

Generation factors (trips produced per employee) resulted from dividing the total visitors by total employees:

$$\text{Building A} = 1,300/622 = 2.1$$
$$\text{Building B} = 1,960/941 = 2.1$$

The equivalent value for the two buildings was, of course, something of a coincidence. For the purposes of the model, it was thus assumed that this value was representative. It is obvious that this is not universally true. Each employee in a retail store would not generate the same number of business (not shopping) trips as would his counterpart in a municipal office building. However, with the possibility that such wide variations would tend to balance, a factor of 2 business trips generated per downtown employee was applied across the board.

The mode of transportation employed and the distances covered in these trips were determined by analysis of individual trips obtained from pedestrian interviews at office buildings. Fifty-two separate trips were analyzed, totaling 147,800 ft, for an average trip length of 2,800 ft and a median of 2,100 ft (Tabel 2). Of these 52 trips, 6 used mass transit, 3 used taxicabs, 5 were in private automobiles and 38 walked.

Shopping Trips

There are essentially three categories of shoppers: primary shoppers who come downtown principally to shop; downtown employees who shop during lunch or before or after work; and people who come downtown for other purpses and incidentally shop.

TABLE 3

Stopper	Store	No. of Persons Making Stops										Total Persons	Total Stops
		1	2	3	4	5	6	7	8	9	10		
Shopper	A	20	43	26	8	6	2	1	-	-	-	106	265
	B	12	21	20	4	1	1	-	-	-	-	59	141
	C	12	20	19	12	2	1	-	1	-	-	67	181
	D	25	34	21	10	4	2	-	-	-	1	97	238
	E	6	12	13	11	3	1	-	-	-	-	47	141
	F	34	30	25	13	4	-	-	-	-	-	109	259
	Total											485	1,225
	Avg.											2. 5	
Worker	A	20	2	2	1	-						25	34
	B	19	2	1	-	-						22	26
	C	19	11	3	-	-						33	50
	D	10	5	2	-	1						18	31
	E	11	4	2	1	1						19	34
	F	13	3	3	-	-						19	28
	Total											136	203
	Avg.											1. 5	
Others	A	15	8	6	2	-						31	57
	B	12	4	2	1	-						19	30
	C	9	8	4	1	1						23	46
	D	13	5	4	2	-						24	43
	E	1	4	5	5	-						15	44
	F	7	3	5	3	-						18	40
	Total											130	260
	Avg.											2. 0	

The pedestrian interviews at retail stores were analyzed by trip purpose to determine the number of shopping stops made (Table 3). It was found that where the principal purpose for coming downtown was to shop, an average of 2.5 stores were visited. Where the principal purpose was work or other but shopping was also involved, the corresponding figures were 1.5 and 2.0 respectively.

Mode of travel was again based on analysis of pedestrian interviews. Distance per shopping trip, determined as shown in Table 4, averaged 1,210 ft. Interviews at retail generators indicated a shoppers' composition of 50 percent primary, 25 percent employees, and 25 percent others.

To determine the attraction of workers to shopping, a gravity model formula was tested. It was assumed that the attraction was directly proportional to the size of the retail generator measured by the number of employees in the store (Fig. 1) and inversely proportional to the square of the distance involved. The 6 major generators were used as a combined attractor, and a "retail index" determined as the summation of the 6 individual indices (Table 5). Office buildings in close proximity to each other were combined, resulting in five groupings of employment. The weighted averages of the individual indices gave the group index, which was then plotted against the percent of shoppers as determined from the employee questionnaires on semilogarithmic paper (Fig. 2). With respect to the individual points on this curve, the average income for Group IV was 83 percent of the over-all average, whereas the comparable figure for Group II was 112 percent.

A tangential exploration into the mutual attractions of retail generators yielded the results indicated in Figures 3a and 3b. Figure 3a shows the original plotted points on log - log paper that evolved into the graph shown in Figure 3b. These relative attractions were determined from analysis of interviews with shoppers.

The graph can probably best be explained by an example of two stores with 600,000

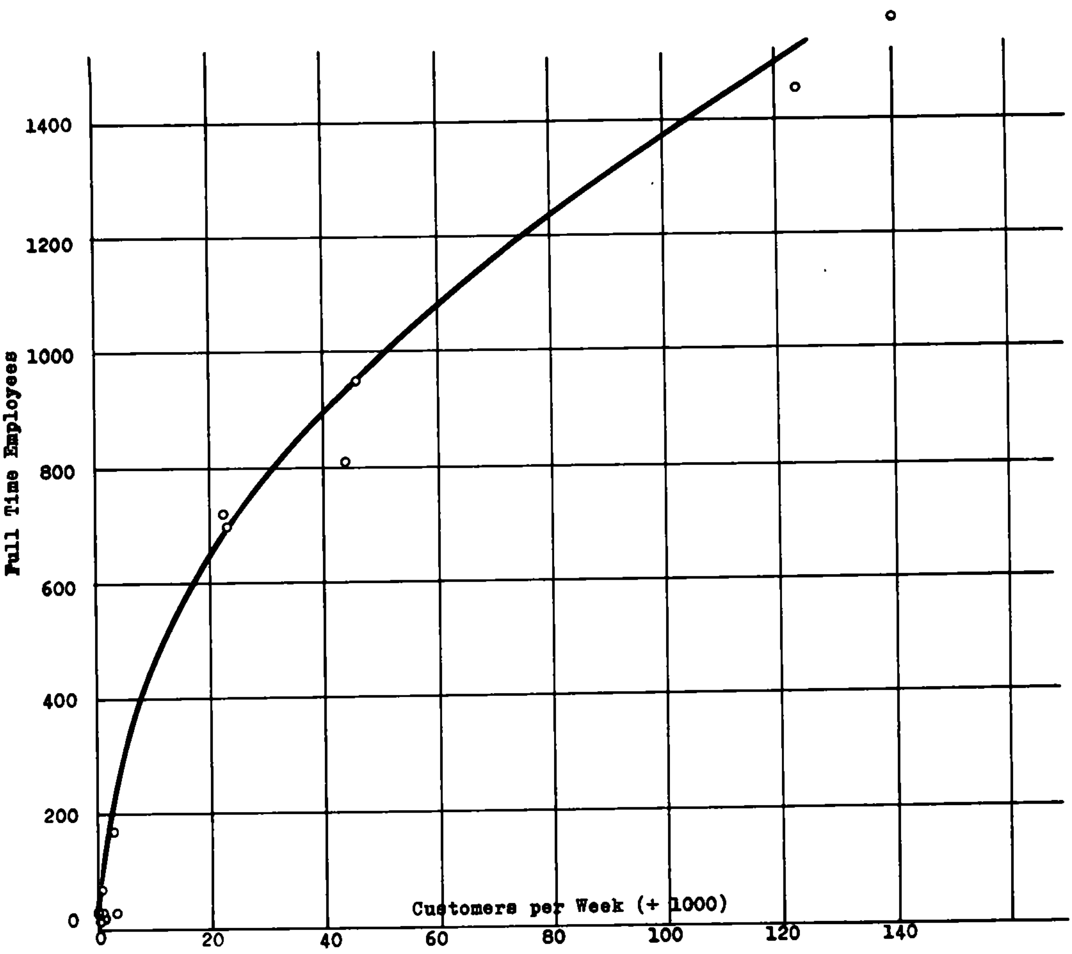


Figure 1.

and 200,000 sq ft of net usable floor area, respectively, that are 1,000 ft (walking distance) apart. One enters the graph at the abscissa representing 600,000 sq ft, goes vertically to the 1,000-ft line, follows this line down to its point of intersection with the 200,000-sq ft abscissa, then reads horizontally to the corresponding ordinate—in this case about 0.21 trips per trip. This indicates that for every 100 persons shopping in the larger store, 21 will go also to the smaller store. Similarly, the impact of the smaller store on the larger can be determined by entering the graph at the 200,000-sq ft point and reversing the procedure with the result of 0.35 trips per trip. That is, of every 100 persons visiting the smaller store, 35 will go on to visit the larger store.

As a further example, there is one large store, A, surrounded by 10 satellite stores B, each equal to $1/10$ the size of the larger store and equidistant from it. The figures involved are one at 600,000 sq ft and ten at 60,000 sq ft and 1,000 ft away. Each 100 trips to A will generate 11 trips to each B, for a total of 110 secondary trips generated. Conversely, each 10 trips to each B (again a total of 100 primary trips) will generate 3.5 trips to A, for a total of only 35 secondary trips. The implications, it would seem, are that for maximum commercial intercourse, large concentrations of retailing are preferable to more spread-out areas.

Lunch trips were considered as a special subcategory of shopping trips. The percentage of employees who go out to lunch was determined from the office questionnaires. Where no cafeteria was provided in the building (these are found principally in government buildings outside the downtown area of study), the average figure was 85 percent. Distances covered in the lunch trip, determined from analysis of pedestrian interviews at a typical office building, are shown in Figure 4. The average trip length was 470 ft.

Miscellaneous Trips

As noted previously, study conditions precluded any further breakdown by trip purpose. It was therefore assumed that all other trips within downtown, not specifically evaluated, would comprise approximately 10 percent of the total.

APPLICATION

One of the pedestrian counts at a typical midblock downtown location was used as the control to evaluate the usefulness of the model. Trips within the zone of influence of this point were distributed in the following manner:

1. Terminals. —Cars parked per day at each facility were multiplied by 1.5

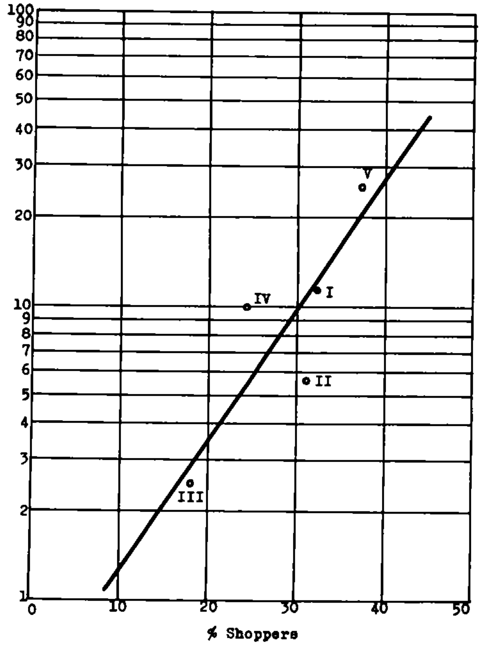


Figure 2.

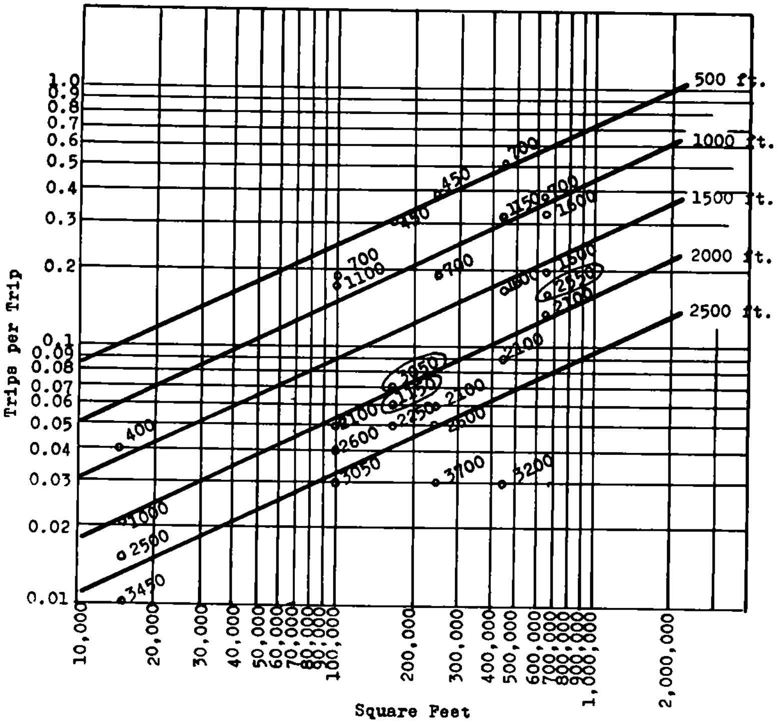


Figure 3a

TABLE 4

Stores		A	B	C	D	E	F	G	Total Trips
A		Trips/Distance	24/1,600	34/700	17/2,550	17/2,100	27/1,600	2/1,100	121
B	Trips x Distance (÷ 1,000)	38.4		15/1,100	1/4,150	2/3,700	3/3,200	0/700	21
C		23.8	16.5		5/3,050	7/2,600	11/2,100	3/400	26
D		43.3	4.2	15.2		62/450	33/1,150	1/3,450	96
E		35.7	7.4	18.2	27.9		62/700	0/3,000	62
F		43.2	9.6	23.1	38.0	43.4		1/2,500	1
G		2.2	0	1.2	3.5	0	2.5		
Total		186.6	37.7	57.7	69.4	43.4	2.5		

Total Trips x Distance (÷ 1,000) = 397.3

Total Trips = 327

$\frac{397,300}{327}$ = 1,210 ft, average distance

occupancy ratio. People were then distributed in proportion to the total employment as follows:

50 percent with 300 ft
25 percent within 300 to 600 ft
15 percent within 600 to 1,200 ft
10 percent within 1,200 to 2,000 ft

Trips were multiplied by two. Buses and streetcars (the only forms of mass transit in Washington) provide stops at every corner in the area, so that the distances involved would be somewhat less. Here the distribution was as follows:

60 percent within 300 ft
30 percent within 300 to 600 ft
10 percent within 600 to 1,200 ft

Again, total trips were multiplied by two.

2. Lunch Trips.—Of the total employment 85 percent was distributed uniformly (there is a wide choice of eating establishments throughout the area) and multiplied by two:

75 percent within 300 ft
15 percent within 300 to 1,000 ft
10 percent within 1,000 to 2,000 ft

3. Business Trips.—Trips generated were two times the total employment. Trips were distributed in proportion to the total employment within 3,000 ft.

4. Shopping Trips.

a. Employees. The percent of total employees per block who shop was de-

TABLE 5

Office Building	Store	A	B	C	D	E	F	Retail Index
	Employees	724	700	1,600	1,400	948	810	
M	(Distance/100)^2	400	961	1,296	2,601	3,265	3,865	
	Employees/D^2	1.8	0.7	1.2	0.5	0.3	0.2	4.7
N	D^2	1,855	1,770	2,170	3,480	2,704	2,220	
	E/D^2	0.4	0.4	0.7	0.4	0.4	0.4	2.7
P	D^2	4,900	3,980	3,480	2,320	1,770	1,370	
	E/D^2	0.1	0.2	0.5	0.6	0.5	0.6	2.5
Q	D^2	2,025	1,370	843	289	576	841	
	E/D^2	0.4	0.5	1.9	4.8	1.6	1.0	10.2
R	D^2	225	100	289	900	529	484	
	E/D^2	3.2	7.0	5.5	1.6	1.8	1.7	20.8
S	D^2	2,500	1,855	1,525	576	343	324	
	E/D^2	0.3	0.4	1.0	2.4	2.8	2.5	9.4
T	D^2	100	196	484	1,195	870	815	
	E/D^2	7.2	3.6	3.3	1.2	1.1	1.0	17.4
U	D^2	169	464	841	1,764	1,370	1,296	
	E/D^2	4.3	1.5	1.9	0.8	0.7	0.6	9.8
V	D^2	72	81	289	872	784	1,089	
	E/D^2	10.0	8.6	5.5	1.6	1.2	0.7	27.6
W	D^2	361	872	1,225	2,500	3,090	3,670	
	E/D^2	2.0	0.8	1.3	0.6	0.3	0.2	5.2

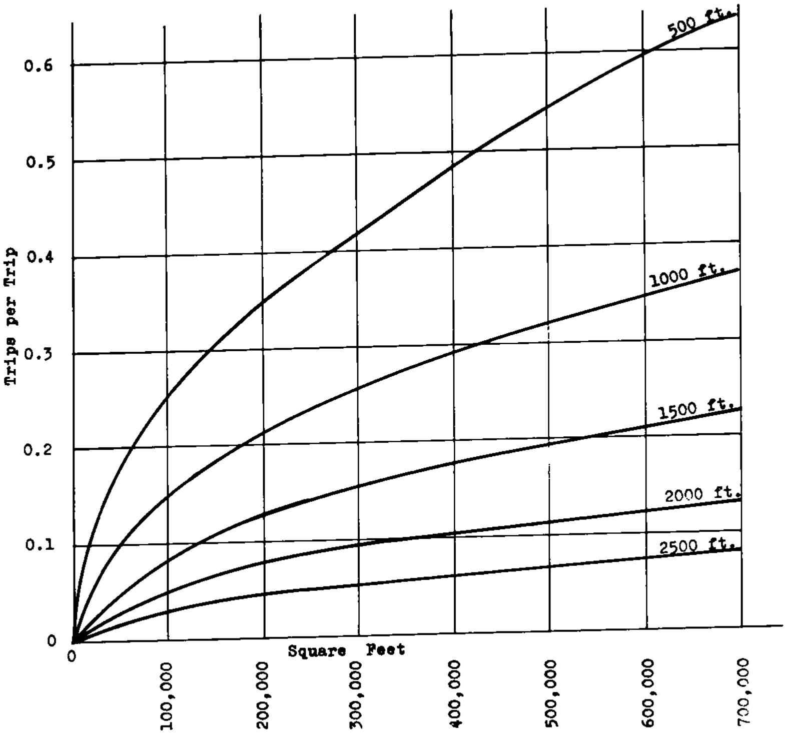


Figure 3b

termined. These shoppers were distributed in proportion to the surrounding retail employment:

50 percent within 500 ft
40 percent within 500 to 1, 500 ft
10 percent within 1, 500 to 2, 500 ft

One-half of these trips were redistributed in the same manner, then returned to the place of employment. The other half of the trips were multiplied by two.

b. Primary shoppers. Each department store employee generates six trips; all other retail employees generate two trips (a necessary oversimplification). These trips were distributed as with employee shoppers. Each of these was redistributed, then one-half were again redistributed.

c. Others. Generation is one-half that for primary shoppers. These were distributed as with employee shoppers, then redistributed once.

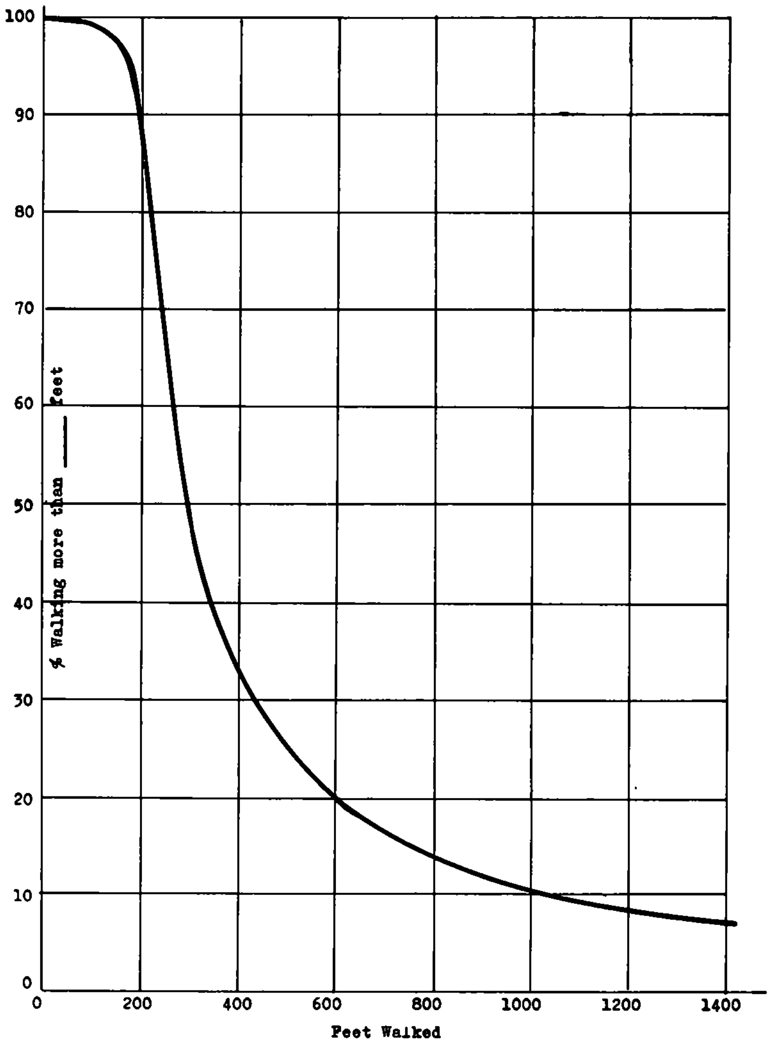


Figure 4.

The accumulation of trips across the control block as determined from the model was approximately 16,500. The addition of 10 percent for the miscellaneous trips brought a close correlation to the actual count of 18,500. (Totals in each case refer to "daytime" volumes, from 8:00 AM to 6:00 PM).

TABLE 6

Station	1960	1980
A	12,000	18,300
B	13,500	25,300
C	11,500	18,400
D	18,500	19,100

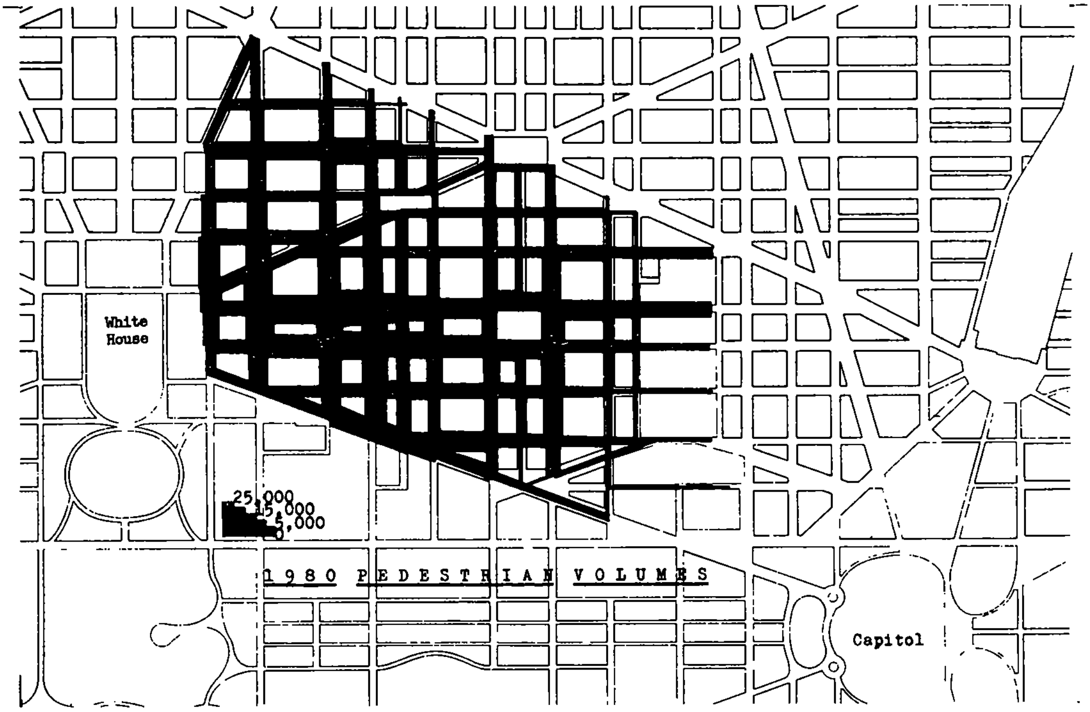


Figure 5.

With confidence that a reasonable approximation of pedestrian volumes can thus be obtained, the model was then applied to the plan for downtown 1980. In addition to changes in land use and employment, a comprehensive rapid transit system was assumed, with bus and subway stations serving downtown, plus a planned parking program integrated with a proposed new traffic plan. These new data were then applied to the model, with the resultant pedestrian traffic flows shown in Figure 5. Comparing existing volumes with projected volumes at the four control stations is shown in Table 6.

In applying the data to the development of an internal circulation system, the composition of the pedestrian volumes can be analyzed by trip purpose to evaluate service requirements. For example, rapid transit stations and long-term facilities would have different requirements for service than would the retail core. The higher the degree of flexibility of vehicles and routing, the better will these individual needs be served.

CONCLUSIONS

The internal circulation model developed for downtown Washington is an admittedly rough tool. It is presented here in the hope that it will stimulate further research. With the growing activity in planning for downtown areas in the U.S., the potential for local circulation systems should not be overlooked. Is it unrealistic to think of a transportation system serving a downtown area that would bring people to a selected number of discharge points, then blanket the central business district with a distribution network composed of vehicles specifically designed for this function, connecting all such points with all prime generators? If such systems are to evolve, means for determining their requirements and demands are essential. It would seem that small effort can bring great rewards in this field.

REFERENCE

1. "Parking." Eno Foundation (1957).

Corridor Analysis of Travel Desires as Utilized in Major Street Planning

JOSEPH W. GUYTON and W. S. POLLARD, JR., respectively,
Transportation Planning Engineer and Partner, Harland Bartholomew and Associates,
Fayettsville, N.C.

• FOR MANY YEARS origin-destination surveys have provided basic travel desire data for guiding traffic engineers and planners in developing major street and highway locations. The methodology for gathering O-D data has been thoroughly discussed, debated, and developed over the years. However, relatively little has been set forth regarding how to use these data for developing a major thoroughfare system for an urban area.

This paper discusses procedures developed by Harland Bartholomew and Associates for utilizing travel desire charts to aid in preparing major street and highway plans for urban areas. The analysis procedures provide a means for determining major thoroughfare systems by traffic service requirements rather than by the procedure of trying to fit traffic to alternative systems in order to find the best plan. Research on possible refinements to the procedures outlined is also discussed.

A corridor analysis of travel desires is designed to provide the following data guides for developing a major street and highway plan for an urban area:

1. A readily perceptible representation of travel desires.
2. An accurate portrayal of desire-volume differential by areas.
3. Representation of desires with a minimum of diversion or "playing" with desire lines.
4. Sufficiently accurate indications of design year capacity deficiencies by areas to indicate the number of new traffic lanes required for adequate service.
5. Versatile tabulations of data that enable specialized studies for smaller, specific areas (such as the central business district).
6. Representation of 24-hr volume levels that can be assigned to study routes to test alternate plans.
7. Data that can be easily adjusted to reflect changing conditions over the years and then to retest the planned elements.
8. Data that can be easily adjusted even during initial study to reflect major changes in land use, the existing street network, or proposed limited-access facilities.

Before presenting the analysis procedures, it is desirable to discuss the philosophies involved in major thoroughfare planning. To provide a frame of reference for this presentation, an urban area of 100,000 population is used. However, the procedures are easily adaptable to smaller or larger areas, even to regions for highway studies.

PLANNING PHILOSOPHY

Experience in various cities throughout the United States has indicated that traffic can best be accommodated by developing relatively few streets and highways with wide pavement widths and generally straight alignment. These major streets have traffic control devices arranged to favor traffic flow and actually carry the majority of vehicular travel. These streets typically accommodate 80 percent of a community's traffic on a coordinated system involving only about 20 to 25 percent of the total street mileage.

With relatively few streets accommodating the majority of the traffic, the remaining streets can be improved with a narrower, less expensive pavement and right-of-way, particularly when located in residential areas. These minor streets need not have direct alignments because their major function is land service. In addition, in developing a system of major and minor streets, greater safety is provided, traffic is accommodated better, and residential areas are protected.

The major streets of a community must be designed as a coordinated network connecting all residential areas with the primary traffic generators—recreational areas, business areas, industrial areas, and other places of employment. There are two basic types of major street systems which are generally utilized in various degrees and combinations. One system is usually referred to as radial or radial-circumferential. It is best adapted to an urban area in which the major traffic generators are concentrated in the central section.

The second type of basic street network is a gridiron pattern. There are, of course, certain elements of radial routes included in the system. With relatively minor alterations, this is the type of network that the majority of cities in the United States have in their built-up areas. Very often this network is used with circumferential elements in the form of bypasses.

Within the general term "major street" there is a varied nomenclature to categorize the streets even further. Certain terms are applied toward legal definitions and others toward defining maintenance responsibilities or levels of service. To avoid confusion of terms this article is written using three basic types of major streets and highways. These are limited access, primary arterials, and secondary arterials.

The primary function of minor streets is to serve abutting property. They should be indirect in alignment and their pavement width should be relatively narrow to discourage through or fast traffic. Some minor streets act as collectors to gather traffic from abutting properties and intersecting streets and direct it to the nearest major street for safe and expeditious movement to its destination. These are termed collector streets. Several subclassifications of collector streets are possible depending on the type of land use served. The streets are often defined as commercial, industrial, or residential collectors. They normally provide for two lanes of traffic and two parking lanes.

In residential areas the basic minor streets, are local streets which need have only 28 to 30 ft of paved width on a 50-ft right-of-way. This is ample for parking and traffic flow in those areas. Additional width is a needless expense and a waste of land.

The public depends on a good transportation system for the efficient movement of goods and persons. It is mandatory that such a system be adequate to meet not only present needs but also anticipated future traffic. A major planning principle is that provisions be made for street and highway improvements so that when the need arises the opportunity exists. Because proposed improvements must be programed commensurate with demand, pre-obtaining of right-of-way properly located to allow improvements ultimately to be required is mandatory. Conversely, a plan enables designation of minor streets with a resulting savings where wide rights-of-way are not required.

It is not the purpose of a master thoroughfare plan to present an idealistic pattern warped to resemble slightly the city for which it is recommended. The master thoroughfare plan must embody practical elements of improvement and still adequately meet the anticipated traffic requirements while embodying those details of good planning necessary to present a pleasing, economical, and efficient street network.

A traffic service demand exists anywhere that a driver desires to travel. However, this cannot be considered a "traffic service requirement" for a street until there are enough grouped individual desires to warrant constructing that street. One-half a traffic lane, in all practicality, cannot be built. Conversely, at certain times it is more economical to construct the entire street cross-section rather than just a portion of it.

In addition to a traffic service requirement, there are certain other planning requirements for streets to provide continuity or aesthetic values. Basic principles guiding the location of major streets indicate the desirability to route "through" traffic in this instance means traffic that does not desire to go to a particular district but is routed through that area due to its origin and destination with respect to the street system in existence. Good planning enables the traffic to circumvent the district and thus minimize delay and congestion. Examples of these congested areas are a city, the CBD, major industrial areas, and major college and university campuses.

It is also desirable for major streets carrying traffic to the CBD to route that traffic directly to off-street parking areas. Other major focuses of traffic ideally should be located adjacent to a major street with appropriate minor collector streets to serve the area directly. In all instances there should be provided a minimum of travel distance and a maximum of convenience.

The cornerstone of any master thoroughfare plan should be the existing street system. The key to the adequacy or inadequacy of the existing major street network is a relating of its capacity to the demands of motor vehicular traffic at the design year. The over-all degree of accuracy of such an analysis therefore becomes that which is necessary to insure that there will not be a difference in the requirement of traffic lanes.

The procedure discussed herein determines required traffic lanes by location. It involves determination of capacity deficiencies in lanes at a multiplicity of analysis lines throughout the urban area being studied. Before discussing the procedure, the following definitions are given to provide a basis for mutual understanding of terminology.

1. Major Street, Thoroughfare, or Arterial Street.—An element of the street and highway system that traditionally comprises approximately 20 percent of the mileage in the community but carries about 80 percent of the traffic.
2. Collector Street or Local Street.—Part of the minor street network comprising the remaining 80 percent of the street mileage.
3. Desire Trip.—One vehicular trip as determined from origin-destination charts listing a zone or station of origin and a zone or station of destination.
4. Desire Line.—A straight line drawn between the point of origin and the point of destination of traffic without reference to existing streets and highways. The point of origin or destination is normally considered to be a station for external trip ends and a zone centroid for internal trip ends.
5. Semi-Assigned Desire.—The routing of a vehicle trip from point of origin to point of destination other than in a straight line but not along a specific existing street.
6. Assigned Desire.—The routing of a vehicle trip from point of origin to point of destination along a specific existing or proposed street or highway.
7. Analysis Screen Line.—One of many straight lines defined with respect to the major street network of a community and used in corridor analyses. Each analysis screen line forms one boundary of a corridor and is used for tabulating desire trip volumes by location.
8. Analysis Screen-Line Section.—The portion of a single analysis screen line contained within an intersecting corridor.
9. Internal Traffic.—Traffic having both origin and destination within the survey or study area.
10. Local Traffic.—Traffic having either origin or destination, but not both, within the survey area.
11. Through Traffic.—Traffic having both origin and destination outside the survey area but passing through the survey area. These trips are normally indicated as station-to-station movements.

TYPICAL STUDY OF TRAFFIC DESIRES

Philosophy of Corridor Analyses

The basic theory of a screen-line check of travel desire trips against actual ground traffic counts is not new, having been used for years as part of O-D survey techniques. It is also applicable to major street planning for a design year. The philosophy used can be easily summarized:

1. Across any straight line through an area, the theoretical volumes (desire trips) should balance actual vehicular trips, if certain precautions are taken regarding circulation of traffic, double crossings, daily volume variations, etc.
2. By using a series of screen lines, checks of design year desire trips can be

made at sufficient intervals to provide sound planning data regarding the collective demand for street facilities.

3. If screen lines are prudently located, an accurate estimate can be obtained of actual design year vehicular trips across each line. This involves recognition of several facts:

a. Consideration must be given to circulation and forced double crossings of the screen line.
b. Many of the relatively short trips, as well as the beginnings or ends of other trips, are made on local streets and not major streets. (Traditionally, this has been considered to be approximately 20 percent of all travel.)
c. Diversions of traffic from the most direct path will occur; but travel time factors being equal, this tends to be compensative between various routes for the study area as a whole.
d. Traffic zones for tabulating and grouping trips with similar origins and destinations must be small enough to distribute desire trips adequately. At the same time, the zones should not be so small that undue tabulating time is required.

Preparatory Data

The following supporting data are necessary in these phases of major street planning, and should be obtained before initiating the corridor analysis tabulations:

1. Definition of existing major street network. This may be from the existing thoroughfare plan, or it may require designation of a major street network as determined by public use of the streets. This latter method necessarily involves much judgment, but is often necessitated in smaller communities having no formal thoroughfare plan.

2. Inventory of rights-of-way, pavement widths, parking restrictions, and traffic control measures.

3. Determination of existing traffic flow characteristics on the major street network. This involves tabulation of turning movements at key intersections, calculations of peak-hour volumes as a percentage of 24-hr volumes, determination of directional distribution factors for morning and evening peak hours, and development of existing 24-hr volume data.

4. Development of design year travel desires. This in itself may be a major step, and often involves projection of an existing origin-destination survey tabulation to the appropriate design year.

5. Location of physical factors influencing major street locations. Prudent location of the analysis screen lines is a necessity for the analysis of over-all travel as well as the specialized studies required later. The locations of major traffic generators, both existing and planned, are needed, as well as such pertinent physical factors as major railroads, rivers, topographic conditions, and even limited access routes locations.

Analysis Procedures

The technique of corridor analysis is not completely new, but the procedures discussed herein are the evolution of years of modifications of procedures used by Harland Bartholomew and Associates in various studies in Illinois, Michigan, North Carolina, Tennessee, Texas, and Virginia. These procedures are not considered perfect or inflexible, but they provide the theory and generalized methodologies involved and must be adjusted to the specific requirements and peculiarities of each individual study.

There are two basic purposes of the various tabulations and illustrations prepared in the corridor analyses. The first of these is to present as concisely and explicitly as possible the desire trip tabulations by corridor groupings to enable study of high concentrations of desire volumes. The other purpose is a determination of capacity deficiencies by areas.

Desire Trip Tabulations. —Screen lines for analysis purposes can be oriented in any number of ways. In various studies throughout the country, radial lines from the CBD, concentric circles, and series of parallel lines forming corridors have been used. Experience has indicated that for even the most radially oriented city, a series of parallel lines can effectively be used. Because computations are simplified with parallel analysis lines, the "corridor" approach has become standard although modifications can always be introduced for specialized requirements.

The analysis lines forming the corridors for any given study can be oriented at any angle to the existing street network. Thus an initial step in a corridor analysis is to designate the series of lines to be used for analysis purposes. These are referred to as corridor lines or analysis screen lines, for each pair of parallel analysis screen lines forms a corridor. Each series of corridor orientations is composed of two groupings, each at right angles to the other. The corridor lines are each located to provide volume tabulations at critical locations, such as a river or a major railroad, but at the same time they must be systematically spaced across the study area.

The location of the analysis screen lines becomes most important. For any particular study, the number of corridor orientations used will vary. However, in a typical study, two area-wide orientations will most likely be used in addition to special corridor studies involving a portion of the urban area. These two basic series of corridor orientations are each composed of the two groupings of corridors, each at right angles to the other. The orientation used in the final depicting of lane deficiencies is referred to as the cardinal corridor orientation whereas the second grouping is usually a 45° orientation. These cardinal corridors are designated basically paralleling the existing thoroughfare network (Fig. 1). The analysis screen lines for the cardinal corridors should be such that the following obtain:

1. Each is a straight line parallel to the designated X or the designated Y axis.
   a. The X and Y axes are at right angles to each other.
   b. The X and Y axes are established generally parallel to the basic existing major street network.
2. Each pair of parallel lines forms a cardinal corridor.
3. No analysis line crosses the intersection of two existing major streets.
4. No analysis line crosses through any design year analysis zone centroid.
5. All lines follow as closely as possible the analysis zone boundaries.
6. The CBD is enclosed by sections of four analysis screen lines.
7. Where possible, lines should generally follow
   a. Main line railroads,
   b. Rivers,
   c. One side of an existing expressway,
   d. Other elements when it is desirable to know design year volume crossings.
8. The cardinal corridors formed should be
   a. Approximately ¾ to 1¼ mi wide,
   b. Narrower near the CBD and wider near the fringes,
   c. Located to include at least one major through street, if possible.

The remaining series of corridor orientations involve corridors oriented at an angle to the cardinal corridors. These may be a rotation of the system about the CBD, although the spacing of the analysis lines normally varies for different corridor orientations. For a typical study each orientation involves twenty corridors, ten in each direction. The analysis screen lines for each series of supplementary corridors are generally located in the same manner as those analysis screen lines for the cardinal corridors, except they are at an angle to the designated X or Y axis. The most typical orientation is usually at 45°.

In the development of all tabulations of corridor desires, internal trips are assumed to be concentrated at their respective zone centroids. Vehicle trips involving an external survey station are plotted from the location of the station involved to the appropriate zone or other station. Care must be taken to minimize the effect of so grouping the travel desires, and two precautions are always followed. In the development of the design year desire trip tabulations, zone boundaries are caused to coin-

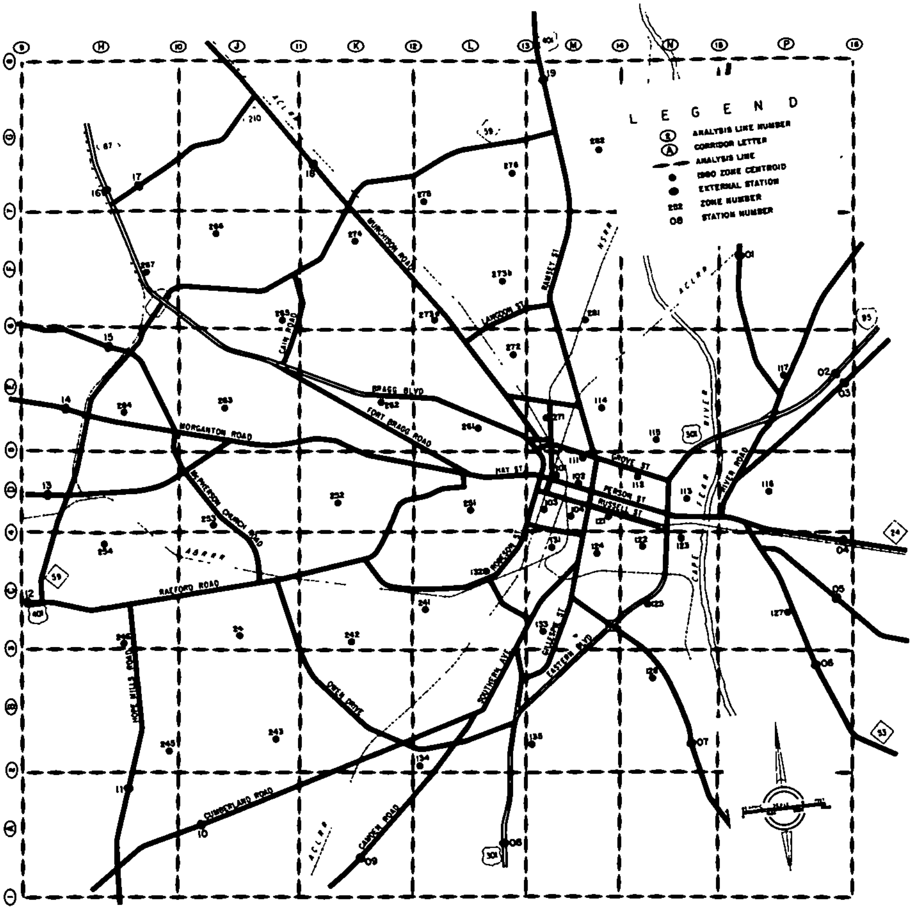


Figure 1. Orientation of cardinal corridors, Fayetteville, N. C., urban area.

cide as closely as possible with the analysis screen lines to be used. This often dictates the splitting of the initial origin-destination survey traffic zones. This is of primary importance relative to the cardinal corridor analysis screen lines. In addition, land uses with very high trip generations per acre (such as a major shopping center) are considered as separate zones.

The total volume of traffic crossing an analysis line section is determined by considering each desire movement (zone to zone, zone to station, or station to station) as traveling in a straight line, or desire line, from centroid to centroid. This is done even if there is no major street in the corridor the desire line traverses. Each time the tracing of the desire line movement crosses an analysis line, the desire volume is tabulated at that line section. When all movements being considered for that particular tabulation have been treated in this manner, those crossing each analysis line section are summed and the resulting volumes then are plotted to scale on a map of the urban area.

To define corridor desires further and facilitate later analyses, it is also desirable to differentiate between various types of desires tabulated at each analysis screen-line section. For example, internal, local, and through traffic may be traced separately, and further delineation can be made by separating truck and passenger vehicle volumes. In addition to these differentations, it is most desirable to contrast true corridor desires with those desires that do not trace their entire movement with a single corridor. True corridor desires are those movements between zone centroids which lie completely within a given corridor. Therefore, all movements within a study area can be categorized as true cardinal, true 45°, and "all others."

For a corridor analysis of design year travel desires for a typical urban area, the following tabulations are most often required. For each of these, separation by type of traffic (external, internal, truck, passenger, etc.) should be done as required for the particular study analyses involved.

1. Cardinal corridor analysis lines
   a. True cardinal corridor desires (design year),
   b. Forty-five degree corridor desires (design year),
   c. All other corridor desires (design year),
   d. All travel desires (design year),
   e. All desires eliminating those assigned to special facilities (design year),
   f. All existing year desires.
2. Forty-five degree corridor analysis lines
   a. True 45° corridor desires (design year),
   b. True 45° corridor desires eliminating true cardinal corridor desires (design year),
   c. All desires (design year).
3. Special corridor analysis lines
   a. True corridor desires (design year),
   b. True corridor desires eliminating true cardinal corridor (design year).
   c. All desires (design year).

Appendix A contains a procedural outline of the steps involved in obtaining basic desire trip tabulations. This general outline has been designed to provide typical tabulations and should be modified to provide the necessary data for the particular study involved. A section is included regarding a hand (mechanical) procedure for desire tabulations as well as a computer program which provides the same type of data. Examples of coding sheets are included.

From these tabulations of desire year, desires, corridor desire volumes are plotted on maps of the urban area to provide graphic portrayal of the volumes. All of the data indicated previously should be considered, but the desire maps most often utilized are indicated below. The raw tabulations of other data on an area-wide basis are usually sufficient for typical studies inasumuch as the specific items required for a specific location can be obtained from those listings.

1. True cardinal corridor desires (Fig. 2).
2. True 45° corridor desires (Fig. 3).
3. True radial corridor desires (Fig. 4).
4. Semi-assigned cardinal corridor desires, separated to indicate those volumes actually semi-assigned and those volumes which are true corridor desires (Fig. 5).

The true cardinal and the true 45° corridor desires are used in study of possible radial street movements, both existing and contemplated. In addition, the 45° corridor desires are used in later studies involving tentative assignments of volumes to street systems to determine 24-hr volume levels for streets proposed for construction. By combining data from those cardinal and 45° corridors radiating from the CBD, a true radial corridor desire portrayal can be prepared. In the development of these data, an example of which is shown in Figure 4, care must be exercised to eliminate duplication of desire trips in the data from the two corridor networks. Those desire volumes between the corridors radiating from the CBD can either be semi-assigned to the corridors used in the figure or they can be indicated as separate movements between corridors.

The true corridor desires for 45° corridors are then semi-assigned to the cardinal corridor system in addition to all other desire movements that have not been considered. These volumes are then indicated on a map of the area similar to that in Figure 5 with the true cardinal corridor desires. This provides representation of 100 percent of the design year trippages. It is most advantageous to differentiate be-

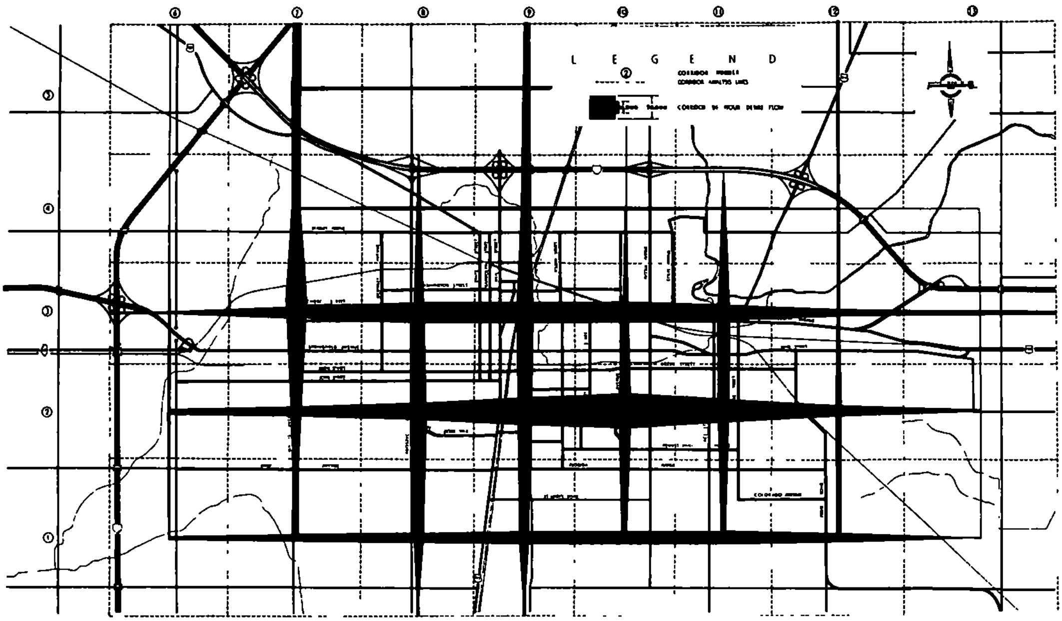


Figure 2. 1980 cardinal corridor desire flow, Champaign-Urbana, Ill., urban area.

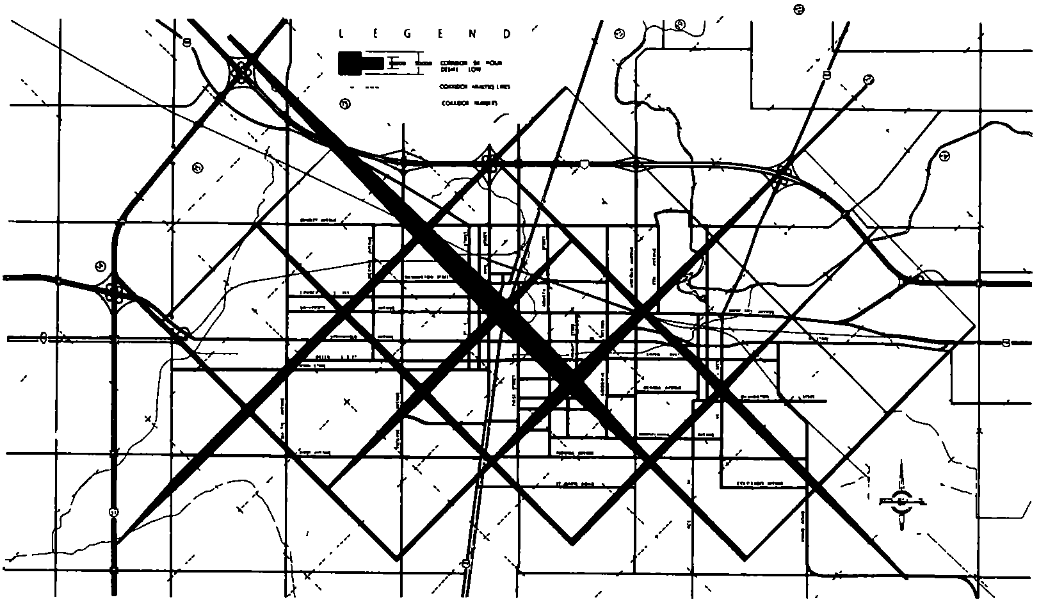


Figure 3. 1980 45° corridor desire flow, Champaign-Urbana, Ill., urban area.

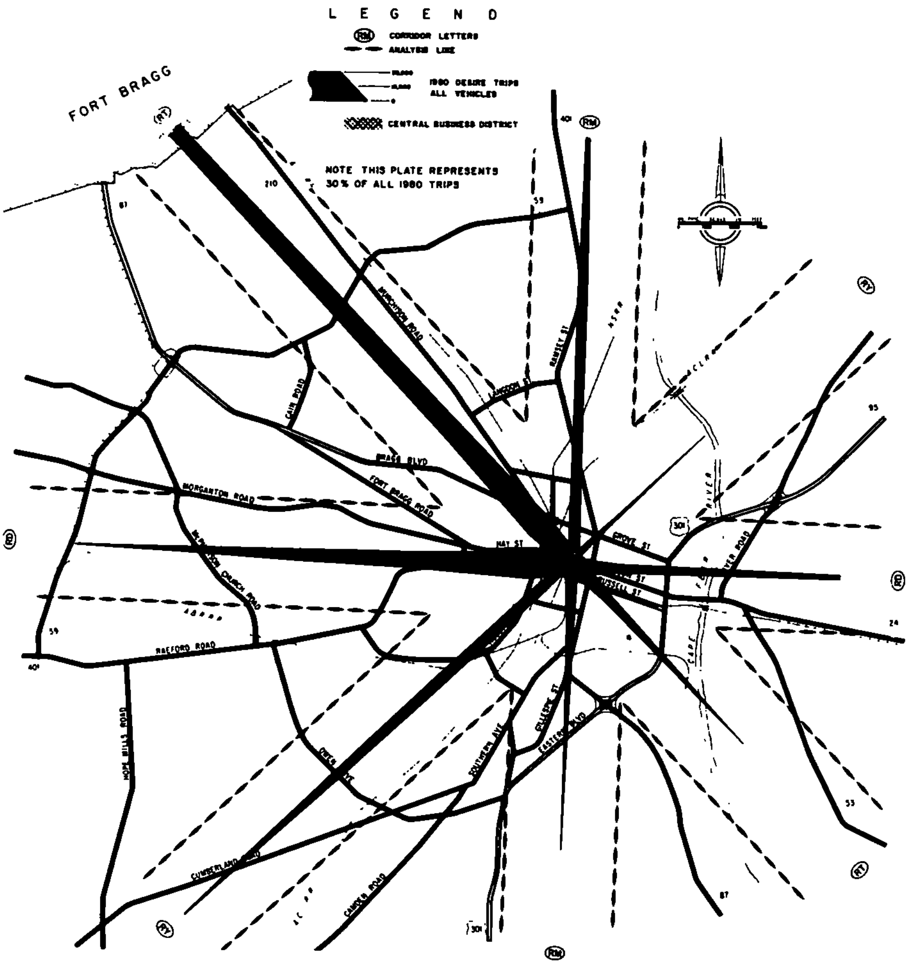


Figure 4. 1980 radial corridor desires, Fayetteville, N. C., urban area.

tween the true corridor desires and the semi-assigned volumes in this portrayal. If such is done, future efforts regarding estimating traffic volume levels for particular streets by the design year are simplified.

Table 1 gives pertinent data relative to these desire volume tabulations. The true corridor desires, though comprising a high percentage of trips, do not include desire volume crossings in proportion to the number of trips because most of the short trips are contained whereas the majority of long trips are considered "all other" desire movements. On the average, cardinal corridor desires represent 35 to 40 percent of all trips within a study area while constituting only one-fourth of the analysis line volume crossings. The average internal trip length factor for cardinal corridor desires is usually only 60 to 70 percent of the value for all internal trips. A comparison of these trip length factors is given in the table for a typical study area. Average trip length factors are based on the total volumes crossing the analysis lines, the average spacing of analysis lines, and the total number of trips included in the volumes used to determine crossings.

The treatment of limited-access facilities, either existing or proposed, requires special steps in addition to those outlined previously. When a limited-access facility is introduced into the street system, the previously discussed desire tabulations should be developed and then supplemented with modifications made in consideration of the effect of the limited-access facility. In this, each interchange of the limited-access

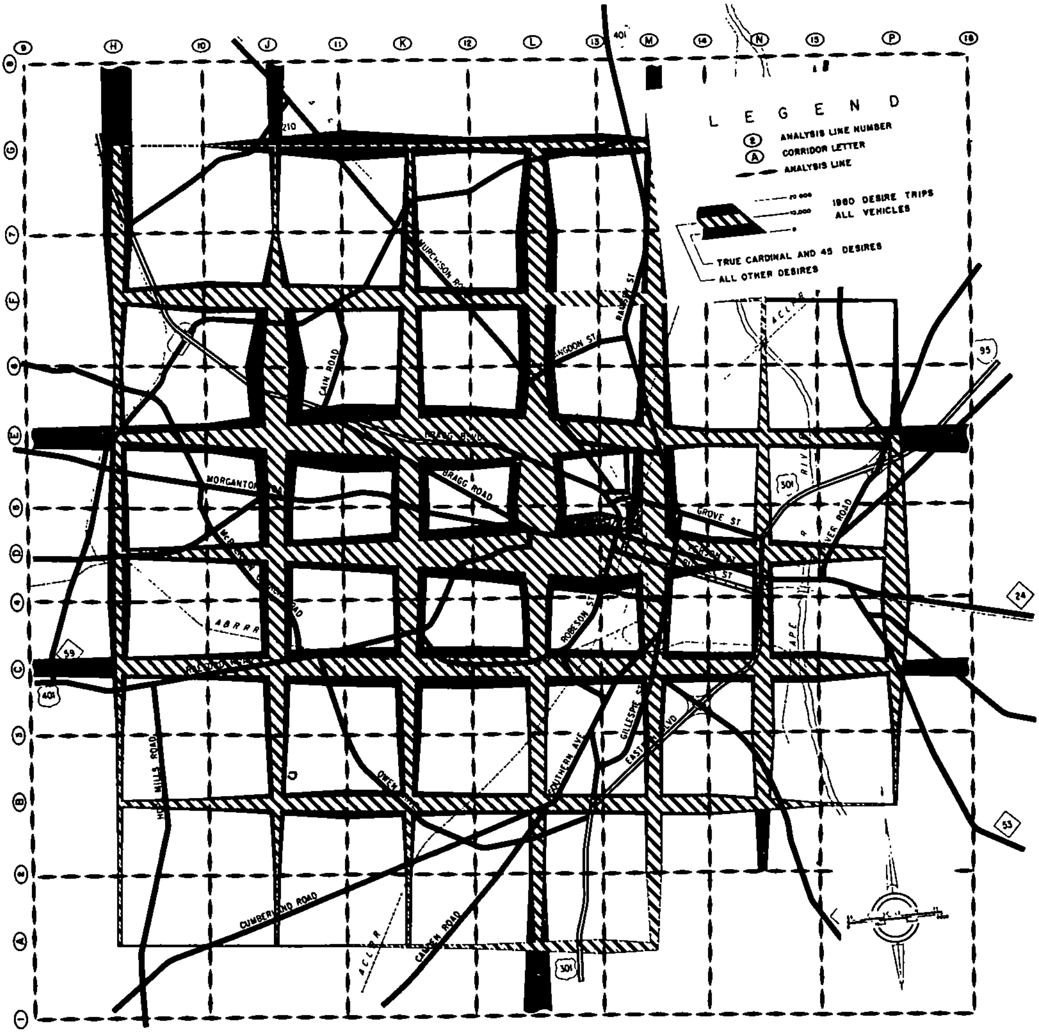


Figure 5. 1980 24-hr semi-assigned desires, Fayetteville, N. C., urban area.

facility is treated as a zone centroid, travel time ratio assignments of desire trips to the limited-access facility are made, and the origin-destination desire tabulations are adjusted to include limited-access interchange zone centroids. In this manner, a trip using the limited-access facility is traced for the purposes of the corridor analysis as follows:

1. From a zone centroid to the interchange at which the trip enters the limited-access facility.
2. From that interchange location to the interchange at which it leaves the limited-access facility.
3. From the final interchange to its zone of destination.

For purposes of preparing study maps of desire volumes within the study area, the trip movements on the limited access facility (step 2) are plotted separately and are not included in the corridor desire portrayals. In effect, this removes the travel on

TABLE 1

SUMMARY OF CORRIDOR DESIRE TABULATIONS FOR TYPICAL URBAN AREA

Corridor Desires	Total Crossings of Analysis Screen Lines	No. of Trips Included	Trip Length Factor
True cardinal	154,000	99,000	1.8
True 45°	112,000	65,000	2.1
All others	338,000	84,000	4.8
All semi-assigned to cardinal corridors	604,000	248,000	2 9

limited-access facilities from the corridor analysis and enables separate study of the requirements for the limited-access facility and for the requirements of the arterial street system.

After development of all the previously discussed corridor desire tabulations, including specialized limited-access facility studies, the next step involves the determination of peak-hour traffic desires by corridors. This is normally a matter of converting the 24-hr desires shown in Figure 5 to peak-hour volumes at each analysis screen-line section. This is accomplished utilizing factors derived from study of existing peaking characteristics determined for the major street network. An example of these peaking characteristics for a typical community is shown in Figure 6.

From study of the data in Figure 6, peak-hour factors and directional distributions are determined for each analysis line section. The peak-hour percentage factor is applied to the 24-hr desire volume, and in turn this is multiplied by the directional distribution factor to provide one-way, peak-hour desires. This result is the one-way volume that the major street system in that corridor must be able to accommodate. The ability of the existing major street network to meet this one-way volume desire is determined through a capacity analysis of the existing streets on a corridor basis.

For complete study of an urban area, peak-hour volume determinations are required for morning and evening peaks for both the cardinal corridor orientation and the 45° corridor orientation. For brevity, discussion here is limited to capacity deficiency studies determined using the cardinal corridors and the evening peak-hour volumes because the procedures are applicable to all orientations.

Corridor Capacity Determinations.—The purpose of the corridor capacity data is to provide a measure of the ability of the existing major street network to meet the design year peak-hour desires by location to determine where lanes of traffic are required by the design year. Final determinations of exact level of development of cross-section elements for a specific street or highway are not made from this phase of the analysis but are made after assignment of volumes to specific routes. However, this analysis must represent as accurately as possible the lane capacity to be provided by the design year, as well as those locations which will require intersection improvements. Consideration of these factors indicates the degree of refinement required in the corridor capacity determinations.

In view of these factors, a set of standard capacity charts has been prepared for corridor analyses. These capacity charts are used to determine the capacities of the various elements of the major street network within each corridor at as many locations as are required. Corridor capacities are then determined by summing the capacities of each individual street element. For each corridor, capacities normally are required at analysis lines, major street intersections, major crossings of railroads, rivers, and limited-access facilities, and all other locations deemed critical.

Intersection capacities are normally based on the 1958 revisions of the Bureau of Public Roads standard capacity charts for average conditions, adjusted to reflect practical capacity. The more detailed charts can be used when needed; however, such

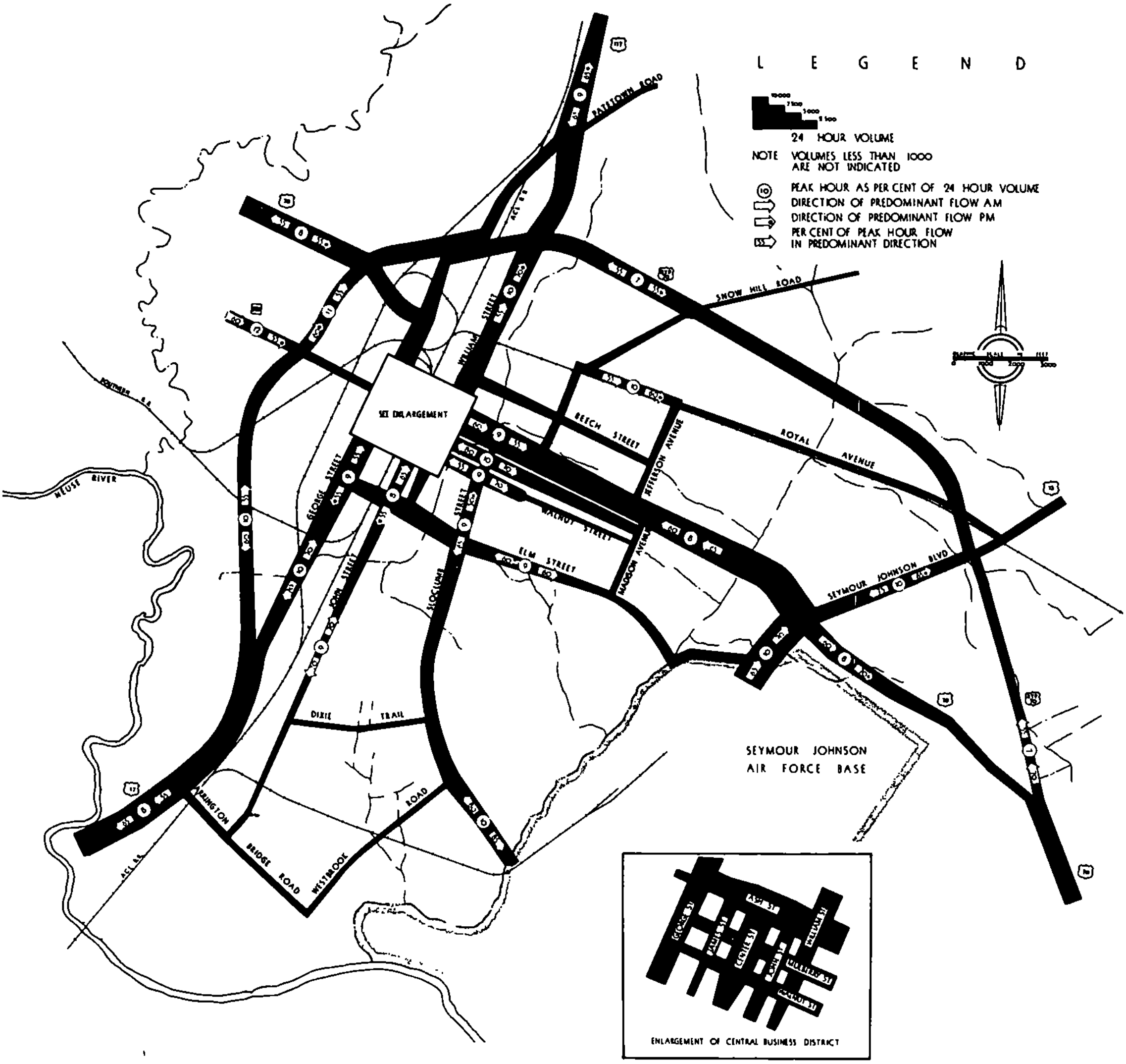


Figure 6. 1960 24-hr volumes, Goldsboro, N. C., master thoroughfare plan.

comprehensive capacity studies are warranted at this phase of the analysis only where multiphase controllers are used at signalized intersections or very heavy turning movements are involved. Although oversimplification must be avoided, at the same time unnecessary "exactness" of detail is not warranted either. Consideration must be given to the over-all accuracies involved and the desired end result in determining the required degree of refinement.

Figure 7 shows the series of capacity charts for one-way streets and Figure 8 shows charts for two-way streets. These charts represent typical conditions involving 20 percent turning movements, 10 percent truck volumes, and average interference from bus maneuvers and pedestrians. The practical capacities provided are one-direction approach volumes in vehicles per hour of green time, which must be adjusted to reflect the percent of green time for the street approach under consideration.

Corridor capacities for uninterrupted flow conditions are based on operating speeds desirable for the various types of major streets considered. Criteria for operating speeds recommended for general use where local criteria are not available are given

TABLE 2

CRITERIA FOR OPERATING SPEEDS WHERE LOCAL STANDARDS ARE NOT AVAILABLE

Area	Operating Speed (mph)		
	Principal Highways	Secondary Routes	Other Major Streets
Rural	55	50	--
Suburban	45	40	35
Other	40	30	30

in Table 2. For operating speeds above 30 mph, as speeds increase, practical capacity decreases. Thus, for general use, Figures 9 and 10 have been prepared from data in the U.S. Bureau of Public Roads "Highway Capacity Manual," 1950, to relate capacity in vehicles per hour to operating speed. Figure 9 shows these data for two-lane routes for 12- and 10-ft lanes. These curves assume a 1,500-ft minimum restricted sight distance, 10 percent truck volumes, and obstructions not closer than 6 ft. The capacities shown in Figure 9 are two-way in vehicles per hour and must be adjusted to one-way capacities by applying a directional distribution factor. Adjustments can be made for greater sight distance restrictions or truck volumes and for different lane widths in accordance with factors provided in the "Highway Capacity Manual."

Figure 10 relates capacity to operating speed for multilane routes and provides one-way lane capacity in vehicles per hour. Again, it is assumed that 10 percent of the volume is composed of commercial vehicles and there are no obstructions closer than 6 ft. Adjustments can also be made for different conditions or for different lane widths in accordance to factors provided in the "Highway Capacity Manual." The values derived from Figures 9 and 10 are generally comparable to those provided in AASHO policy manuals, "A Policy on Geometric Design of Rural Highways," 1954; and " A Policy on Arterial Highways in Urban Areas," 1957.

For stop-sign conditions on major streets, two policies are normally employed. All-way stop-sign control is generally calculated on the basis of 400 vehicles per hour approach lane. This is generally compatible with capacity determinations across the country and presumes relatively balanced lane volumes between approaches and approximately 10 percent commercial vehicles. More refined estimates are considered unwarranted, and for long-range planning it is presumed that all-way stops will probably be replaced with traffic signals.

Two-way stop signs at intersections of major streets are considered to proportion the intersection capacity to the streets at 100 percent for the unimpeded street and 0 percent to the stopped street. The philosophy used in this is that assignment of less than the unimpeded (free-flow) capacity to the non-stop street is not warranted; therefore, the stop-street should have no capacity assigned to it for the corridor capacity determination.

In considering corridor capacities, it is imperative to remember that they represent conditions for the existing major street network. Present traffic control measures, including signal timing where applicable, are used, and in some instances capacity above that indicated for a corridor is available merely by removing parking or improving the signal phasing.

Capacity Deficiency Analysis. —The resulting capacities by corridor sections within the urban area can be graphically compared to the estimated desire volumes by corridor sections to provide a positive guide for the location of major streets. Figure 11 shows such a comparison for a typical study. It is apparent from this portrayal that certain areas have lane capacity deficiencies or intersection capacity deficiencies, whereas other areas provide capacity sufficiencies. Generally speaking, areas of deficiency at analysis lines require major widenings or construction by the design year, whereas little or no gross widening programs are necessary where sufficiences are indicated. In the latter instances, however, intersection widenings may be required.

To summarize the relationships shown in Figure 11, it is desirable to translate the analysis line deficiencies from vehicles per hour to lanes of traffic. A most meaningful tabulation therefore becomes an indication of two-way lane deficiencies at each analysis screen-line section. Figure 12 shows the two-way lane deficiencies developed in this manner for a typical study. In developing these data from these shown in Figure 11, a lane of traffic was considered to represent 600 vehicles per hour on the

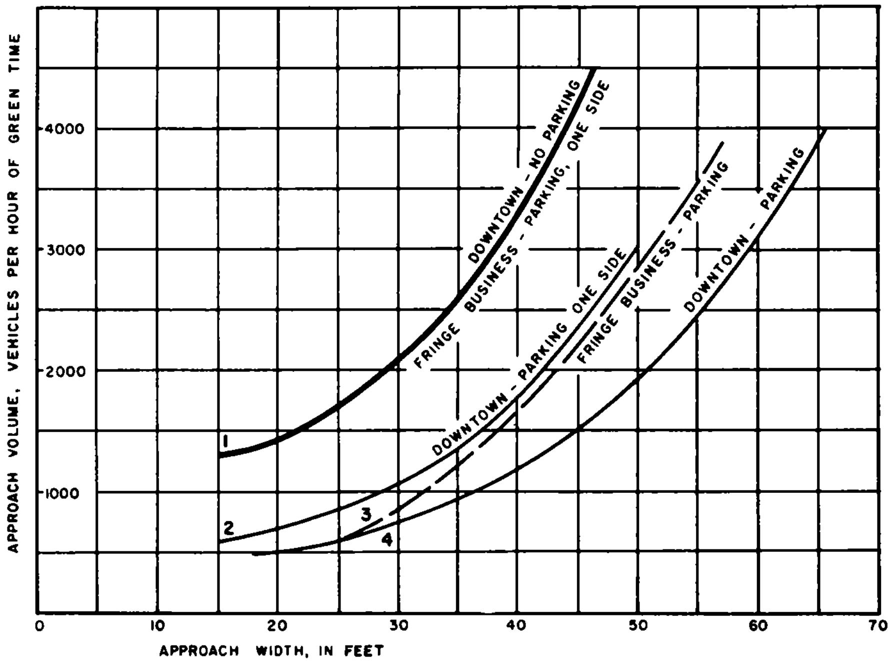


Figure 7. Intersection capacity, one-way streets.

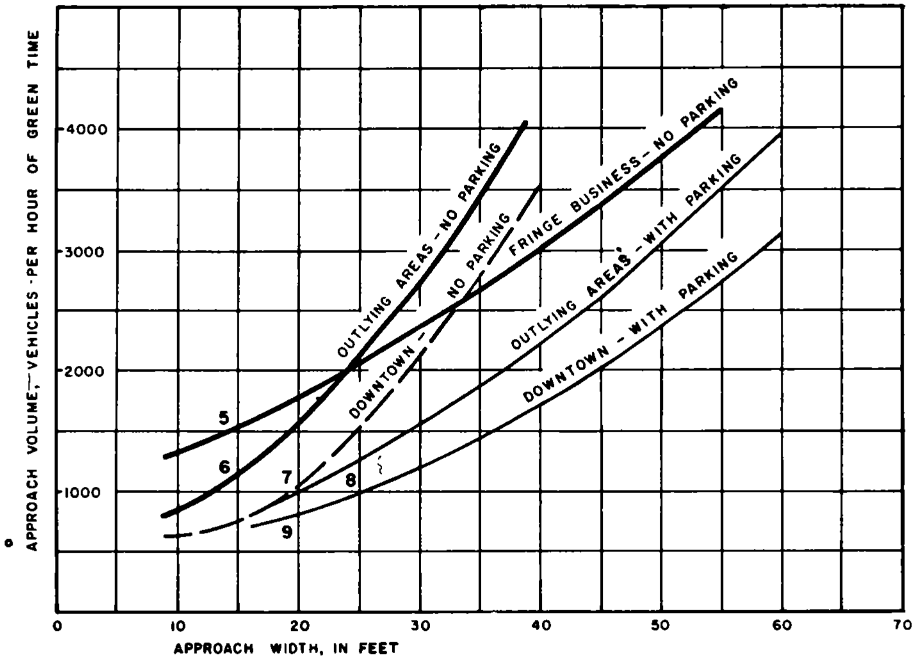


Figure 8. Intersection capacity, two-way streets.

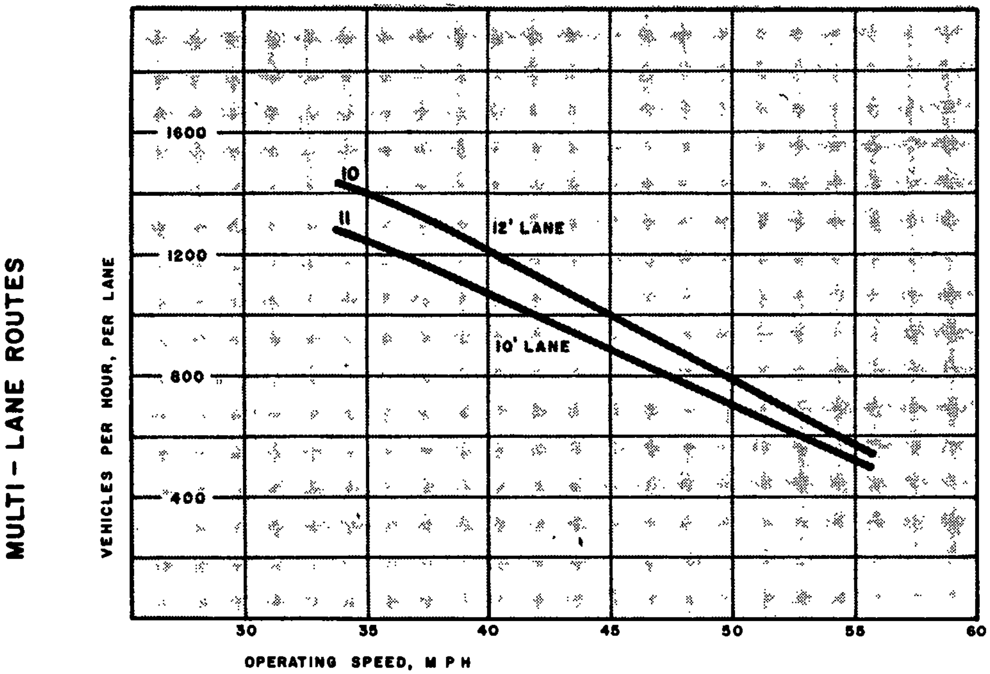


Figure 9. Capacity vs operating speed, multi-lane routes.

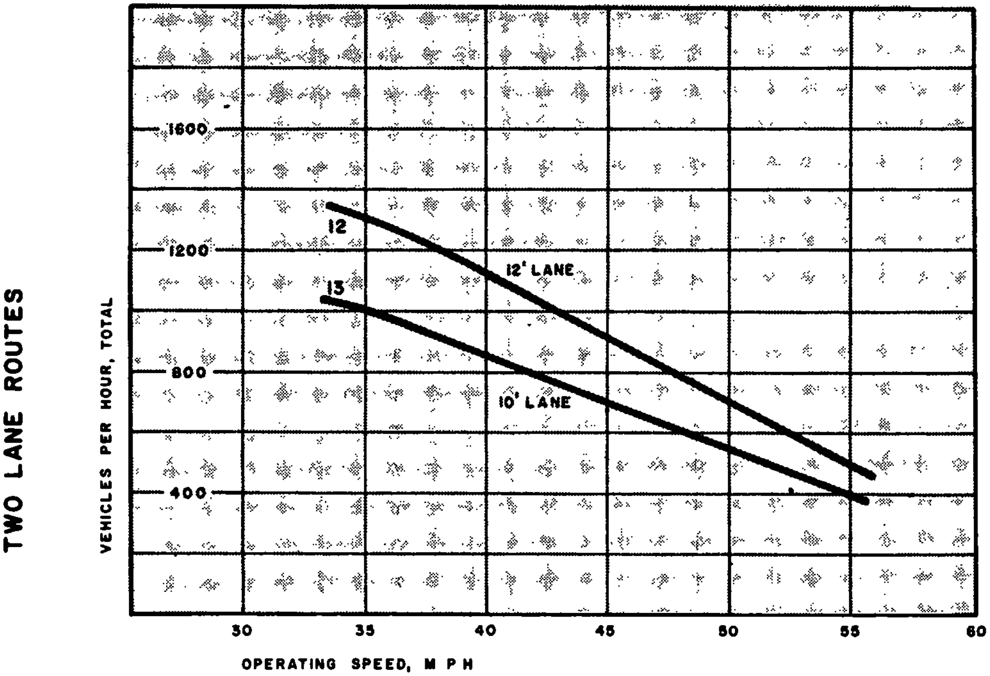


Figure 10. Capacity vs operating speed, two-lane routes.

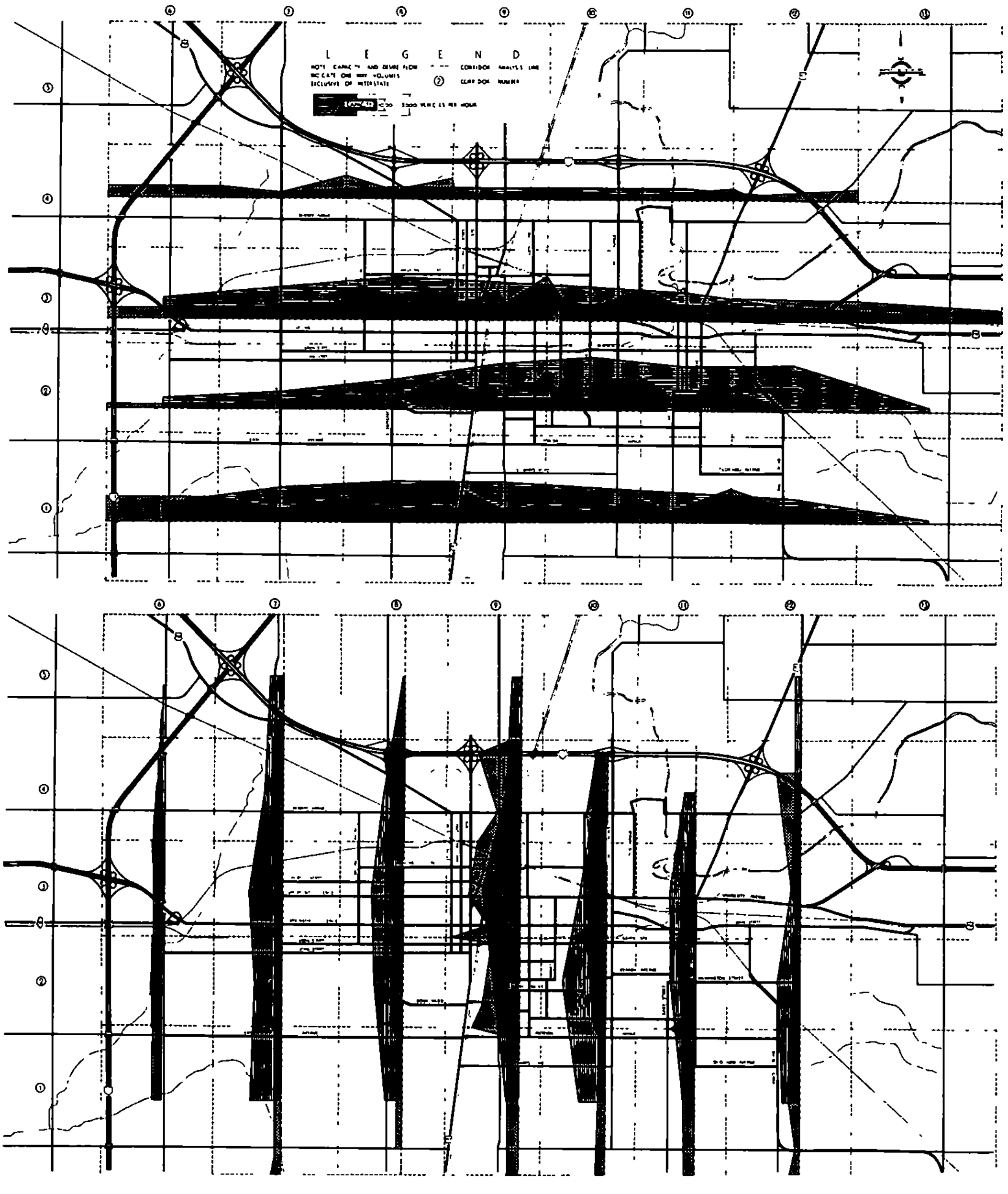


Figure 11. 1980 peak-hour desire flow, Champaign-Urbana, Ill., urban area.

average. However, a deficiency of 0- to 50-vehicle capacity during the peak hour is not normally considered sufficient to dictate a lane of deficiency at analysis line sections where there are no existing major streets in peripheral areas. Logically, arguments can be presented for using various figures other than 600 vehicles per hour per lane as a guide to the number of lanes of deficiency at an analysis screen line. Limited-access facilities can provide two to three times the lane capacity of a normal arterial street, which in itself varies considerably depending on the character of adjacent land uses. However, the "average value" approach proposed herein is con-

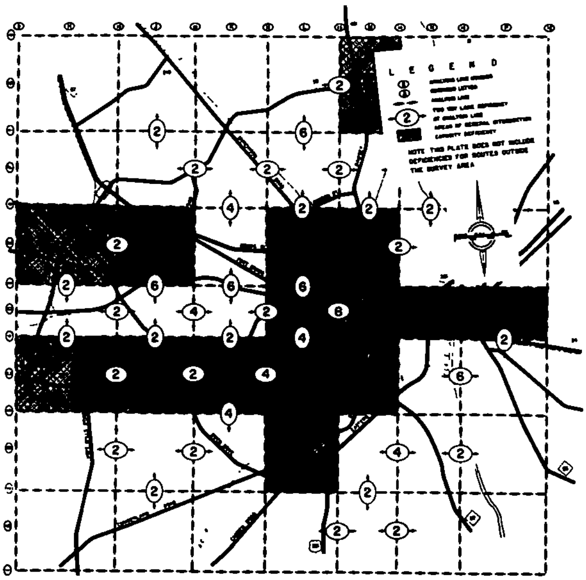


Figure 12. 1980 capacity deficiency, Fayetteville, N. C., urban area.

sidered best in view of the intent of the procedures and the fact that detailed analysis of specific street capacities are considered in later phases of the entire study.

Thus, the number within each ellipse in Figure 12 is considered the two-way traffic service requirement in lanes by location for the design year. In addition to lane deficiencies, Figure 12 also shows general intersection capacity deficiencies above the lane requirements as determined from Figure 11.

Although the capacity deficiencies for the existing major street network are indicated by areas, it is not axiomatic that proposed improvements by solely located in accordance with such deficiencies. This is due in part to the grouping of desires to depict deficient areas in a readily perceptible manner. Other considerations, particularly of an economic, planning, or aesthetic nature, may dictate that portions of the corridor desires be diverted to adjacent corridors.

The corridor analysis is an engineering-planning tool to aid in the development of a major street system rather than an unequivocal dictate of street and highway location. The capacity deficiencies are used in evaluating study plans to determine the traffic call for a particular lane capacity by location, and those thoroughfares that can meet such a traffic call are normally indicated in all trial study plans whereas other improvements are considered a lane service or long-range planning element. Thus the capacity deficiencies developed can be used to test the adequacy of any number of alternative plans being considered for implementation.

APPLICATION TO MAJOR STREET LOCATION PLANNING

The capacity deficiency analysis provides a sound guide to test families of plans and, in many instances, determine the necessity of various street elements. In addition to that guide, it is also necessary to consider physical factors influencing the desirable location of major streets for the study area involved. Figure 13 is an example of a summary of the principal factors affecting major street locations as prepared for a recent study. Primary traffic generators, daily train movements, substandard housing, existing grade separations, and other physical factors are among those items indicated. Other considerations include the location of existing streets relative to established neighborhoods, the degree of continuity afforded, and the existing standard of development of each route studied.

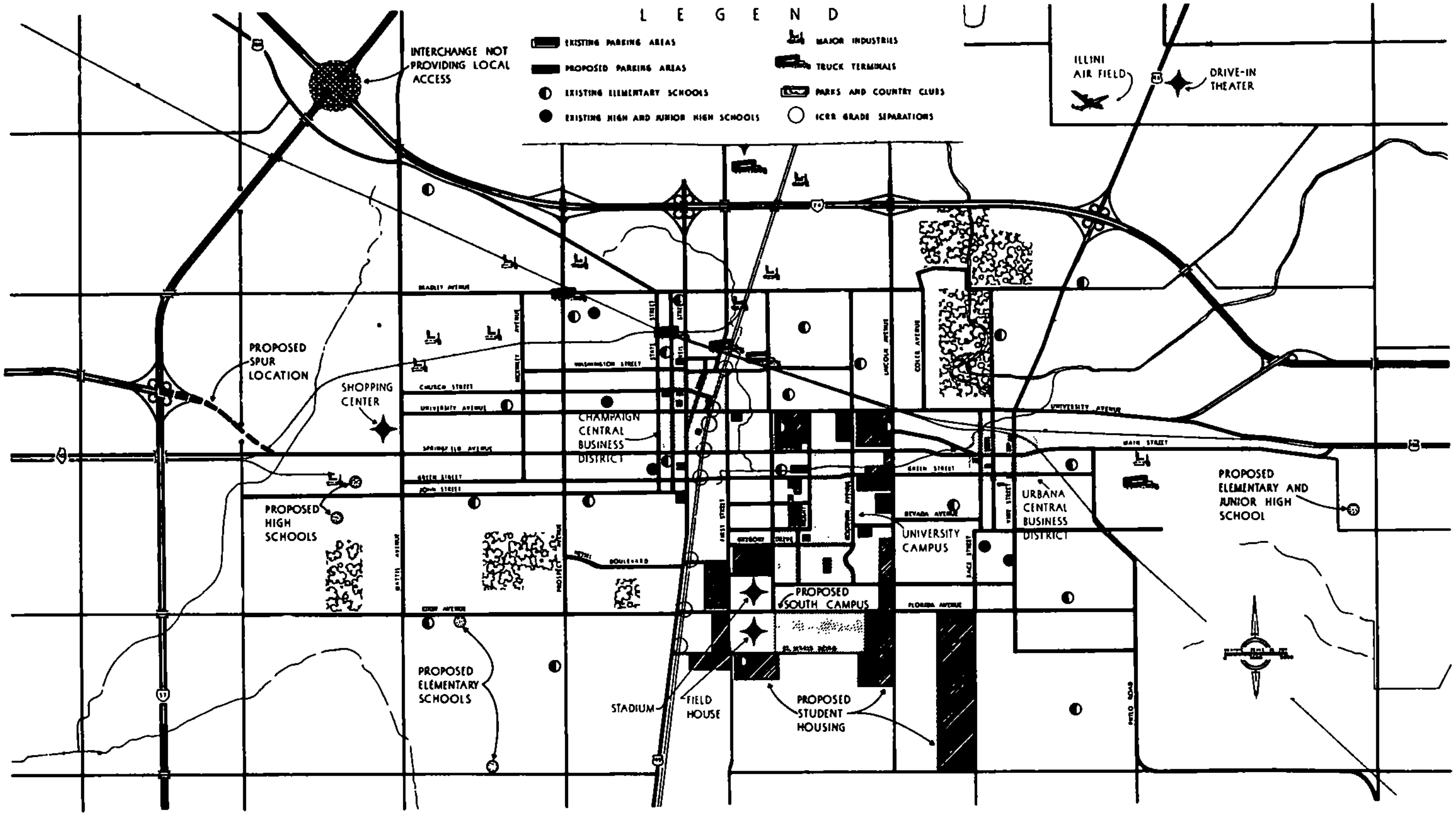


Figure 13. Factors affecting major street locations, Champaign-Urbana, Ill., urban area.

Testing Alternative Plans

The usual procedure followed in developing the final thoroughfare plan involves delineating on study plans the elements to meet design year traffic requirements, to meet land service requirements, and to provide possible long-range extensions. The design year capacity deficiencies in lanes provide a means of testing each plan studied. In addition, Figure 13 aids in the criticism of each study plan. A thorough knowledge of the area traversed by each street element is also necessary.

After the development of study plans, estimates of 24-hr volume levels for the design year are prepared for each street location possibility. This is accomplished by preparing an overlay for the study plan map on which the following data are indicated at each analysis screen-line section:

1. The true cardinal corridor desires.
2. The semi-assigned 45° corridor desires.
3. The semi-assigned "all other" desires.
4. The total design year desires.
5. The total existing desires.
6. The total existing volumes crossing that section on existing major streets.

Using these data, estimates are prepared for each tentative element of the study thoroughfare plans to indicate the volume level that desires to utilize each portion of the arterial street network. From study of the resulting information, in conjunction with an inventory of available rights-of-way and pavement widths, consideration is given to the level of development dictated for each route, the development of new limited-access facilities, and the necessity by the design year for each of the elements tentatively included. Revisions then are made as required to the study plans, to the volume levels tentatively assigned to routes, and to the level of development to be proposed for each element. This results in a final master thoroughfare plan as well as a guide for required developments by the design year.

In deciding the desirability of adding new limited-access route considerations and the question of inclusion or elimination of various elements, detailed analyses for specific sections of the study area may be required. Two examples of this are the CBD and a major river crossing. In these special studies it is often desirable to tabulate the desire crossings by categories as shown in Figure 14. This involves denoting by direction those desires crossing each analysis line section as well as those volumes terminating just across the analysis line. A typical tabulation for a CBD is given in Table 3. Such data facilitate preliminary estimates of volumes that may be diverted to limited-access facilities near the special section studies.

Traffic Assignment

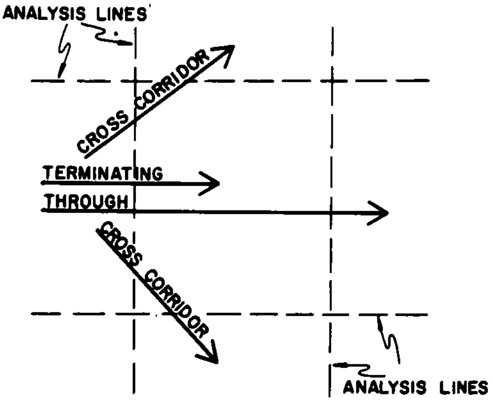


Figure 14. Corridor section, desire volume definitions.

On delineation of the master thoroughfare plan, including all limited-access facilities, a restudy of 24-hr volumes (design year) for each element of the plan may be necessary. Volumes for limited-access facilities are determined by travel-time ratio assignments using standard diversion curves. The remaining volumes are then assigned to specific streets of the network. A summary of the typical relationship between screen-line section desire crossings and actual major street volumes based on studies relating those items for existing conditions provides excellent guidance here. Generally speaking, the screen-line sections enclosing the

TABLE 3

SUMMARY OF CENTRAL BUSINESS DISTRICT CORRIDOR SECTION SPECIAL ANALYSES, 1980 DESIRE CROSSINGS, 24-HR

Analysis Line	True Cardinal	True 45°	All Other	Total	Cross-Corridor	Through	Terminating
4	4,900	3,500	14,200	22,600	5,700	3,900	13,000
5	6,900	7,600	14,200	28,700	12,800	3,900	12,000
13	11,200	12,300	30,600	54,100	10,600	4,500	39,000
14	3,400	4,800	14,200	22,400	7,900	4,500	10,000
Total	26,400	28,200	73,200	127,800	37,000	16,800	74,000

CBD indicate a 1.4 ratio of actual volumes to desire crossings. This can be compared to results from other research showing approximately 50 percent of the vehicles entering the CBD between 10:00 AM and 6:00 PM do not stop to park. Similar comparisons of actual and desire volumes for other analysis screen-line sections indicate ratios of 0.9 for intermediate areas and 0.8 for outlying areas. The ratio of actual major street volumes to desire crossings approximates 0.9 for study areas as a whole. The difference between actual and desire volume plus the approximately 10 percent of the desire trips (mostly intrazone) that do not cross analysis lines represent those volumes relegated to minor street travel.

Specific guidance is derived from each corridor screen-line tabulation, the limited-access route assignments, existing volume levels, or travel time studies for estimating design year 24-hr volumes. However, in developing a plan with guidance by the corridor analysis procedures discussed, arterial streets are located in accordance to desire volume demand resulting in a balanced location of traffic lanes. This enables minimizing differences in travel time via alternate arterial streets of equal length; thus travel time ratio assignments are only required where limited-access routes are involved.

Traffic assignments in thoroughfare planning normally involve assigning to a complete network of streets and highways which has been designed to minimize circuity and enable direct routing of desire trips. Traffic assignment may be thought of as the determination of the routes that people are most likely to use in getting from one place to another and in further determining how many vehicles will travel on each of the possible routes. The primary controllants are time of travel and distance of travel, with time seeming to be the primary determinant of route selection by most drivers.

Traffic assignment and traffic distribution on alternate routes should be carefully distinguished. Traffic assignment, properly done, reveals the amount of traffic that most logically is assignable to a given route by virtue of its location and its general characteristics. Assignment, for planning purposes, is most ideally an indication of what the driver would do on a generally free choice basis without the sometimes present restriction of route saturation. Traffic distribution to alternate routes is more an indication of what people do because of existing conditions. Traffic flow maps, for example, can be misleading to one who does not appreciate the fact that the relative amount of traffic on present routes might very well be where it is for the simple reason that there is no other way for this traffic to get from its origin to its destination.

Thus, through the use of the corridor analysis technique, the location of the elements of the thoroughfare plan is accomplished on a service of desire basis. It is then necessary to evaluate the ability of the area concerned to provide the entire system, to outline the required and proposed elements to be provided by the design year, and then to determine the level of development required for each section on the basis of traffic assigned to the elements proposed for construction by the design year. These programed developments require periodic review, as does the thoroughfare plan, and the corridor analyses aid greatly in these steps.

CONCLUSION AND SUMMARY

The preceding discussion presents in general terms a procedure for analyzing street and highway requirements for an urban area as well as a technique for testing alternative plans proposed for the major thoroughfare network for that area. Among other things, the procedure enables designation of design year capacity deficiencies by area to determine the number of new facilities required for adequate service as well as an estimate of traffic assignable to the entire street network proposed. Desire volume data are based on tabulations in origin-destination desire charts which can be easily adjusted to reflect major changes in land use at a later date, if the need arises. These adjustments are simply added to, or deducted from, the original desire tabulations, to permit re-evaluation of lane requirements.

This generalized technique is still being refined and modified as it is utilized in various studies throughout the country. The procedures presented for major thoroughfare studies represent those currently considered appropriate for typical analyses, although special mitigating circumstances often dictate modifications. Among the areas currently being researched are the following:

1. Which tabulations are most meaningful for most studies, and which are supplementary or of secondary benefit?
2. Is there a significant difference between the two methods for determining peak-hour, one-way desire volume, the two methods being factoring down from (a) 24-hr data, and (b) peak-hour data tabulations, which would require separate projections.
3. What is the desirable scope of computer program(s) to accommodate desire volume tabulations? The existing working program, although a tested and reliable one, has been designed primarily to provide great versatility of application in aiding the researches involved in defining procedures.
4. To what degree do shifts in contemplated land uses, or trip generation, or trip linkages between zones, actually affect the lane calls for the entire urban area?

Also, the general procedures discussed here have application in such studies as mass transit requirements, special truck routings, or even pedestrian movements. The corridor analysis technique can be adapted to small city studies or to regional studies, as the need arises. The discussion in this article are oriented towards urban are populations of approximately 100,000. The procedurial outline in the Appendix is also generalized and certain sections must be expanded or simplified, depending on the study area involved.

ACKNOWLEDGMENTS

The authors wish to thank the North Carolina State Highway Commission for use of Figures 1, 4, 5, 6, and 12, and the Illinois Division of Highways for Figures 2, 3, 11, and 13.

PROCEDURAL OUTLINE FOR CORRIDOR CAPACITY DEFICIENCY STUDY

1. General

A. The indication of capacity deficiencies by corridor sections provides a guide for the location of major streets in an urban area. In addition, it indicates the degree of development required for the major street network. This generalized outline provides a basic guide for the typical capacity-deficiency analysis. However, for a specific application of this procedure, certain sections of the outline may require expansion while other sections may be grossly simplified due to the nature of development within the area.

B. Although the final capacity deficiencies for the existing major street network are indicated by areas, it is not axiomatic that proposed improvements be solely located in accordance with such deficiencies. Other considerations, particularly of an economic, planning, or aesthetic nature, may dictate that portions of the corridor desires be diverted to adjacent corridors. This is an engineering-planning tool to aid in the development of major street planning rather than an unequivocal dictate of street and highway location.

C. The following phases of study must be completed prior to a corridor capacity-deficiency analysis.

(1) Land-use projection to design year.
(2) Design year traffic origin and destination desires by zones.
(3) Location of analysis zone centroids for design year.
(4) Designation of the existing major street system.

D. Examples of the forms used are reproduced at the end of this outline.

2. Corridor Designations

A. Determine the basic orientation of the existing major street network.

B. Designate cardinal corridors generally paralleling the existing major street network by establishing the location of the analysis screen lines. These analysis screen lines generally should be designated so that

(1) Each is a straight line parallel to either the designated x or y axis.
  a. The x and y axes are at right angles to each other.
  b. The x and y axes are established generally parallel to the basic major street network.
(2) Each pair of parallel lines forms a cardinal corridor.
(3) No line crosses the intersection of two existing major streets.
(4) No line crosses through any design year analysis zone centroid.
(5) All lines follow as closely as possible the analysis zone boundaries. (Zones must be split and trip linkages re-estimated if necessary.)
(6) The CBD (central business district) is enclosed by sections of four analysis screen lines.
(7) Where possible, lines should generally follow
  a. Main line railroad tracks.
  b. Rivers.
  c. One side of an existing expressway.
  d. Other elements where it is desirable to know design year volume crossings.
(8) The cardinal corridors formed should be
  a. Approximately $\frac{3}{4}$ to $1\frac{1}{2}$ mi wide.
  b. Narrower near the CBD and wider near the fringes.
  c. Located to include at least one major through street where possible.

C. Designate supplementary corridors at an angle to the cardinal corridors.

(1) Generally there will be at least one set oriented at approximately a 45°

angle to the x and y axes. Quite often several supplementary orientations will be necessary to study specific desires.

(2) Conceivably could have radiating wedges or radials and circumferentials can be considered in travel time ratio assignments to separate corridors in a later step.

(3) Analysis screen lines are generally designated in the same manner as in step B, but at an angle to the x and y axes.

D. Prepare exact scale maps to indicate the locations of existing major streets, the analysis zone centroids, and each set of corridors. Analysis zone centroids are determined by locating the approximate center of traffic generation by the design year within each zone. These maps will then be used in the following analysis steps:

(1) Coding for computer analysis, if used.
(2) Designation of study locations for limited-access facilities (expressways).
(3) Designation of movements that could conceivably use expressways.
(4) Determining travel time estimates for percent of diversion of traffic to expressway and limited-access locations.

E. Designate study locations or probable locations for limited-access facilities. These locations should be relatively general at this stage and may be thought of as special "corridors" rather than exact thoroughfare locations.

(1) Locations should be indicated on a work map with the existing major streets, the cardinal corridors, and the analysis zone centroids.
(2) Traffic assignments will be made to all locations warranting detailed study. Such assignments will be made on a travel time ratio basis.

3. Analysis Procedure

A. General

(1) The primary purpose of a corridor analysis is to tabulate the design year desire volumes by locations and compare these to the capacity potential of the existing major street system.

(2) Existing limited-access facilities must be given special consideration. This includes facilities planned and located but not yet constructed.
   a. Traffic assignments should be made to these facilities utilizing standard traffic diversion curves relating travel time ratios to percent of traffic diverted.
   b. In determining capacity deficiencies of the basic street system, routing of volumes assigned to existing limited-access facilities must reflect travel to and from the facility interchanges rather than as straight line desires from origin to destination.

(3) True corridor desires should be developed to study possible locations for radials, circumferentials, or other limited-access faciliites. True corridor desires are those desires wholly within a single given corridor.

B. Mechanical (Hand) Procedure for Desire Tabulations

(1) Assign traffic to existing limited-access facilities by travel time ratios.

(2) Tabulate on form CD-1 desires falling entirely within cardinal corridors as determined by locations of analysis centroids with respect to the corridors (true corridor desires).
   a. Through, local, and internal movements should be tallied separately.
   b. All zones with centroids located to provide desire movements cleanly within a corridor are included.
   c. Volumes assigned to limited-access facilities should be excluded (use form CD-2) but must be included in corridors leading to the expressway.

(3) Tabulate desires falling within secondary corridors as determined by location of analysis centroids (form CD-1). Some movements still may be

unassigned after this step, depending on the number of secondary orientations used.

(4) Tabulate all other desires on the appropriate screen lines, using CD-1. This results in semi-assignment of the desires to the various corridor orientations.

(5) Prepare graphic representation of each of the desire tabulations.

(6) From data previously prepared, determine locations of circumferentials and/or radials requiring detailed special analysis.
  a. These normally consist of considerations for limited-access facilities because the cardinal and secondary corridor tabulations will enable considerations of normal major streets.
  b. Existing routes or special locations can be included.
  c. Designate locations as separate special corridors.

(7) Assign desires to special corridors by travel time diversion curves and tabulate on form CD-2.
  a. Assigned desires previously indicated in cardinal or secondary corridors must be deducted from those corridors for determining final 24-hr volumes.
  b. Travel time ratios and the percent diversion are tabulated on form CD-4 for each zone-to-zone or station-to-station movement. Form CD-2 is then used in tabulating these movements as they cross various screen lines.

(8) Assign all secondary corridor desires to cardinal corridors as necessary.
  a. Consider straight line movements from zone centroid to zone centroid.
  b. Tabulate the total desires and each cardinal analysis line that it crosses.
  c. This results in semi-assigned desires to the various cardinal corridor sections.
  d. Exclude desires assigned to limited-access facilities.

(9) Investigate the desirability of eliminating or adding new "special" corridors.
  a. Repeat assignments if changes warrant such.
  b. Proceed if assumed special corridors are justified.
  c. The cardinal corridors contain the desires that the major street network must accommodate.
  d. The special corridors must provide adequate lane capacities for the assigned desire volumes.

(10) Summarize cardinal, secondary, and special corridor desire information on form CD-3.
  a. Through, local, and internal desires are separated.
  b. Through desires and assigned or semi-assigned desires are separated.
  c. Peak-hour volumes are calculated using corridor percentage factors.

C. Desire Tabulations by Electronic Computer (IBM 704)

(1) This program was developed to trace desires as straight-line movements from zone or station centroid to zone centroid and tabulate all desire volumes crossing each screen-line section. Each of these movements can be traced and tabulated six separate times with one different factor being applied each time and the values then being totaled on a single set of analysis screen lines. This is possible for two sets of analysis lines for each run of the computer. This enables the following:
  a. Including only true corridor desires by applying either a 1.00 or 0.00 factor to each movement, depending on its orientation with respect to the corridors.
  b. Excluding a percentage of a movement that has been assigned by travel time ratio to a limited-access facility.
  c. Excluding movements (0.00 factor) that have previously been placed in a corridor series.
  d. Factoring down (or up) to change the volume to represent a different design year. (Care must be exercised to insure that the zone centroid location changes are properly evaluated).

e. Separating through, local, and internal desires; although this may also be done by introducing a different deck of cards representing the trip data.

f. Factoring 24-hr volumes to peak-hour volumes, secondary peaks, etc.

(2) Coding procedure

a. The instruction cards to the computer consist of
  1. Basic instruction deck (same for each problem).
  2. Trip data cards.
  3. Cardinal screen lines.
  4. Secondary screen lines (one set only per run).
  5. Zone centroid coordinates.
  6. Control cards.

b. Trip data cards
  1. Each zonal movement (i.e., a movement from an origin zone or station to a destination zone or station) is represented by a trip data card in giving input data to the computer. An example of the code sheets for this card is form CD-6.
  2. The groups of factors are used to tell the computer whether to include or exclude (or the proportion to include) the volume listed in columns 13 to 18 in the particular tabulation on the respective analysis screen lines. This could enable, for example, the following tabulations for a given run of trip data cards through the computer:
    (a) The A-1 factor could be used to indicate those zone-to-zone movements that are true cardinal corridor movements.
    (b) The A-2 factor could be used to indicate (by punching either 100 or 000) those movements that are not cardinal corridor oriented and are not in the secondary corridors (are "all other" movements).
    (c) The A-3 factor could be used to indicate the percentage of the volume in columns 13 to 18 which was not travel time ratio assigned to an expressway.
    (d) The A-4 factor could then always be 1.00 which would enable calculations of all movements within the area as tabulations on the cardinal screen lines.
    (e) Another possible use of the factors would be to indicate a percentage of each volume to be included to show that portion of the total volumes which was assigned to a particular expressway system. The same percent diverted to the expressway would be used as the factor for that tabulation.
    (f) A similar series of factor uses could be made with the group B factors which would be tabulated on the secondary screen lines rather than the cardinal screen lines.

c. Cardinal screen-line cards
  1. The cardinal screen lines are coded as card 2 using form CD-7. (This same form is used for coding the secondary screen lines)
  2. Each analysis screen line for the cardinal corridor network is defined by rectangular coordinates.
  3. The coordinates used can be taken from the basic map indicating locations of the screen lines and the analysis zone centroids, but care must be exercised to insure that the analysis screen lines are indeed rectangular. It is recommended that the map of the area which indicates the location of analysis screen lines and zone centroids should be developed at an appropriate scale to include the entire area easily. Measurements should then be made from the x and y axes to provide the necessary coordinates.

d. Secondary screen lines
  1. These analysis screen lines are defined on form CD-7 and are indicated as card 3.

2. The secondary screen lines will be at an angle to the cardinal screen lines or corridors. No matter what the exact angle is, the following is the recommended procedure for determining coordinates for screen line entries.
   (a) Prepare a map to scale indicating the locations of the zone centroids to be utilized in the study and the locations of the x and y axes. (The x and y axes have been defined in previous sections and consist of the cardinal analysis screen lines that are the farthest to the left and the farthest to the bottom of the map of the area.)
   (b) Prepare in sketch form as an overlay the general locations desired for the secondary corridors and therefore for the secondary analysis screen lines.
   (c) Plot one of the analysis screen lines on the previously prepared map.
   (d) Determine from the single secondary screen line the slope of the line with respect to the x and y axes.
   (e) Determine graphically by measurement the coordinates of one point on the first secondary screen line in terms of the x and y axes. Enter on form CD-7.
   (f) Calculate the x and y coordinates of the second point by using the slope previously calculated. Enter on form CD-7.
   (g) Locate the next secondary screen line on the base map and determine the x and y values for point one by measurement.
   (h) Determine the x and y coordinates of point two by applying the slope determined for the first secondary screen line. (This is necessary in order to insure that line 2 is parallel to line 1.)
   (i) Make the appropriate entries on form CD-7 for this screen line.
   (j) Continue in this manner until all of the analysis screen lines parallel to the first line have been entered.
   (k) Prepare the secondary analysis screen lines perpendicular to the first set of secondary analysis screen lines using the slope of the first secondary screen lines defined so that the two sets of screen lines are indeed perpendicular to each other. (If the slope of the first set is 1.1/1.2, the slope of the second set of lines becomes -1.2/1.1.) Determine coordinates for the remaining screen lines in the same manner as the coordinates were determined for the previous screen lines. Make all entries on form CD-7.

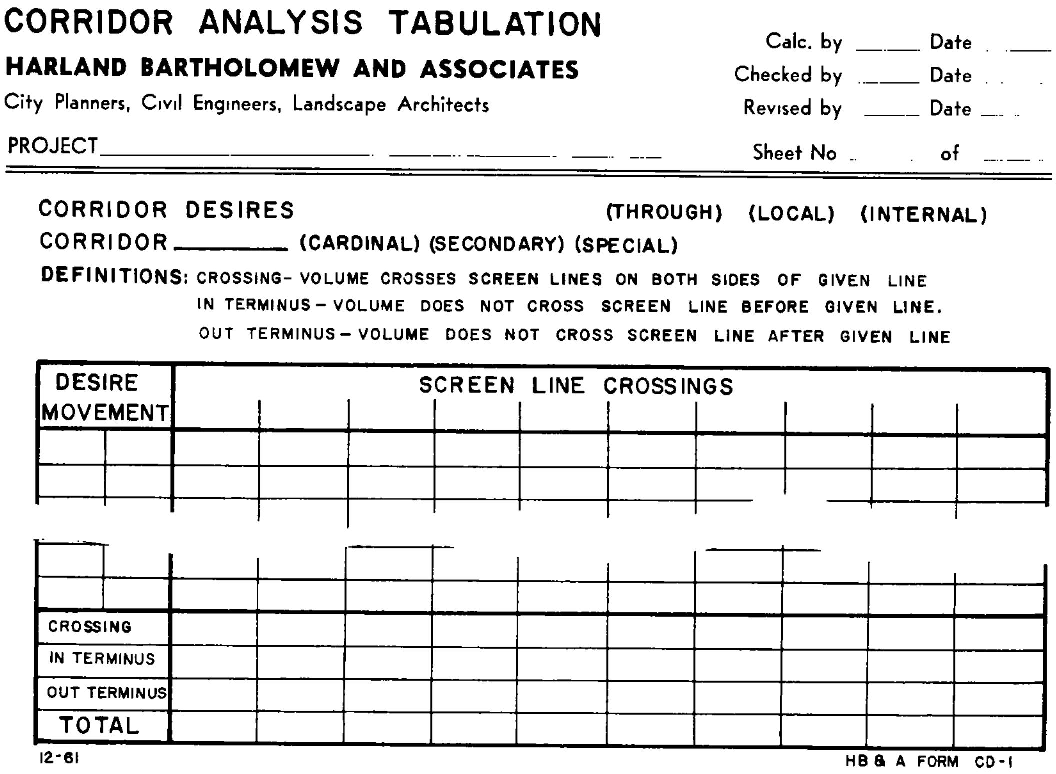
e. Zone centroid coordinates
   1. The coordinates of each zone or station centroid are entered on a separate card punched from data on form CD-8.
   2. From the basic map indicating the location of the zone centroids and the x and y axes for the cardinal corridors, the coordinates of the zone centroids are measured using the same scales which were used in determining coordinates for the analysis screen lines. The appropriate entries are made on form CD-8.

f. Control card
   1. Each control card is coded to indicate the number of number 2 cards; the number of A factors to be applied; the number of number 3 cards; and the number of B factors to be applied.

g. It is also recommended that for each study a tabulation be made of all the trip data cards (card 1) to indicate the total volume punched into columns 13 to 18 for each run. This tabulation will provide a check to be sure that all zone movements have been included and that no sheets have been lost in the process of data punching. Additional consideration should be given in this tabulation to totaling those volumes included by 1.00 factors in order to be able to compute a percentage of the total traffic desires included in that factor application. For example, this would enable indicating the cardinal corridor-oriented desires as a percent of the total desires within the area.

(4) The following corridor desire tabulations should be made for all studies for all analysis lines in order to evaluate desire movements properly.
  a. True desires within each corridor orientation.
  b. "All other" desires.
  c. 24-hr semi-assigned desires (includes all movements).
  d. 24-hr semi-assigned desires corrected for movements to limited-access facilities (special corridors).
  e. True desires for secondary corridors exclusive of movements that are also a true cardinal corridor desire.

(5) Other tabulations will be necessary, depending on the particular area being studied.



CORRIDOR ANALYSIS TABULATION

HARLAND BARTHOLOMEW AND ASSOCIATES
City Planners, Civil Engineers, Landscape Architects

Calc. by ______ Date ______
Checked by ______ Date ______
Revised by ______ Date ______

PROJECT ______________________________

Sheet No ____ of ______

CORRIDOR DESIRES (THROUGH) (LOCAL) (INTERNAL)
CORRIDOR ________ (CARDINAL) (SECONDARY) (SPECIAL)

DEFINITIONS: CROSSING- VOLUME CROSSES SCREEN LINES ON BOTH SIDES OF GIVEN LINE
IN TERMINUS - VOLUME DOES NOT CROSS SCREEN LINE BEFORE GIVEN LINE.
OUT TERMINUS - VOLUME DOES NOT CROSS SCREEN LINE AFTER GIVEN LINE

DESIRE MOVEMENT		SCREEN LINE CROSSINGS									
CROSSING											
IN TERMINUS											
OUT TERMINUS											
TOTAL											

12-61

HB & A FORM CD-1

CORRIDOR ANALYSIS TABULATION

HARLAND BARTHOLOMEW AND ASSOCIATES

City Planners, Civil Engineers, Landscape Architects

Calc by ______ Date ______
Checked by ______ Date ______
Revised by ______ Date ______

PROJECT ______________________________

Sheet No ______ of ______

ASSIGNED CORRIDOR DESIRES (THROUGH) (LOCAL) (INTERNAL)
CORRIDOR ______ (CARDINAL) (SECONDARY) (SPECIAL)

SCREEN LINE CROSSINGS																									
% ASSIGN																									
24 HR. VOLUME																									
DESIRE MOVEMENT																						CROSSING	IN TERMINUS	OUT TERMINUS	TOTAL

12-61

HB & A FORM CD-2

CORRIDOR ANALYSIS TABULATION

HARLAND BARTHOLOMEW AND ASSOCIATES

City Planners, Civil Engineers, Landscape Architects

PROJECT ____________________

Calc. by ______ Date ______
Checked by ______ Date ______
Revised by ______ Date ______
Sheet No ______ of ______

CORRIDOR DESIRE SUMMARY

CORRIDOR ________ (CARDINAL) (SECONDARY) (SPECIAL)

SCREEN LINE	DESIRES FROM	SEMI-ASSIGNED DESIRES						24 HR VOLUME	PEAK HOUR %	DIRECTIONAL DISTRIBUTION	ONE-WAY PEAK HOUR VOLUME	PRACTICAL CAPACITY
		THROUGH		LOCAL		INTERNAL						
		ACROSS SECTION	SECTION TERMINUS	ACROSS SECTION	SECTION TERMINUS	ACROSS SECTION	SECTION TERMINUS					
	CD–1							▨	▨	▨	▨	▨
	CD–2							▨	▨	▨	▨	▨
	TOTAL											
	CD–1							▨	▨	▨	▨	▨
	CD–2							▨	▨	▨	▨	▨
	TOTAL											
	CD–1							▨	▨	▨	▨	▨
	CD–2							▨	▨	▨	▨	▨
	TOTAL											
	CD–1							▨	▨	▨	▨	▨
	CD–2							▨	▨	▨	▨	▨
	TOTAL											
	CD–1							▨	▨	▨	▨	▨
	CD–2							▨	▨	▨	▨	▨
	TOTAL											
	CD–1							▨	▨	▨	▨	▨
	CD–2							▨	▨	▨	▨	▨
	TOTAL											
	CD–1							▨	▨	▨	▨	▨
	CD–2							▨	▨	▨	▨	▨
	TOTAL											
	CD–1							▨	▨	▨	▨	▨
	CD–2							▨	▨	▨	▨	▨
	TOTAL											

12-61

HB & A FORM CD-3

HARLAND BARTHOLOMEW AND ASSOCIATES

City Planners, Civil Engineers, Landscape Architects

PROJECT ______

Calc by ______ Date ______

Checked by ______ Date ______

Revised by ______ Date ______

Sheet No ______ of ______

TRAFFIC DIVERSION ESTIMATES

ROUTE A ______

DESIRE MOVEMENT		TRAVEL TIMES ROUTE A	ROUTE B	ROUTE C	RATIO B/A	% DIVERTED	RATIO C/A	% DIVERTED

HB&A FORM CD-4

HARLAND BARTHOLOMEW AND ASSOCIATES

City Planners, Civil Engineers, Landscape Architects

PROJECT ______

Calc by ______ Date ______

Checked by ______ Date ______

Revised by ______ Date ______

Sheet No. ______ of ______

CAPACITY ANALYSIS
CORRIDOR ______

LOCATION		CONDITIONS	CURVE AND CHART REFERENCE	CAPACITY SECTION	CORRIDOR

12-61

HB & A FORM CD-5

CORRIDOR ANALYSIS CODING SHEET – TRIP DATA

HARLAND BARTHOLOMEW AND ASSOCIATES

City Planners, Civil Enginee Landscape Architects

PROJECT ______________________

Calc. by ______ Date ______
Checked by ______ Date ______
Revised by ______ Date ______
Sheet No ______ of ______

CARD NUMBER 1 (1)

CITY NUMBER ☐☐ (78 79) RUN NUMBER ☐ (80)

SERIAL NUMBER					ORIGIN ZONE			DEST ZONE			VOLUME						GROUP A FACTORS																		GROUP B FACTORS																	
																	A 1			A 2			A 3			A 4			A 5			A 6			B 1			B 2			B 3			B 4			B 5			B 6		
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54

HB & A FORM CD6

CORRIDOR ANALYSIS CODING SHEET

HARLAND BARTHOLOMEW AND ASSOCIATES

City Planners, Civil Engineers, Landscape Architects

PROJECT ____________________

Calc by ______ Date ______
Checked by ______ Date ______
Revised by ______ Date ______
Sheet No ______ of ______

CARD NUMBER ☐ 1

______ SCREEN LINES

CITY NUMBER ☐☐ 78 79

RUN NUMBER ☐ 80

SERIAL NUMBER					LINE NR			POINT 1										POINT 2									
								X_1					Y_1					X_2					Y_2				
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29

HB & A FORM CD-7

CORRIDOR ANALYSIS CODING SHEET

HARLAND BARTHOLOMEW AND ASSOCIATES

City Planners, Civil Engineers, Landscape Architects

PROJECT ____________________

Calc by ______ Date ______
Checked by ______ Date ______
Revised by ______ Date ______
Sheet No. ______ of ______

CARD NUMBER 4 1

ZONE CENTROID COORDINATES

CITY NUMBER ☐☐ 78 79

RUN NUMBER ☐ 80

SERIAL NUMBER					ZONE NR			COORDINATES									
								X					Y				
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

HB& A FORM CD-8

Forming a Comprehensive Transportation Flows Model

ANTHONY R. TOMAZINIS and GEORGE V. WICKSTROM, respectively, Chief, Transportation Flow Simulation Section, and Director, Transportation Division, Penn-Jersey Transportation Study, Philadelphia

• DURING THE 1950's a number of urban transportation studies have been carried out by special ad hoc agencies or other organizations in an increasingly comprehensive manner. Significant improvements in both basic study philosophy and analysis methodology have greatly contributed to increased understanding of the complexity and peculiarities of the urban transportation problem.

One of the main objectives of a transportation study is to reproduce or "simulate" (within accepted limits of accuracy) traffic flows within the region based on present or future land-use characteristics. This process of simulation has developed during the past few years and several different approaches have been used by various study groups. These different approaches represent different philosophies regarding the nature of transportation movement and its relationship with lane-use patterns and transportation systems. These relationships are expressed in a "transportation flows model" (Fig. 1) which incorporates various techniques to simulate the over-all pattern of movement at any given time and in response to given inputs of fundamental importance to the entire process.

When the Penn-Jersey Transportation Study started its work early in 1960 various models in actual use by other major studies included components that were well developed as well as components in a preliminary stage of development. It was soon realized that changes made to any of the several component parts of a model would in turn affect the form and structure of the entire model. This realization made it apparent that it would not be possible to outline a new (or a final) transportation flow simulation model satisfactorily before outlining basic methods of analysis. There was the alternative, of course, of adapting the complete model package of some other study, but even forgetting for the moment the philosophical issues of approach within the transportation model, analysis techniques used to determine some of the main components of these transportation models were still in the development stage and thus within the range of constructive debate. Besides, Penn-Jersey techniques for predicting intraregional changes of lane-use activity were basically different in design than those used by any other study, a fact which was further complicating any quick adaptation of other studies' techniques. (Penn-Jersey Transportation Study has undertaken to project future land-use patterns with the aid of a mathematical elaboration of verified locational relationships within the region. This attempt, referred to as a "regional growth model" is to encompass all the other submodels of the study. Thus the "transportation flow simulation model" is one submodel within the regional growth model.)

In response to the previous considerations, efforts were oriented to design a transportation flow simulation model that (a) would be expressing the authors' philosophical approach, and (b) would consist of techniques that would explicitly indicate relationships to be investigated and clarify the analytical process to be followed in each case.

Some of these techniques represent departures from the comparable steps in existing models or are new elements introduced by the Penn-Jersey staff. Their brief elaboration might serve to explain their relative importance and at the same time make clear the analysis they indicate. Portions of this model have been used in simulating 1947 travel patterns and are in the Philadelphia region currently being used in simulating 1960 travel patterns within this region.

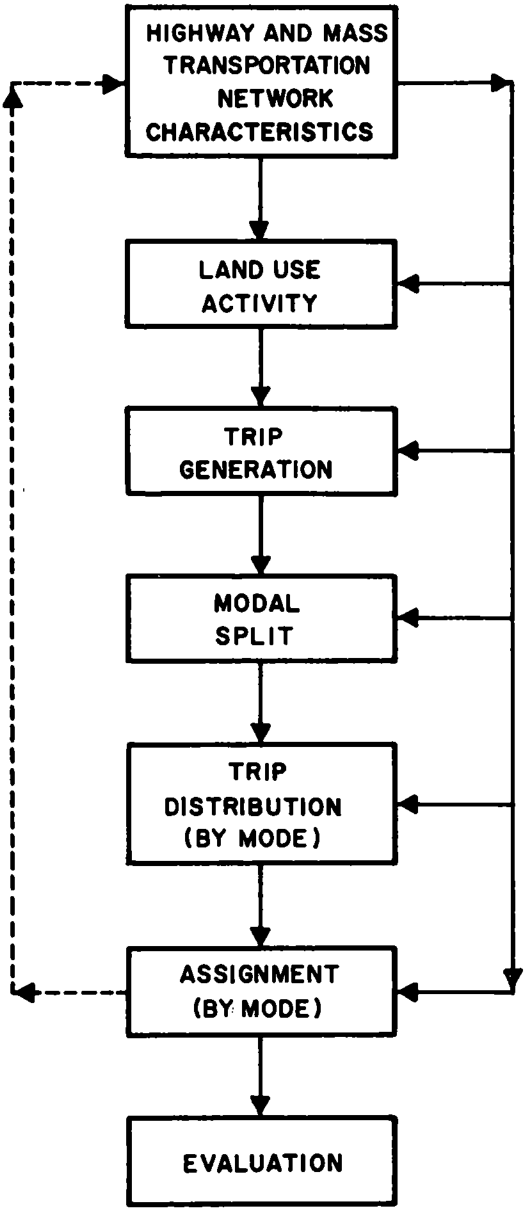


Figure 1. Simplified chart of transportation flows model.

TRIP GENERATION ANALYSIS

In general, the first step in a transportation flow model is the simulation of total trips generated (produced and attracted) within the various parts of the region. The multiple regression technique used in this analysis is the one established by other transportation studies.

The output of the trip generation model component should be the total person-trips generated by each activity and in turn by each subarea of the region, without regard to travel mode. Mass transit trips are included in the projection of total trips because this inclusion expresses an approach according to which the total person-trips generated by an activity are estimated as the basic unit of the trip generation propensities of an activity. This approach was chosen primarily because of a belief that the total person-trips generated by a unit of an activity is a more stable and meaningful estimate than any estimate of auto and transit trips taken separately. It can also be said that in many respects total person-trips can be more confidently projected to a future year than a segmental projection of trips by particular modes or for particular trip purposes. (However, this statement should not be interpreted that, after the projection of total person-trips has been carried out, subsequent estimations of trips by purpose should not or could not be carried out.)

Another point in the analysis approach is the inclusion of accessibility factors which affect the total trip generation propensities of an activity in an area. These accessibility measures are correlated with the amount of trips generated by each activity, and are described in terms of the amount of jobs, retail trade, and population located within certain increments of driving and riding time.

The third significant point is the separate generation of truck trips expressed as an aggregate of truck trips generated by the combination of all activities located within each subarea of the region. Only for special large-scale activities with a sufficient number of data observations is there an attempt to estimate truck trip generation rates per unit of activity.

MODAL SPLIT

The second step of the transportation flows model deals exclusively with the manner in which mass transportation trips in a region can be simulated and in turn be projected at any given time in the future.

The amount of travel in any area by public and private modes of travel has been considered to be primarily dependent on three major variables:

1. Automobile ownership.
2. Intensity of land use.
3. Relative time and cost of travel by mass transportation vs the automobile.

Methods used in other studies to estimate future mass transportation trips are either the automobile ownership-residential density method or the travel time ratio diversion curve method. Neither method, if used alone, can satisfactorily explain the division of total trips into modes of travel.

The approach here is to express mass transportation trips as a percentage of the total trips generated in each subarea. With this percentage as the dependent variable various characteristics of the subarea itself are used as independent variables in a multiple correlation analysis.

These characteristics include three groups of variables which could be classified as "user variables," "area variables," and "accessibility variables." User variables are those expressing the "kind" of people living in a district; e.g., income, automobile ownership, education level, population, and age distribution.

A number of variables express the "area type" in general terms. These variables are the net residential and employment densities and the school population (enrollment) in the district.

The "accessibility variables" comprehensively express the relative accessibility provided to an area by each of the two major transportation systems, namely, the highway network and the mass transportation network. One of these variables defines a concept of "time accessibility" and the other a concept of "cost accessibility." They are determined as follows. The trip generation analysis provides total person-trip destinations in each subarea. Each subarea is referenced to all others by travel time, by mode determined from the highway and transit networks coded in a computer assignment program. A set of bands (called time codes) is formed of trip ends within certain upper and lower time limits from each area. This is done for auto travel as well as for mass transit travel. Then ratios are calculated for each area between the cumulative total person-trip desitnations within each auto time code and its corresponding transit time code. The arithmetic mean of these ratios enters the analysis as one continuous variable.

A similar procedure establishes a set of ratios and an arithmetic mean of a number of "cost codes" in the region, using cost rather than time increments for both systems. These two variables are of particular importance because they introduce aspects of the urban environment (e.g., the distribution of trip opportunities in the region) into the analysis and also incorporate any proposed changes in routes, speeds, or costs of travel in either of the two transportation systems.

Conceptually, this approach of generating mass transit trips does not require a separate analysis of mass transit trips by special purposes (e.g., to school) or to special destinations (such as the CBD).

TRIP DISTRIBUTION

When all aspects of the trip generation analysis by mode of travel are completed, the third step of the transportation flow model is to distribute trip ends for auto person trips, mass transit trips, and truck trips. Two particular points should be elaborated further.

The first of these is the introduction of a new method of trip-end distribution. The theory on which this model of trip distribution is based is being presented at this meeting in another paper (1). It would, perhaps, be sufficient to mention that the new method is based on the theory of probability and also utilizes several concepts developed by users of gravity models. To a certain extent, the new method bridges the gap between the present schools of thought. In any case, the new method distributes trips by mode (or any other stratification desired) provided a high enough number of events (interchanges) is always retained so as to minimize the effects of the law of chance.

The second point is the independent distribution of truck trips. Although it is possible to express truck trips as equivalent vehicle trips somewhere early in the analysis and thereafter distribute "vehicle" trips, in this approach distribution of truck trips is attempted separately just as they are "generated" separately.

TRIP ASSIGNMENT

The last observation leads to the fourth step which involves assignment of trips onto networks, both highway and transit. This process is now in the testing stage, and the authors are currently choosing between diversion and all-or-nothing assignment, and deciding if time or total cost (including a monetary value of time plus operating costs or fares) should be used as the path trace variable. By including operating costs, the paths traced tend to be more reasonable in terms of over-the-road distances than those traced on time alone.

Perhaps the traveler places some or even more emphasis on total cost, including a value for his time, in reaching a decision as to where to terminate his trip and how to get there. It has been found, for example, that the limited number of toll crossings of the Delaware River have a marked effect on trip distribution patterns.

Also, the need for a feedback process or operational loop in the model is being investigated. Traffic assignment is based on a set of minimum paths. A minimum path, however, is subject to the degree of utilization of each link in the path because there is a need to adjust travel times on links in the highway network when volumes assigned to these links approach capacity. This would then affect the transportation network characteristics incorporated in each preceding component of the model.

EVALUATION

The model includes an estimation of travel in terms of mileage, time and costs incurred on each system tested. A three-way evaluation of any proposed future transportation system is then made. Penn-Jersey has advanced five exogenously derived alternative transportation systems. These systems would be loaded with the traffic demand at a given date. The traffic demand in each case would have been adjusted in terms of magnitude, directions, and modes according to the influence of the transportation system under the testing procedures specified. The evaluation of the system would involve three tests: (a) a sufficiency test comparing future travel demands with system capacity, (b) cost-benefit analysis of operating costs vs total investment expenditures, coupled with a cost-benefit analysis between modes of travel, and (c) an accessibility evaluation that would specify the number of trip opportunities that can be reached within certain time intervals from each area by mode.

SUMMARY

Many of the concepts expressed in this paper are not new. Certainly the over-all flow model design incorporating trip generation, modal split, trip distribution, assignment and evaluation has been pioneered by other transportation studies. The major differences lie within the components or submodels themselves.

The transportation networks, both highway and transit, are conceptually permitted to influence every submodel. (This transportation network consideration is also introduced into the determination of future land use activity in the over-all regional growth model, of which the transportation flow model is a part.) They are used to condition the amounts of trips generated. They play a major role in determining the split between modes of travel. They influence the distribution of trips as well as their usual role in assignment. It appears necessary to establish different travel demands for each new transportation network advanced for testing.

Much research remains to be done, but the design of such research to incorporate transportation network variables in all phases of the model appears significant.

REFERENCE

1. Tomazinis, A. R. "A New Method of Trip Distribution in an Urban Area." HRB Bull. 347, 77-99, (1962).

Capacity Restraint in Multi-Travel Mode Assignment Programs

N. A. IRWIN, Vice-President, Traffic Research Corporation, N. Y., and
H. G. VON CUBE, Project Director, Traffic Research Corporation, KCS, Toronto

• TRAFFIC ESTIMATING METHODS have been developed primarily for urban areas to help shape and justify road planning decisions. Because peak-hour congestion exists in most cities today on almost all road and rail facilities and will continue to exist to some degree in the future, any realistic method of traffic prediction must recognize the presence of road capacity limitations and its effect on traffic pattern and travel mode.

Developers of traffic assignment programs have realized the necessity of introducing road capacity restraints—the cause of congestion. Moreover, they have also felt it necessary to introduce factors affecting people's choice of travel mode. However, it has been frequently decided for the sake of simplicity (or lack of better methods) that it is sufficient to deal with road users and transit users separately.

It is well known that delay caused by congestion will cause travelers to seek other less congested routes to their destination or other means of travel or will persuade some travelers to cancel their trips entirely. A great number of such decisions may ultimately restrain the functioning of a city or sectors thereof.

Conversely, it is known that the existence of an uncrowded direct route between two urban areas will quickly draw traffic from other more crowded routes and will even create new traffic demand between the two areas. These effects are implicit in the traffic pattern of any city.

Assignment programs that do not take road and parking capacity and choice of travel mode into account in an explicit manner can make no allowance for changes in the pattern of congestion and/or travel mode used which will inevitably occur as the city evolves. In fact, such assignment programs tend to freeze the congestion pattern and travel mode to whatever shape it had when the last O-D survey was made; moreover, they ignore the interaction between road and transit usage which tends to produce a compatible balance between the two travel modes.

The lack of capacity restraint and choice of travel mode in an assignment program can cause considerable error, especially if there are significant differences between the land-use pattern and/or traffic facilities proposed for the future and that in existence when the base survey was made.

Under contract with the Metropolitan Toronto Planning Board the Traffic Research Corporation has developed a systematic model for estimating vehicular and transit flow using high-speed electronic computing techniques. This model contains a direct feedback mechanism by which capacity restraints and the resultant congestion on roads and parking lots are allowed to affect the choice of travel mode, the route selection, and trip volume distribution in successive program blocks.

Thus, the traffic forecasting model described in this paper becomes a powerful tool for the transportation planner. It provides him with a means of estimating traffic flows in an area based on land-use patterns and traffic facilities within the area. It is essentially a working model of the area's transportation system.

Having projected existing land-use patterns to their probable configuration at some given future date, the planner can use the model to analyze and compare alternative proposed transportation systems. For all sections of a proposed system, he can use the model to estimate traffic flows via autombile, commuter train, transit, and truck during an average morning or evening rush hour or during a longer period, if necessary. Using the model he can then estimate the total cost of transportation on the proposed system during the study period, enabling him.to judge how effectively that system serves the given land-use pattern and how well it compares with the other proposed transportation systems. Armed with this tool, the planner is now for the first time able to try out a proposed transportation system, to compare its benefits with its costs, using a model instead of being forced to experiment directly with multi-million dollar investments.

This program has been tested in full-scale studies of the metropolitan Toronto area and has been found to give most satisfactory results when compared with observed data. This paper describes briefly how the forecasting model works and shows how some of its results compare with observed data.

GENERAL DESCRIPTION MODEL

The six basic prgram blocks comprising the model are

Block 1	Tree generation
Block 2	Time factor
Block 3	Trip distribution
Block 4	Proportional split
Block 5	Assignment
Block 6	Link updating

Two auxiliary program blocks, the grid reduction block (not in operation at the present time) and trip generation block are run beforehand, where necessary, to provide basic data for the model. The order of sequence and flow of information between these units are shown in Figure 1.

Basic Input Information

The area to be studied is divided manually into small contiguous zones, and the road and transit networks are represented by a detailed grid of links and nodes, where a link is the travel path between two adjacent nodes, and a node is the junction point between two or more links. All links are directional, so that the bidirectional travel path between two nodes would be represented by two links. Some nodes are merely intersections in the grid network; others, "centroid nodes" or "home nodes," are taken to represent all properties, except size, of the zone in which they are located.

Input data describing the zones (population, employment, income, car registration, etc.) and the grid (road lengths, flow characteristics, number of lanes, speed limit, transit headways, etc.) are gathered and tabulated in the form of tables and formulas. Traffic prediction is then carried out by means of the six types of program blocks mentioned.

The Flow of Information

The flow of information in the model is briefly as follows:

1. A trip generation is carried out for the land-use patterns and the time period under study. Once completed, this block is never repeated, unless it is desired to start another run based on a different land-use pattern and/or time period.
2. Using the tree generation block (block 1) a first set of routes is determined, one between each pair of zones. Each route is the shortest possible in terms of travel time.
3. The time factor block (block 2) estimates the effect these travel times will have on travelers' propensity (time factors) to travel for various purposes from one zone to another zone, to use one travel mode instead of another (modal split factors) and to follow one route instead of another (assignment factors).
4. The trip distribution block (block 3) takes into account these propensities (time factors) and also opportunities offered for beginning and ending trips in each zone to estimate how many people in total will travel from one zone to another.
5. The proportional split block (block 4) uses these total trip interchange volumes

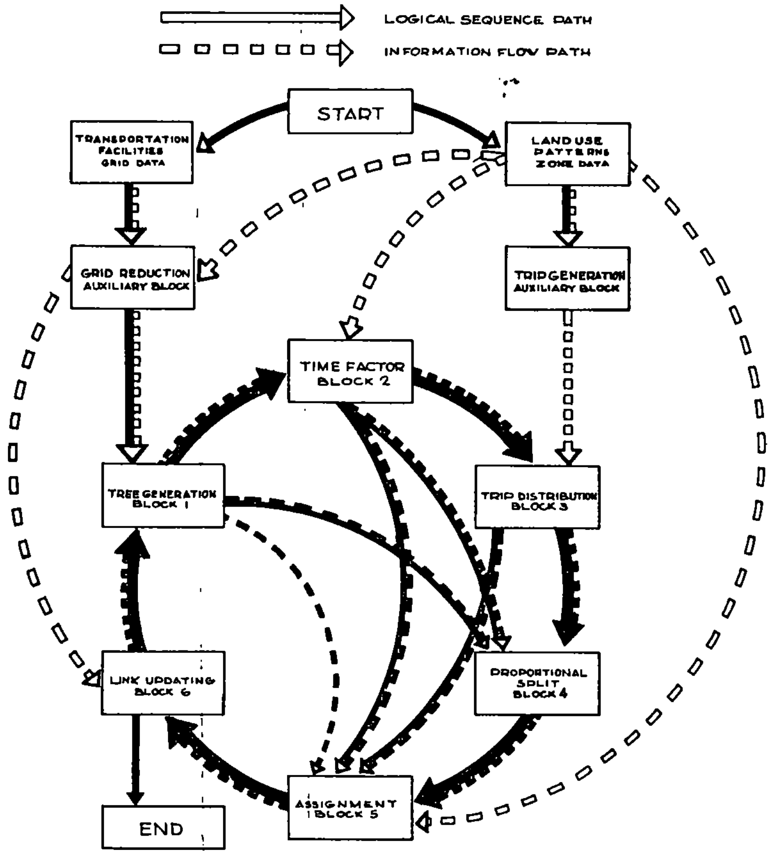


Figure 1. Traffic prediction program block diagram.

and the "split factor," of block 2 to calculate how many people will travel via each mode and via each alternative route from zone to zone (split trips).

6. The assignment block (block 5) assigns these "split trip" figures to the pertinent routes to give estimates of traffic flows, or volumes, via all available travel modes, on each road section or link (link loads) and parking lot of the transportation network.

7. The link updating block (block 6) uses these "link loads" combined with the flow propensities of each link to calculate the link travel times currently applying to all links in the network.

In general, these new link times will be different from those on which the previous determination of routes and travel propensities were based. It is necessary, therefore, to turn again to block 1, using this time the new link times. Weighted averages of the new route times via all available routes between each origin and destination are then used in block 2 to calculate new travel propensities, leading to a new calculation of zone interchange volumes in block 3, and so on around the loop through blocks 4, 5, and 6. It is by this means that feedback occurs. The effects of road traffic congestion and parking lot overflow are fed back within the model to effect the travel patterns as they do in real cities. This feedback procedure is repeated until equilibrium is reached; i.e., until link loads and travel times produced by one cycle are not appreciably different from those produced by a previous cycle.

It can be seen from the foregoing that travel time is the variable that ties all blocks of the model together. It is apparent that the capacity restraints as incorporated in this model play a major part in traffic prediction and are therefore described next.

Capacity Function

The term "capacity function," as used in this paper, means the mathematical formula developed to describe the relationship between traffic volume and travel time for a given road section called link. Flow of vehicles along a road is a very complex phenomenon, depending on many factors. Each road section is probably unique in its combination of factors affecting the flow and should, for precise simulation, have a unique capacity function not only for various speed limits, number of signalized intersections per mile, number of lanes, and presence of public transit but also for different time periods and different weather conditions, etc. Perhaps computer capacity and empirical data will be sufficient someday for this degree of precision.

For the purpose of this paper, however, it is approximated as follows: when large numbers of vehicles are attempting to use a given road section, the speed at which they can travel is materially reduced, a phenomenon that is known as traffic congestion. For any road section it is possible to measure the relationship between the volume or flow, of vehicles traversing the link (cars per hour per lane) and the resulting travel time in minutes per mile. Two typical volume-time relationships of this type are shown in Figure 2, where f is the per-lane flow of vehicle and t is the resulting travel time per mile, known as the per-unit travel time. It can be seen that the expressway can carry a much greater flow than the city arterial street before congestion causes the per-unit travel time to soar. Also, for each of the road sections shown, there is a point, known as the critical flow, f_c, above which the per-unit travel time starts to rise rapidly, and another point, known as the maximum flow, f_m, which is the maximum volume that the road can carry. If user demand continues to climb above f_m cars per hour per lane, then a queue will start forming at some point on the road section and the average travel time per mile experienced by users will increase while the link flow will remain static f_m cars per hour per lane or in some cases drop off to lower values.

To calculate the per-unit vehicle travel time on a given link it is necessary to know in mathematical terms the volume-time relationship for that link. As shown, the shape of this relationship is different for different types of links, such as urban arterial roads and controlled-access freeways. In the present program, 20 different types of links are defined for this purpose, depending on three basic parameters: the speed limit, the number of signalized intersections per mile, and the type of transit vehicles (if any) sharing the road section with automobiles. These 20-link types cover a range from a 30-mph arterial street with 60 streetcars per hour and 10 signalized intersections per mile up to a 60-mph controlled-access freeway.

Data on which these curves are based come from a wide variety of sources. Most prolific of these has been the system of radar detectors mounted at the approaches to several intersections in Toronto as part of the computer automated traffic control project. Input from these detectors is analyzed every two seconds by the computer in such a way that delay at each intersection approach can be calculated as a function of

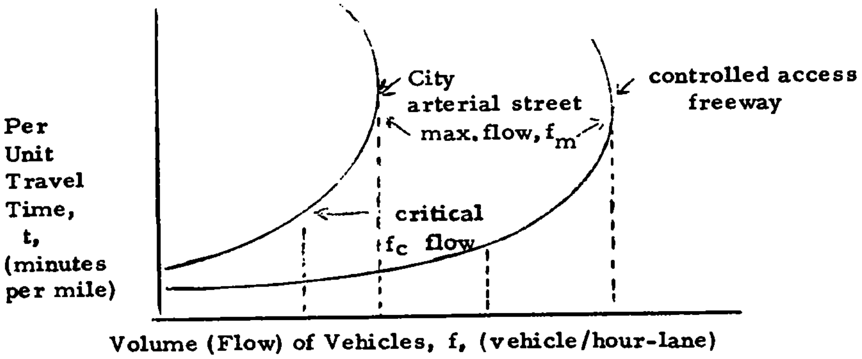


Figure 2. Volume-time relationship for typical road sections.

approach volume. Results from one such location are shown in Figure 3; the observations have been correlated by three straight line segments.

A representative volume-time relationship has been derived for each link type, based partly on empirical data and partly on theoretical considerations. These 20 relationships so derived are called "capacity functions" and are used in block 6 to calculate vehicle link travel times as a function of vehicle flows (see Figs. 4 and 5). Capacity functions are shown in Figure 6.

It can be seen that each capacity function is a simple approximation to the corresponding observed volume-time relationship (shown in Fig. 2) for flows less than f_m cars per hour per lane. However, above f_m, the capacity function differs from the observed volume-time relationship in that the curve does not double back to the left, but continues to slope off to the right. This is because the independent variable in the capacity function (the variable plotted on the horizontal axis) is the demand flow rather than the actual flow. The actual flow cannot, of course, rise above the maximum flow capacity of a given road section; however, the demand flow can rise above the maximum flow capacity, giving rise to higher average per unit travel times as users wait in queues for their chance to travel along the section. The slope of the capacity function for demand flows greater than f_m cars per hour per lane can be calculated by means of simple queueing theory. Figure 6 shows there is a "zero-volume travel time," t_0 (also known as the "ideal time"), which is the average per unit travel time experienced by a vehicle when there are no other vehicles using the road. Similarly, there is a "critical travel time," t_c, which is the average per unit travel time experienced when the flow on the road is f_c, the critical flow; and a "maximum flow travel time," t_m, corresponding to a flow on the road of f_m, the maximum flow. The slope of the capacity function for flows between O and f_c (known as the "free-flow" region) is d_1; the slope of the capacity function for flows between f_c and f_m (known as the "turbulent" region) is d_2; and the slope of the capacity function for demand flows greater than f_m (known as the "overloaded" region is d_3. Each of the 20 types of links has a unique set of the seven parameters t_c, f_c, t_m, f_m, d_1, d_2, and d_3, which describe fully its capacity function (see Table 1).

Mathematically, the general equations describing the capacity functions are as follows:

$$\text{For} \quad 0 \le f(V) < f_c : \quad t(V) = t_c + d_1 [f(V) - f_c] \quad \text{min per mi} \tag{1}$$

TABLE 1

CAPACITY TABLE

Type	Speed Limit	Signal. Intersec. per Mi	d_1	d_2	d_3	t_o	t_c	t_m	f_c	f_m
Cars	30	10	0.0013	0.0188	0.0563	4.4	4.9	7.4	400	533
		5	0.0011	0.0167	0.0500	3.4	3.9	6.4	450	600
		3	0.0010	0.0150	0.0450	3.0	3.5	6.0	500	667
		1	0.0008	0.0125	0.0375	2.3	2.8	5.3	600	800
Buses	30	10	0.0013	0.0188	0.0563	4.4	4.9	7.4	400	533
		5	0.0011	0.0167	0.0500	3.4	3.9	6.4	450	600
		3	0.0010	0.0150	0.0450	3.0	3.5	6.0	500	667
		1	0.0008	0.0125	0.0375	2.3	2.8	5.3	600	800
Streetcars	30	10	0.0016	0.0242	0.0726	4.4	4.9	7.4	310	413
		5	0.0014	0.0208	0.0625	3.4	3.9	6.4	360	480
		3	0.0012	0.0183	0.0548	3.0	3.5	6.0	410	547
		1	0.0010	0.0147	0.0442	2.3	2.8	5.3	510	680
Cars	40	2	0.0007	0.0100	0.0300	1.9	2.4	4.9	750	1,000
		1	0.0006	0.0083	0.0250	1.7	2.2	4.7	900	1,200
	50	1	0.0005	0.0068	0.0205	1.5	2.0	4.5	1,100	1,467
		0	0.0004	0.0058	0.0173	1.2	1.7	4.2	1,300	1,733
	60	0	0.0004	0.0054	0.0161	1.0	1.5	4.0	1,400	1,867

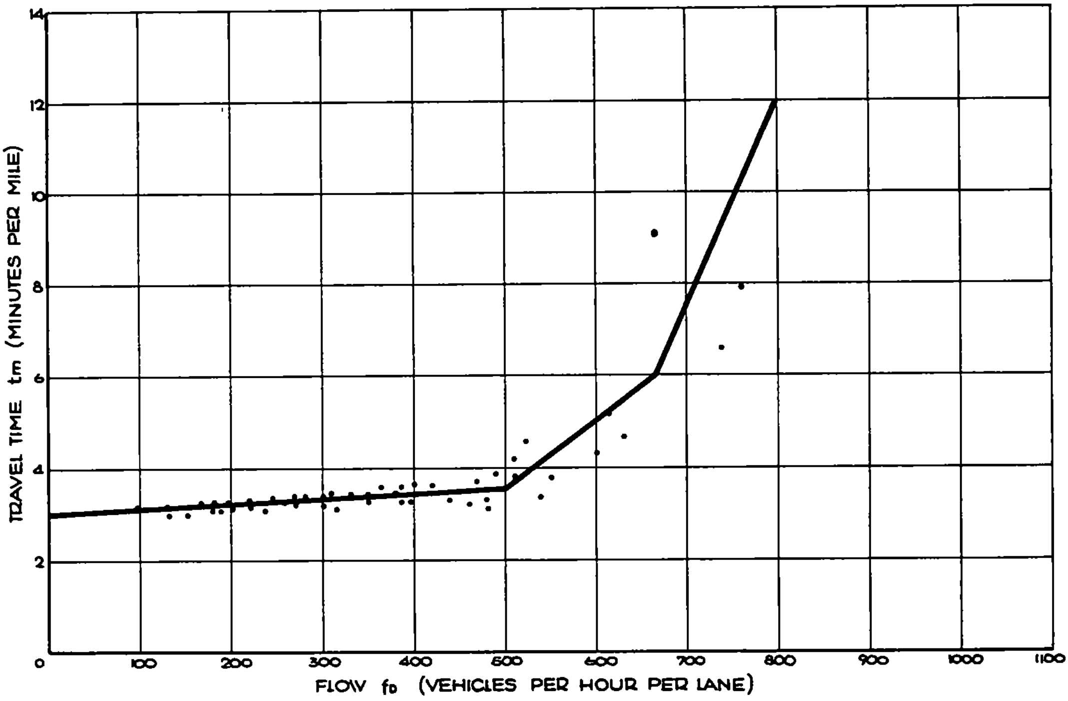


Figure 3. Capacity function for roads with cars only; 30 mph, S = 3.

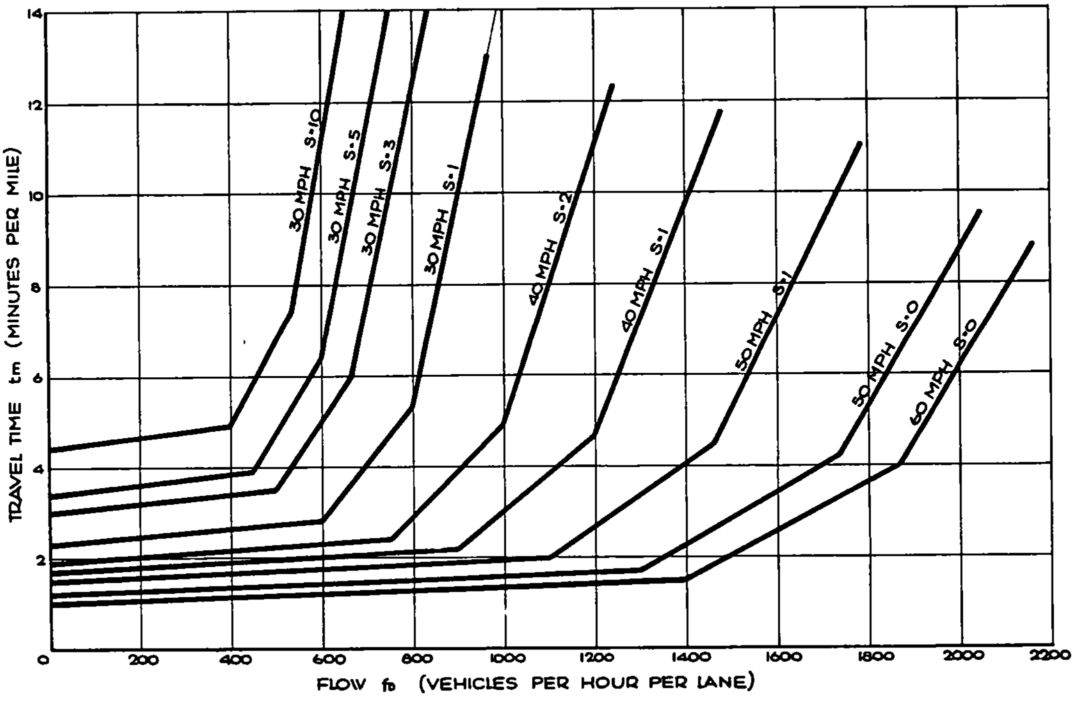


Figure 4. Capacity function curves for roads with cars only, traffic prediction model, Toronto, 1956.

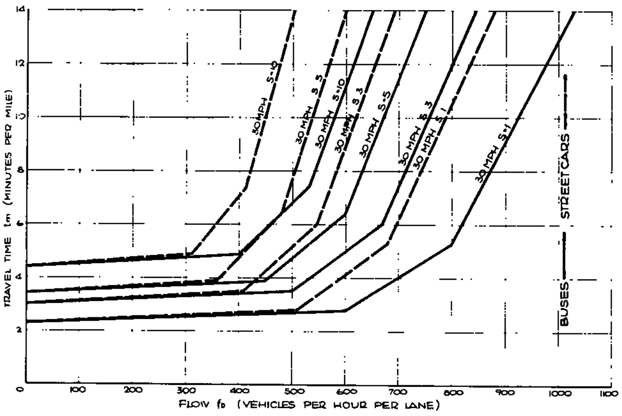


Figure 5. Capacity functions for roads with buses and streetcars, traffic prediction model, Toronto, 1956.

$$\text{For} \quad f_c \le f(V) < f_m : \quad t(V) = t_c + d_2\,[f(V) - f_c] \quad \text{min per mi} \qquad (2)$$

$$\text{For} \quad f_m < f(V) \quad : \quad t(V) = t_m + d_3\,[f(V) - f_m] \quad \text{min per mi} \qquad (3)$$

in which

$f(V)$ = vehicle demand flow in vehicles per hour per lane, and

$t(V)$ = average per unit vehicle travel time in min per mi.

It can be seen that if the seven parameters t_c, f_c, t_m f_m, d_1, d_2, and d_3 are known for a given road section, and the demand vehicle flow, $f(V)$ (cars per hr per lane) is also known, then the average per unit vehicle travel time, $t(V)$ (min per mi) can be calculated using Eq. 1, 2, or 3, depending on whether the given value of f puts the link into the free-flow, turbulent, or overloaded region.

Equivalent Vehicle Flow

The demand flow used in Eqs. 1, 2, and 3 does not have to be simply the automobile flow in cars per hour per lane. For links on which transit vehicles and trucks also travel, it is possible to calculate an "equivalent vehicle flow," f_e (cars per hr per lane) which takes into account the effects on traffic flow of these other types of vehicle. To obtain the relationship between transit vehicle flow and car flow, conditions at the point of maximum congestion (f_m) were analyzed using observations taken on several major streets in Metropolitan Toronto. The relationship was derived in terms of the number of equivalent cars per transit vehicle (NVPQ) and expressed in

$$F(V) = C + (NVPQ)\ F(Q) \qquad (4)$$

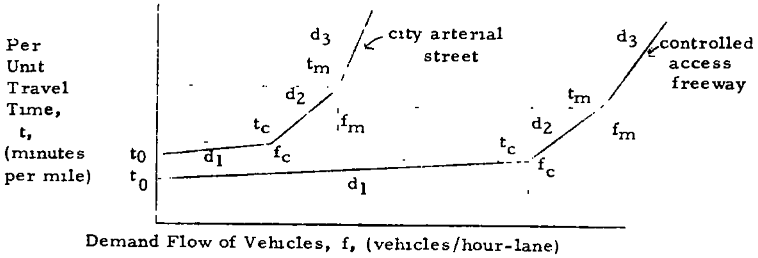


Figure 6. Capacity function for two typical road sections.

in which

$F(V)$ = number of cars per hour;

C = a constant equal to difference between extrapolated value of car flow on a transit route with no transit flowing and theoretical value of a street with cars only at maximum congestion;

$NVPQ$ = ratio of cars per transit vehicle and is equal to inverse of slope of graph (Fig. 7);

$F(Q)$ = number of transit vehicles per hr.

The analysis yielded the following results for

$$\text{Buses} \quad F(V) = 0 + 4.5\ F(Q) \tag{5}$$

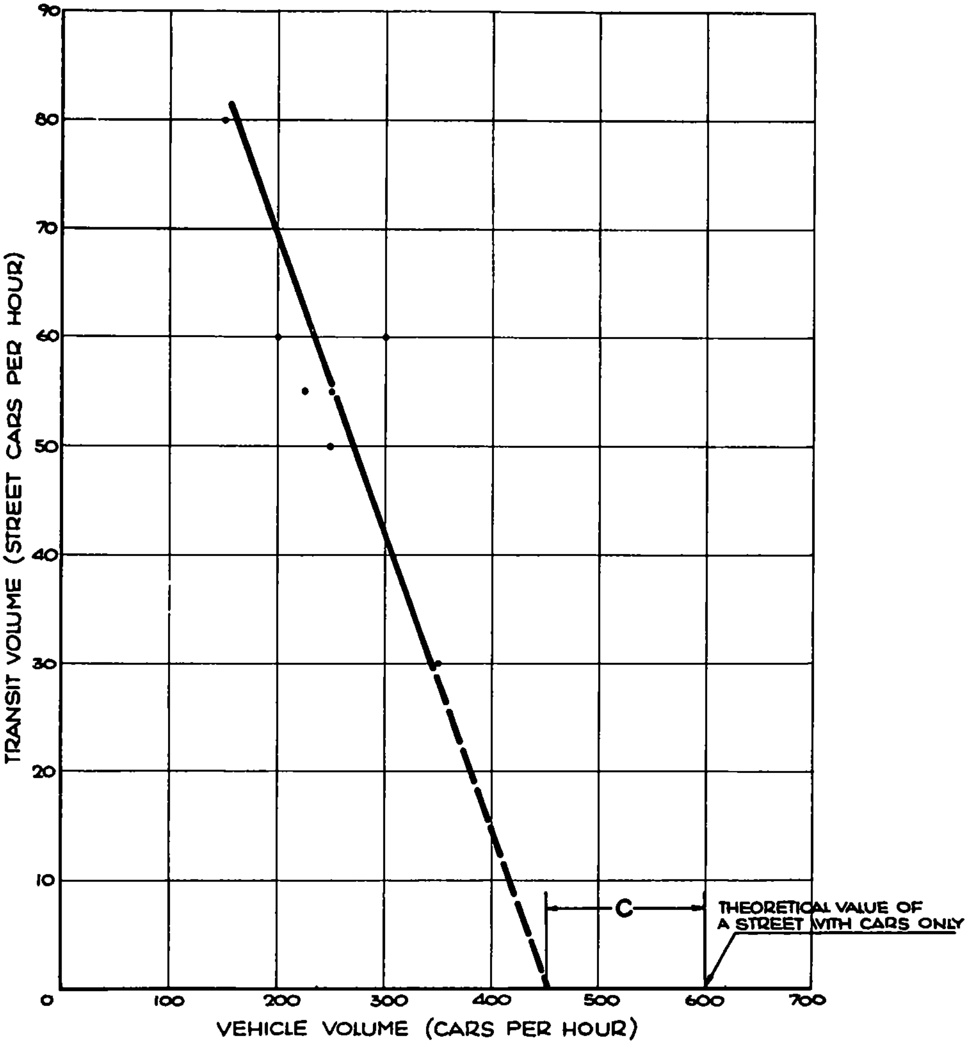


Figure 7. Transit volume (streetcars) vs vehicle volume (cars) at maximum congestion on roads with S = 5 and SL = 30 mph.

$$\text{Streetcars} \quad F(V) = 150 + 3.5\ F(Q) \tag{6}$$

C is zero for bus routes (in all cases the agreement was within 5 percent). Consequently, the capacity function curves as prepared for streets with cars only were directly applicable to streets with buses.

The constant term in the equation for streetcars is explainable by the fact that streetcar tracks themselves impede vehicular flow as well as loading and unloading of passengers. Therefore, it was necessary to develop separate capacity function curves for streets used by streetcars and cars incorporating this constant (see Fig. 5).

In the present program these intermodal relationships are described by two parameters: NVPQ (the number of equivalent cars per transit vehicle) and NVPT (the number of equivalent cars per truck).

The equivalent vehicle flow, for a link that is used by all three modes, may then be calculated using

$$F_e(Q) = (NVPQ) \times F(Q) \tag{7}$$

$$F_e(T) = (NVPT) \times F(T) \tag{8}$$

$$F_e(V) = F(V) + F_e(Q) + F_e(T) \tag{9}$$

in which

$F_e(Q)$, $F_e(T)$ = equivalent flows (in terms of equivalent automobiles) of transit vehicles and trucks, respectively;

$F(V)$, $F(T)$ = link loads of automobiles and trucks, respectively, as produced by block 5;

$F(Q)$ = transit flow as given by transit schedule and listed in a "link table";

$F_e(V)$ = equivalent vehicle flow taking into account effects of transit vehicles and trucks; and

NVPQ, NVPT = intermodal parameters described earlier.

(In this context, f is used to represent flows in cars per hr per lane, and F to represent cars per hr on all lanes of a given link; similarly, t always represents min per mi, whereas T represents min taken to travel from start to end of a given link.)

The equivalent vehicle flow per lane is then calculated from

$$f_e(V) = \frac{F_e(V)}{(NULA)} \tag{10}$$

in which

NULA = number of lanes on the link in question.

When the average per unit vehicle travel times have been calculated the average vehicle travel times, T(V), for a given link is calculated by means of

$$T(V) = t(V) \times L \tag{11}$$

in which

L = link length in miles.

DESCRIPTION OF PROGRAM BLOCKS

Trip Generation (Auxiliary Block)

The Metropolitan Toronto Planning Board carried a home interview survey in 1956. This indicated how many trips for each purpose and mode of travel were generated in each zone for all time periods during the day. Regression analyses were carried out to correlate the data for each time period, trip purpose, and travel mode. Workable relationships were found between automobile trips generated and three land-use parameters: population, dwelling units, and car registration. Multiple correlation coefficients for the time periods studied exceeded 0.95.

Using these relationships the following categories of trips emanating from each zone are calculated:

1. Primary trips.—Trips having one terminus at the place of residence. These are broken down into three purpose categories:

(a) Work,
(b) Business-commercial,
(c) Social-recreational.

2. Secondary trips.—Trips having neither terminus at place of residence. These are subdivided into the same three categories of trip purpose. The distinction between primary and secondary trips is necessary because different generating relationships are required for each type.

As input for the trip distribution block later in the program, it is also necessary to determine how many trips of each purpose will be attracted to each zone during the period under study. Again, the home interview survey was used to determine relationships between land-use parameters and trip attractor figures for the three purposes. It was found that the work attractors (i.e., the number of work-trips arriving at each zone) could best be correlated by the variable total employment; business-commercial attractors were correlated by retail employment, and social-recreational attractors by population.

When 1956 census data are used, the preceding calculations yield values of trips generated and attracted for each zone in good agreement with the survey figures, as would be expected. Relationships established for 1956 will not necessarily remain valid for future years, and a study is being carried on to determine what trends exist, if any. For present purposes, however, the established relationships must suffice. Quantities such as population, employment, and car registration can be estimated for the future on the basis of past trends, zoning restrictions, and economic forecasts. If desired, ranges of such quantities can be studied. Having made these estimates, the trips generated in and attracted to each zone can be calculated for the future time period under study. This is the function of the trip generation block.

Once, the trips generated and attracted are determined, these "generator" and "attractor" figures are considered fixed for each centroid node. They are changed, by a new run of the trip generation block, only if it is desired to start a new study of a different time period or based on different land-use data.

Before being used by the main program, each set of generators and attractors is adjusted, so that for each trip purpose

$$\sum_{j=1}^{NUHN} A_j = \sum_{i=1}^{NUHN} G_i \tag{12}$$

in which

G_i = generator for ith home node;

A_j = attractor for jth home node; and

NUHN = number of home nodes.

This adjustment is necessary to ensure convergence of the trip distribution calculation for each trip purpose. Usually, Eq. 12 is very nearly met for each purpose before adjustment; one would expect this because the equations linking trip generation and attraction to land-use variables are in general quite accurate. Experience has shown that generators at place of residence can be more accurately determined from source information than can attractors. Therefore, it is always the attractors that are modified to make their sum equal that of the generators; this is done by applying to each attractor for each trip purpose,

$$A_j = \frac{\sum_{i=1}^{NUHN} G_i}{\sum_{j=1}^{NUHN} A'_j} A'_j \qquad (13)$$

in which

A'_j = attractor before adjustment; and
A_j = attractor after adjustment.

Tree Generation (Block 1)

As mentioned earlier, the road network under study is represented by a grid of nodes and links. Each link is fully described for purposes of traffic prediction by the following variables: road capacity function applicable, number of lanes, length in tenths of a mile, transit facility available, and time headway between transit vehicles.

Given the volume of cars per hour using a link at any time during the prediction procedure, it is possible, using the appropriate capacity function, to calculate the travel time required to traverse that link. This information is required by the tree generation block, which determines the shortest route in terms of travel time between every pair of centroid nodes in the grid.

The algorithm used is based on that developed by Dantzig (7) and Moore (8) but has been modified to minimize the number of times a given node must be queried. This means that routes going from an origin to nodes close by are minimized before longer routes are built onto them.

Given the travel time for each link the tree generation block determines for any or all travel modes (automobile, transit, mixed, trucks) the shortest route from each zone to every other zone. The set of all such routes via a given mode emanating from a given centroid node is called the "minimum time tree" for that node and mode.

During one pass of the tree generation block, up to three sets of routes may be found: one set for each of the travel modes (V, Q, and VQ or QV) described later. A separate pass of the tree generation block is necessary to calculate a set of truck routes, should this be desired.

One pass of this block is not capable of determining more than one set of routes for any one mode; if the analyst wishes to have more than one, say, vehicle route in use between any O-D pair, he must determine the second, third, etc., vehicle routes in subsequent passes of the tree generation block, based on different link travel times. These different link travel times are determined by subsequent passes of block 6 as previously described.

There are four different types of trees generated by this block:

1. Vehicle (V) Trees.—These are trees in which all routes are via private automobile only.
2. Transit (Q) Trees.—These are trees in which all routes are via transit only. In this context transit includes buses, trolley buses, streetcars, subways, elevated trains, and commuter trains.
3. Mixed (VQ or QV) Trees.—These are trees in which all routes are via a combination of private automobile and transit. The type of travel mode that these routes are designed to simulate is that of the suburbanite who drives his car in the morning to the local commuter train station, parks it there, and takes the train into the city center. He may or may not take some other form of transit from the downtown station to his office. This type of mixed route is called a VQ route because the private automobile portion of it takes place first and the transit portion last. The return trip in which urban traveler

takes a commuter train from the city center to a suburban station and thence an automobile to his home, requires a QV route for its simulation. In any urban region there is a daily ebb and flow of trips to and from the city center as workers carry out their daily duties. In considering mixed mode trips, this means that VQ trips will predominate in the morning rush hour and QV trips will predominate in the evening rush hour. Because this traffic prediction model has been designed to deal mainly with rush-hour conditions, two versions of the model have been created: one to handle the AM rush hour and one to handle the PM rush hour. In the AM program, VQ trees are the only type of mixed tree generated; in the PM program, QV trees are the only type of mixed tree generated.

4. Truck (T) Trees.—These are trees in which routes are via truck only; that is, they follow roads on which trucks of the particular class in question are allowed to travel.

The second function of the tree generation block is to update trees that have been found by previous passes of the tree generation block. Because these trees were found under different conditions of link travel times, it is necessary to trace each previously generated tree, substituting current link travel times for old ones, to determine the current route travel time pertaining to each route in these trees.

The program generates other sets of routes in subsequent iterations. A given set of routes tends, therefore, to avoid areas that are congested at the time it is generated. Because up to nine routes for any O-D pair can be retained, this allows travelers from an origin to a destination a reasonable choice to follow. This is shown in Figure 8, where four alternative auto routes are shown for one O-D pair: the first route follows a roundabout course to utilize 60 mph expressways for most of its length; route 2 also makes use of an expressway, and routes 3 and 4 are forced by expressway congestion to use slower arterial roads.

Time Factor Block

Given the travel time from each origin to each destination via each route generated between them, together with other pertinent land-use and trip behavior data, the time factor block is capable of calculating 3 sets of factors.

Time Factors.—The time factor between an origin and a destination describes the effect that travel time between them has on the propensity of travelers to travel from the origin to the destination. This factor is calculated by means of a negative exponential function:

$$TF = e^{-t} \qquad (14)$$

in which

TF = time factor;

t = weighted average travel time via all route-modes available between origin and destination;

β = time factor exponent, determined empirically.

In general, β differs for different trip purposes; for instance people seem to be willing to travel further to work than to shop and this is reflected in a smaller value of β for work trips than for shopping trips. The time factors calculated in the time factor block are used in the trip distribution, therefore, new time factors are calculated only when a new trip distribution is desired.

Modal Split Factors.—MSFQ, the transit modal split factor, indicates what proportion of the total trips going from an origin to a destination will make the trip via public transit (Q) as opposed to private vehicle (V). MSFV, the vehicle modal split factor, indicates what proportion will travel by private vehicle. Because travelers treated in this model must take one or another of these travel modes (mixed trips, the VQ and QV trips already described are defined as transit trips in this context), it can be seen that MSFQ + MSFV = 1 for each O-D pair. The modal split factors are used in block 4

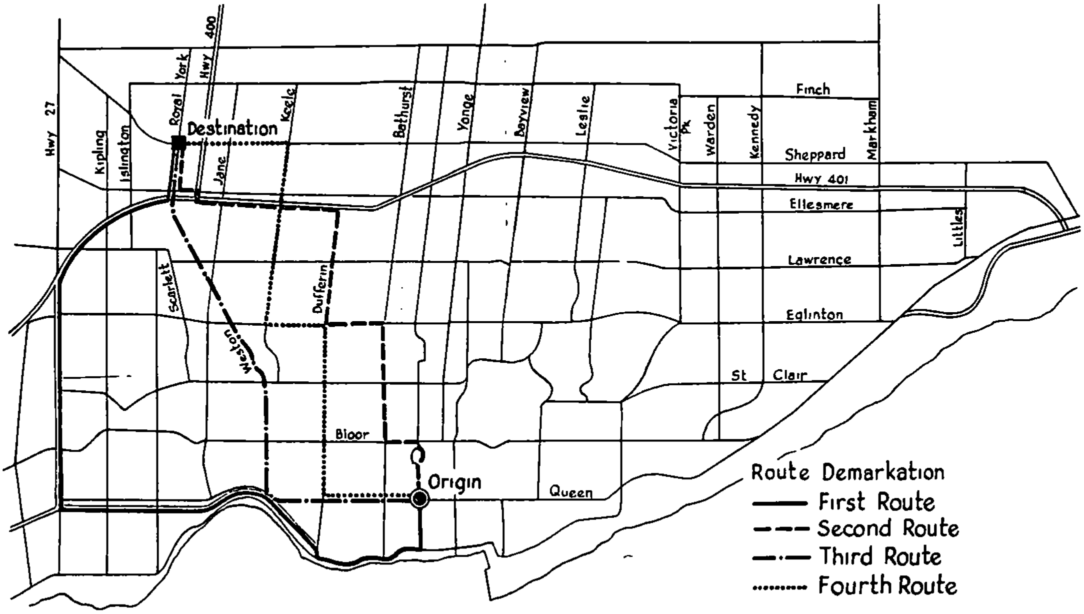


Figure 8. Four routes from a CBD origin.

where they and the assignment factors are multiplied by the total trip interchanges to provide the split trips for each O-D pair. They need be determined only when both modes of travel are available within the model; that is, runs in which only private vehicle flow is being studied would, of course, omit calculation of the modal split factors. A description of the modal split calculation has been reported elsewhere (30, 31).

Observations show the factors influencing choice of travel mode is strongly interdependent. One example of this is the observation that relative travel times via transit and automobile do not influence the choice of low-income travelers as much as they do that of high-income travelers. Another example is that relative comfort and convenience are more important in the traveler's eye if travel costs are roughly equal than they are if one mode costs much more than the other. In short, the effect of one factor depends on the strength of all the other factors.

Based on observed data, diversion curves have been produced showing percentage transit usage as a function of each of the important factors influencing choice. Contours have been developed for each of these curves to show how it changes in shape as the other factors are varied. Each contour of each curve has been reduced to tabular form and fed into the computer memory. Equations have been derived to describe some of the interaction between factors. To calculate the modal split for any O-D pair, the factors (time, cost, convenience, income) applicable to that O-D are determined. Some of these are modified by equations linking them to the values of others. Then the correct tables are entered into in turn, using as argument the modified factor from the previous step, until the modal split factor is determined.

Assignment Factors.—$(AF)_1$, the first assignment factor, indicates what proportion of the trips going from an origin to a destination via a particular mode will travel via the first route available between that origin and destination for the mode in question. For example, if it is assumed that a given prediction run has made 3 V routes, 2 Q routes, and 1 QV route available between each O-D pair, then $(AF)_1$, $(AF)_2$, and $(AF)_3$ for a given O-D pair would indicate what proportion of the private vehicle travelers going from the origin to the destination would use, respectively, each of the 3 vehicle routes available for that O-D pair, and $(AF)_4$, $(AF)_5$, and $(AF)_6$ would indicate what proportion of the public transit travelers would use the first Q route, the second Q route, and the QV route, respectively, for the O-D pair in question. It can be seen that assignment factors are required only for a mode that has two or more routes available for any O-D pair; for such a mode there is an assignment factor for each route to specify the proportion of travelers within that mode using the route. However, in the initial stages of the program an arbitrary assignment factor can be used even though there may be just one route available for the mode in question. The assignment factors are used in block 4 together with the modal split factors, to determine the split trips from each origin to each destination in the area under study. Assignment factors are calculated in block 2, using the route travel times for each O-D pair obtained from block 1, by means of

$$(AF)_1 = \frac{(\frac{1}{T_1})^{a(V)}}{(\frac{1}{T_1})^{a(V)} + (\frac{1}{T_2})^{a(V)} + \ldots\ldots\ldots + (\frac{1}{T_n})^{a(V)}} \tag{15}$$

in which

$(AF)_1$ = assignment factor for route 1 (specifying what percentage of private vehicle travelers are using the first vehicle route for the O-D in question);

T_n = travel time via nth route from origin to destination (there is a total of n routes for the O-D pair in question);

$a(V)$ = assignment factor exponent for vehicles which is emperically determined and specified by the analyst.

At present this proportional assignment is carried out with a(V) set equal to 1. Further investigation is proceeding to determine a more representative value, if necessary.

It can be seen that the proportional assignment is another means by which capacity restraints are taken into account in this prediction model. Although the shortest route from an origin to a destination will have the shortest travel time under non-loaded conditions, its popularity may lead to traffic congestion which increases its travel time to a higher value than that for the other available routes. The proportional assignment allows this effect to be simulated in a reasonable manner.

For determining assignment factors within the transit mode, a(Q) would replace a(V) in Eq. 15. For a given mode the sum of the calculated assignment factors for a given O-D pair is always equal to 1; i.e., if there are four V routes and two Q routes available for each O-D pair, then for each O-D pair, for the V mode,

$$(AF)_1 + (AF)_2 + (AF)_3 + (AF)_4 = 1 \tag{16}$$

and for the Q mode,

$$(AF)_5 + (AF)_6 = 1 \tag{17}$$

Trip Distribution

Given the attractor and generator corresponding to each centroid node for each trip purpose and given the time factor for each O-D pair for each purpose, the trip distribution block determines the total trips via all modes and for all purposes combined from each origin to each destination. These trips are first determined separately for each purpose and then added together to provide the "total trip interchange" for each O-D pair.

The number of trips between any two points for a particular purpose is dependent on the total number of trips generated for distribution at the origin for that purpose, G_i, the total number of trips attracted to the destination for the same purpose, A_j, and the time factor, $(TF)_{ij}$, describing the "friction" between the origin and destination for the particular purpose in question.

The following is used to calculate trip interchange volumes:

$$J_{ij} = G_i A_j (TF)_{ij} \tag{18}$$

in which

J_{ij} = number of trips going from origin i to destination j for purpose in question;

G_i = total trips generated for this purpose at origin i;

A_j = total trips attracted for this purpose at destination j; and

$(TF)_{ij}$ = time factor for trip between origin i and destination j for this purpose.

This equation is the well-known "gravity formula," so called because of its similarity to the equation derived by Newton to describe gravitational attraction between two masses.

There are two basic differences, however. One is that Newton's equation replaces $(TF)_{ij}$ by $1/r_{ij}^2$, in which r_{ij} is the distance between the two masses. As previously described, the trip interchange formula used in this model employs instead a negative exponential function of the travel time, because this describes best the observed trip behavior of urban travelers.

The other difference is more fundamental. If Eq. 18 is applied to a city in which all zones are equally spaced and have equal generators and equal attractors, and in which there are no edge effects, then the trip interchanges so calculated for each trip purpose would be such that

$$\sum_{j=1}^{NUHN} J_{ij} = G_i \tag{19}$$

and

$$\sum_{i=1}^{NUHN} J_{ij} = A_j \tag{20}$$

That is, the sum of the trips leaving each zone would equal the generator at that zone and the sum of the trips arriving at each zone would equal the attractor at that zone.

However, real cities are not homogeneous as to zone size and spacing, and some zones are always on the edge rather than in the middle, so that there are many zones for which conditions expressed by Eqs. 19 and 20 are not met if Eq. 18 is used. For example, a zone closely surrounded by many large generator zones would probably tend to receive more trips than warranted by the size of its attractor. The fact that the attractor (the number of trips that can actually be received at the zone) is smaller than the arrivals that the unmodified gravity model would lead to it is due to factors that the gravity model does not attempt to take into account. These could be space or accommodation limitations in the zone, or the fact that wages in the zone have been driven down by competition among the large number of workers who live in neighboring zones and wish to work there.

Rather than trying to take these factors into account explicitly, the gravity formula is modified on an empirical basis to match the departures with the generator and the arrivals with the attractor for each trip purpose at each zone. This is done by the following repetitive process.

Eq. 21 is used in a first pass of the distribution algorithm (a method of calculation following a systematic set of rules; the term often being used to describe specific calculation routines used in a computer program) to obtain the first adjusted generators

$$G_i^{(1)} = \frac{G_i^{(0)}}{\sum_{j=1}^{NUHN} A_j^{(0)} (TF)_{ij}} \tag{21}$$

During this first pass of the distribution algorithm, the generator and attractor figures are further adjusted for each zone by means of

$$A_j^{(1)} = \frac{A_j^{(0)}}{\sum_{i=1}^{NUHN} G_i^{(1)} (TF)_{ij}} \tag{22}$$

and

$$G_i^{(2)} = \frac{G_i^{(0)}}{\sum_{j=1}^{NUHN} A_j^{(1)} (TF)_{ij}} \tag{23}$$

in which the superscript (0) refers to the unadjusted value of G or A, and superscripts (1) and (2) refer to adjusted values produced by the first pass of the distribution algorithm.

If after this first iteration of the distribution algorithm it is felt that matching is still insufficient as determined by the convergence criterion, a second iteration is carried out, (Eq. 26), during which the generators and attractors are adjusted again. Successive iterations can be carried out as many times as necessary to achieve matching of desired accuracy.

At the end of this iterative procedure the generators are adjusted (n + 1) times, whereas the attractor is adjusted only n times. This ensures that the departures will exactly match the generator at each zone, and the arrivals will approximately match each attractor with an accuracy depending on the number of distribution algorithm iterations carried out.

The adjusted generators and attractors produced by the nth iteration of the distribution algorithm are given by the following generalized forms of Eqs. 22 and 23:

$$A_j^{(n)} = \frac{A_j^{(0)}}{\sum_{i=1}^{NUHN} G_i^{(n)} (TF)_{ij}} \tag{24}$$

and

$$G_i^{(n+1)} = \frac{G_i^{(0)}}{\sum_{j=1}^{NUHN} A_j^{(n)} (TF)_{ij}} \tag{25}$$

in which the superscripts (n + 1) and (n) refer to adjusted values of G or A produced by the nth iteration. The table of adjusted generators and attractors, $G_i^{(n+1)}$ and $A_j^{(n)}$, produced by the last iteration of the trip distribution algorithm for each trip purpose, is written on tape by the trip distribution block and can be used as input for a subsequent run of block 3 if desired. This could be done to save calculation time in the subsequent block 3 run if congestion patterns in the study area have not changed appreciably during the intervening cycle.

Use of this trip distribution algorithm has shown that two iterations (i.e., the initial pass plus one repetition) are usually enough to match arrivals and attractors to within 5 percent for the majority of zones in the study area.

There are two criteria by which the analyst can control the accuracy with which arrivals will be matched to attractors for each trip purpose. First, he can specify the value of ϵ (also called EPSI) below which a mathematical expression called the "epsilon convergence criterion" must drop before he will be satisfied. That is, he gives ϵ a value such that as soon as the condition

$$\frac{\displaystyle\sum_{j=1}^{NUHN} 1 - \left[\frac{A_j^{(n)}}{A_j^{(n-1)}}\right]^2}{NUHN} \le \epsilon \tag{26}$$

has been met the desired degree of accuracy will have been reached. Examination of Eq. 26 shows that the epsilon convergence criterion approaches zero as the arrivals match the attractor at more and more zones because the ratio $A_j^{(n)}/A_j^{(n-1)} = 1$ for each j at which such matching has occurred.

Second, he can specify NUIT, the maximum number of iterations of the distribution algorithm to be allowed for the trip purpose in question.

Both NUIT and EPSI are specified by the analyst for each trip purpose. As soon as either criterion is met for a particular purpose, no further iterations are carried out for that purpose. When the adjusted generators and attractors have been so calculated for each trip purpose, the trip interchanges for each O-D pair are calculated for each purpose by means of Eq. 18 and then summed over all purposes to produce the total trip interchange volumes for each O-D pair.

Proportional Split

Given the modal split factors and assignment factors from block 2 and the total trip interchange for each O-D pair from block 3, the proportional split block calculates the number of person trips that will proceed via each route and each mode for each O-D pair in the area under study. These split trips are obtained quite simply: the trips proceeding from an origin to a destination via a given route and mode are calculated by multiplying the total trip interchange for the O-D in question by the modal split factor and assignment factor pertaining to the mode and route in question for the given O-D pair.

The split trips (that is, the number of person-trips that will proceed via each route and each mode for each O-D pair) are then used as input for the assignment block to calculate the passenger and vehicle loads on the various links in the area under study.

Assignment

Given trees describing a number of routes from each origin to each destination, and given the trips that correspond to each of these routes, the assignment block traces each tree and assigns the trips using each route to the links comprising it. The different "bundles" of trips using each link (resulting from the different routes that traverse that link) are summed for each link to give the flow of traffic along each link via each mode, known as the link roads.

A given pass of the assignment block can handle either all non-truck trips or truck trips only. It is not possible for one pass of this block to handle both non-truck trips and truck trips.

Up to this point in a program cycle, trips via all non-truck modes (i.e., V, Q, VQ, or QV) have been handled in terms of person-trips; that is, in terms of people per hour traveling respectively by private vehicle, transit vehicle, and commuter train from zone to zone. The main function of the assignment block is to translate interzone trip volumes via the various routes and modes into link flows via the various modes. For transit and commuter trips it is useful to have these link flows expressed in terms of people per hour; however, for private vehicles the authors are more interested in the number of vehicles per hour traversing a given link than in the number of people per hour traversing the link by car. The flow in vehicles per hour is needed, for example, to estimate the amount of congestion existing on each link and to calculate the average speed and travel time that result from the vehicle flows.

Consequently, a second function of the assignment block is to translate person-trips via automobile into automobile trips. If the truck assignment option is used, there is no need to translate person-trips into vehicle trips, because truck trips are generated, distributed, and assigned in terms of trucks per hour.

A third function is to calculate the parking cost for automobiles in each zone as a function of parking supply and demand. For this purpose the computer is fed a table showing the number of parking places available in each zone and another table relating the cost of parking to the present utilization of these parking places in each zone.

The link loads calculated by the assignment block are output in so-called load tables. There is one load table for each basic mode: V, Q, and T. These load tables can be added to produce a composite load table as output from that pass of block 5, and input for block 6.

Link Updating

The purpose of the link updating block is to determine the link travel times, via any or all modes, for the flow conditions (link loads) obtained in block 5. In addition, when desired, the block will punch out link data (i.e., flows, speeds, travel times, and link characteristics). The input data required are car flows, transit vehicle flows and travel times, truck flows, and transit person trips on each link; link data; and intermodal information. The general methods of calculation used in this block are described previously; further details are explained here.

Special provision is made for overloaded links; i.e., for those on which the flow on a link exceeds the maximum capacity. As in the case of other links, the value of the maximum flow difference $f_e(V) - f_m$ is, in fact, punched out, to show the analyst that the link in question is overloaded; that is, that the demand flow of equivalent vehicles per lane, $f_e(V)$, is greater than the maximum flow capacity of equivalent vehicles per lane, f_m.

Clearly, for such overloaded links, the throughput actually being achieved is

$$F_e(V)_m = f_m(\mathrm{NULA}) \tag{27}$$

in which $F_e(V)_m$ is the maximum possible flow of equivalent vehicles which the link can accomodate, this being equal to the maximum possible flow of equivalent vehicles per lane, f_m, multiplied by the number of lanes, NULA.

The excess of demand flow over maximum possible flow, $[F_e(V) - F_e(V)_m]$, represents road users who will have to wait in a queue and will not actually negotiate the link until sometime during the succeeding hour. Because $F_e(V)_m$ is the actual flow of equivalent vehicles on an overloaded link, the actual flow of vehicles (automobiles only) on an overloaded link, will be

$$F(V)_m = F_e(V)_m - F_e(Q) - F_e(T) \tag{28}$$

in which $F_e(Q)$ and $F_e(T)$ are the flows of transit vehicles and of trucks, respectively, in terms of equivalent vehicles, as described.

It is this value, $F(V)_m$, which is punched out as the vehicle flow on overloaded links. It should be emphasized, however, that the demand vehicle flow F(V), is always put into the load table for such links, and that the link time for overloaded links is always calculated on the basis of $F_e(V)$ rather than $F_e(V)_m$.

AVERAGE TRANSIT TRAVEL TIME T(Q)

As mentioned, there are three types of transit link considered in this program. Types 2 and 3 (subway and commuter train links, respectively) are unimpeded by automobile flow and are, therefore, able to operate to given schedules, having fixed average travel speeds and fixed time headways between successive trains. It is, therefore, possible to list the average per unit transit travel time, t (Q), for each type 2 and type 3 transit link as an input parameter that is unchanged during a given prediction. This parameter is listed in the link table.

However, type 1 transit links represent lines on which the transit vehicles run on roads and, therefore, proceed at an average speed that is strongly dependent on the degree of automobile traffic congestion in existence; i.e., on the average speed of the automobiles using the same road. It is, therefore, necessary to calculate the average travel time of transit vehicles on type 1 transit links as a function of the average automobile travel times on the corresponding vehicle links. This is done by means of the transit travel time table, which lists a value of the transit travel time for each of 60 per unit auto travel times (covering the range t(V) = 1 min per mi to t(V) = 60 min per mi) and is calculated on the basis of transit vehicle acceleration and deceleration rates, loading and unloading times, and interstop distances, in the area under study. The type of relationship described by the transit travel time table is shown in Figure 9.

In general, the maximum inter-stop speed achieved by surface transit vehicles cannot exceed that of the surrounding vehicle flow. Because the transit vehicle is further slowed down by having to stop for passengers, its travel time is therefore higher than that of surrounding vehicles. If transit vehicles had infinite deceleration and acceleration rates and could load passengers instantaneously, they would go as fast as vehicles, and the dotted line in Figure 9 would describe the realtionship between t(V) and t(Q). However, the sort of relationship found in practice is shown by the solid line, which shows t(Q) always slightly greater than t(V). The value of t(Q) corresponding to each pertinent value of t(V), as shown by this curve, is listed in the transit travel time table.

AVERAGE TRUCK TRAVEL TIME T(T)

The acceleration rate of most medium sized and heavy trucks is in general less than that of private vehicles, which results in a different average speed for trucks and is accounted for by a truck travel time parameter. This can be found from

$$TTTP = \frac{t(T)}{t(V)} \qquad (29)$$

in which t(T)/t(V), the ratio of truck travel time per mile to private vehicle travel time per mile, is measured under typical urban conditions for the type of truck being considered in the study. Because trucks travel more slowly than cars, the TTTP is greater than one; it is used in the program to factor up the average travel time on each link for the truck grid.

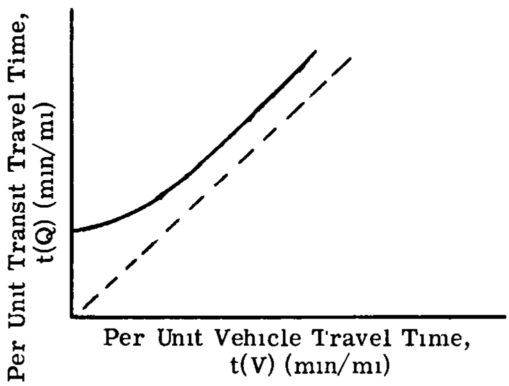


Figure 9. Transit travel time as a function of vehicle travel time.

LINK TRAVEL SPEEDS

For each link, the travel speed via a given mode is the average speed in miles per hour at which travelers using that mode will traverse the link in question under prevailing flow conditions. These travel speeds are calculated for each link in block 6 from the pertinent travel times using the following equations:

For cars,

$$S(V) = \frac{60}{t(V)} \text{ (mph)} \tag{30}$$

For transit,

$$S(Q) = \frac{60}{t(Q)} \text{ (mph)} \tag{31}$$

For trucks,

$$S(T) = \frac{60L}{T(T)} \text{ (mph)} \tag{32}$$

in which

$S(V)$, $S(Q)$, $S(T)$ = link travel speeds via car, transit, and truck, respectively (mph);

$t(V)$, $t(Q)$ = per unit travel time via car and transit, respectively (minutes per mile);

$T(T)$ = truck travel time (minutes); and

L = link length (miles).

NUMBER OF TRANSIT TRAVELERS PER TRANSIT VEHICLE (NPPQ)

The number of transit travelers per transit vehicle (NPPQ) is of interest to the transportation planner, because it indicates what degree of compatability exists between the demand for transit facilities along a given route and the number of seats per hour which are being provided on that route. For each transit link, NPPQ is calculated in block 6 by means of

$$NPPQ = \frac{P(Q)}{F(Q)} \tag{33}$$

in which

$P(Q)$ = flow of transit passengers (people per hour); and

$F(Q)$ = flow of transit vehicles (vehicles per hour) on link in question.

SYSTEM TIME COST

A useful yardstick for comparing alternative proposed transportation systems that are being tested by the traffic prediction model is the system time cost of both systems. The system time cost is the number of hours spent traveling by all system users within the time period under study. For instance, if one proposed system had a system time cost of 50,000 person-hours and another had a system time cost of 60,000 person-hours, both systems serving the same number of trips in, say, an evening rush hour, then it is probable that the first system is the more desirable one. Of course, many other considerations must be weighed in comparing one proposed transportation system with another; however, the system time cost provides an over-all quantitative measure by which the user-benefits of proposed systems can be estimated.

The system time cost is also useful in indicating the degree of convergence reached by the traffic prediction model during a prediction run. If, for example, the system time costs for the various travel modes remain stable during two or more successive iterations of block 6, this is a good indication that equilibrium has been reached by the model. A separate system time cost is calculated for each travel mode, as follows:

For autos,

$$\mathrm{SCTV} = \sum_{\text{all V links}} \frac{F(V) \times T(V)}{60} \text{ vehicle-hr} \tag{34}$$

For travelers,

$$\mathrm{SCTP} = (\mathrm{SCTV}) \times (\mathrm{NPPV}) \text{ person-hr} \tag{35}$$

For auto travelers,

$$\mathrm{SCTQ} = \sum_{\text{all Q links}} \frac{P(Q) \times T(Q)}{60} \text{ person-hr} \tag{36}$$

For trucks,

$$\mathrm{SCTT} = \sum_{\text{all T links}} \frac{F(T) \times T(T)}{60} \text{ truck-hr} \tag{37}$$

in which

SCTV, SCTP, SCTQ, SCTT = system time costs for automobile vehicles, automobile travelers, transit travelers, and truck vehicles, respectively;

F(V), P(Q), F(T) = link loads of autos (cars per hour), transit travelers (persons per hour), and trucks (trucks per hour), respectively;

T(V), T(Q), T(T) = link travel times via auto, transit, and truck, respectively (minutes); and

NPPV = average number of travelers per automobile.

All four of these system time costs are punched out on a card automatically during each pass of block 6.

INTERACTION OF BLOCKS 1 TO 6

Referring to Figure 1, the two basic sets of input information—transportation facilities data and land-use data—are collected and coded to produce grid data for subsequent use in block 1 (for determining trees) and block 6 (for calculating link travel times). Census data are processed by the trip generation block to produce trip generator and attractor figures for subsequent use in block 3 (for calculating interzone trip volumes). Census data are also of direct use in block 2 (for calculating the proportion of trips made by public transportation and by private car between each pair of zones—the so-called "modal split factors") and in block 5 (for calculating vehicle parking costs in each zone). With the preparation and processing of data, the stage is now set for the main part of the traffic prediction program, blocks 1 to 6, to begin functioning.

As shown in Figure 1, the six main program blocks form a sequential loop: when blocks 1 to 6 have been run in that order it is possible to go back to block 1 and start the same sequence again. It is by this means that feedback occurs—the effects of road traffic congestion and parking lot overflow are fed back within the model to affect travel patterns as they do in actual cities.

Many of the cycles carried out in a run of the traffic prediction program will not contain all six program blocks. Possible block sequences in a given cycle are shown in Figure 1. The figure shows the sequential loop formed by blocks 1 to 6 can be short-circuited as follows: block 3 can be eliminated by going directly from block 2 to block 4; blocks 3 and 4 can be eliminated by going directly from block 2 to block 5; and block 4 can be eliminated by going directly from block 3 to block 5.

The meaning of these operations becomes clearer if one realizes the purpose of each block. For example, the main purpose of the first few cycles is to produce the desired number of alternative routes between each O-D pair. Experience has shown that reasonable routes can be obtained based on arbitrarily estimated modal split factors and assignment factors, and that it is not necessary to carry out a new trip distribution during each of these route-generating cycles. Consequently, blocks 3 and 4 can be omitted from most of these cycles with a consequent saving of machine time. Similarly, in the final "settling" cycles when equilibrium is being reached, no new routes are being generated, so it is possible to leave part of block 1 out of each cycle. Experience has also shown that the interzone trip volume figures reach equilibrium before the link loads and travel time have completely settled down so that it is possible to "freeze" the trip distribution and leave block 3 out of the final few cycles.

The flexibility resulting from these alternative sequences is enhanced by a comparable flexibility of input information. For instance, if estimates have already been made of interzone travel volumes (by means of a scaled-up O-D survey, say), it is possible to feed these volumes directly into the model, by-pass the time factor, distribution, and proportional split blocks and find the assigned traffic flows that would result. This procedure would result in a saving of computing time but would be useful only for short-term predictions; over long periods of time, patterns of land use and traffic congestion in the area could be expected to change considerably, therefore requiring a method of estimating interzone travel volumes which will take these things into account. Blocks 2, 3, and 4 in this model have been designed to do so.

The modal split factor percentages, route assignment factor percentages, interzone trip volumes, link flows, and link travel times produced by the final cycle of a given run describe the predicted traffic pattern for the study area and the time period in question, based on the specified land-use patterns and transportation facilities.

Having produced this traffic prediction, it is now possible by inspection to determine which links are most heavily overloaded, which areas are least efficiently served by roads and rail, etc. with a view to proposing new land-use configurations and/or new transportation facilities. Having made these proposals the planner can then make use of the model again, with the new proposals as input data, to test them for efficiency of operation and to compare them with the original proposals. By this means he is able to make planning decisions based on systematic appraisal of the various proposed combinations of land use and transportation facilities.

Various other sorts of information describing the predicted traffic patterns can be produced by the model to aid in planning decisions. One such item, as mentioned previously, is the total time spent traveling by all tri-makers during the time period in question, the so-called "system time cost," which is usually measured in terms of person-hours and vehicle-hours spent on route. Another such item, called "link usage data" is a list, for any link desired, of the number of travelers from each zone who are traversing that link during the time period in question. Such data can be very useful in establishing the relative importance of various links. Another useful set of information shows the turning movements at each interchange along a given facility and the trip lengths along the facility of all travelers entering at each interchange. This information is useful in deciding at what intervals interchanges should be located to serve adequately the adjacent corridor and yet prevent congestion from building up as a result of too much local traffic.

EFFECTS OF CAPACITY RESTRAINTS

The effects of capacity restraints on travel time make themselves felt at four points in this prediction model:

1. In finding of routes. Route generations are carried out under differing conditions of congestion to provide several reasonable routes from every origin to every destination.
2. In choice of destinations. Trip distributions are carried out under prevailing traffic patterns to simulate the effect of congestion on travelers' choice of destinations.
3. In choice of route. Confronted with several possible routes from an origin to a destination simulated travelers are allowed to choose among them so that more take the shortest route than take the longest.
4. In choice of travel mode. The ratio of travel time by car and by transit is the most important factor affecting modal split.

Many of the relationships can be improved given more accurate source information. Nevertheless, the prediction model in its present stage is capable of producing meaningful results as is shown in a test run of the 1956 traffic pattern in Metropolitan Toronto.

Under contract with Metropolitan Toronto Planning Board the Traffic Research Corporation has used the traffic prediction model in a study of the Toronto area (Fig. 10) for the time period of a morning rush hour in 1956.

The year 1956 was chosen for three main reasons:

1. For the year 1956, most comprehensive source information was readily available.
2. The relationships developed and incorporated in this model had to be tested to establish their validity by reproducing a situation that could be compared with observed data.
3. The sequence of operating the various program blocks had to be established in such a way that minimum amount of time was spent in estimating future traffic flows for which no other check is available.

In the following graphs it can be seen that the traffic prediction model reproduced the 1956 traffic situation in close agreement with the observed data for the same period of the day.

Figure 11 shows the system time cost as previously described. In the first iteration of the program, the system time cost has been recorded for the first route time multiplied by the interchange volume for each O-D pair. Because at this stage the roads are not used by any road-user, the system time cost represents the total time of all road-users if the road-user would be restricted in his movements by speed limitations only. At the end of the first iteration only one vehicle route and one transit route were available; consequently, the system time cost reached its highest level. As more routes are generated in the subsequent iterations the system time cost decreased to a level where no further decrease could be gained by new route generation. The slight oscillation of the system time cost curve in the second half of the prediction run is noteworthy. As mentioned earlier, interzone trip volumes reach equilibrium before the link loads and travel time have settled down.

Figure 12 shows the behavior of the frequency distribution of the trip length in terms of time. Here again, reasonable agreement has been achieved between estimated and observed data. In the initial stage of the prediction run, all trips estimated are temporarily shorter than those observed: i.e., the capacity restraints of traffic facilities have not made themselves felt. To demonstrate the inherent oscillation as shown in the system time cost an intermediate frequency curve has been shown in this graph. At equilibrium, the estimated frequency curve tends to follow closely the curve for observed data.

Figures 13, 14, and 15 show the volumes of vehicles and transit passengers crossing a cordon line west of the CBD of Toronto. The total volumes estimated agree very well with those observed, although some of the individual road sections vary considerably. In general, it can be observed that the variation is relatively large for small volumes. In Figure 14 the deviation of the estimated volume on Lakeshore Boulevard is caused by an error in coding the number of lanes available on that road which was not discovered before the run was completed. In Figure 13 the deviation of the estimated volume on Davenport, St. Clair, etc., is caused by an overestimate of the level of service the Toronto Transit Commission had in operation in 1956.

Figures 16 and 17 show the volumes of vehicles and transit passengers crossing a

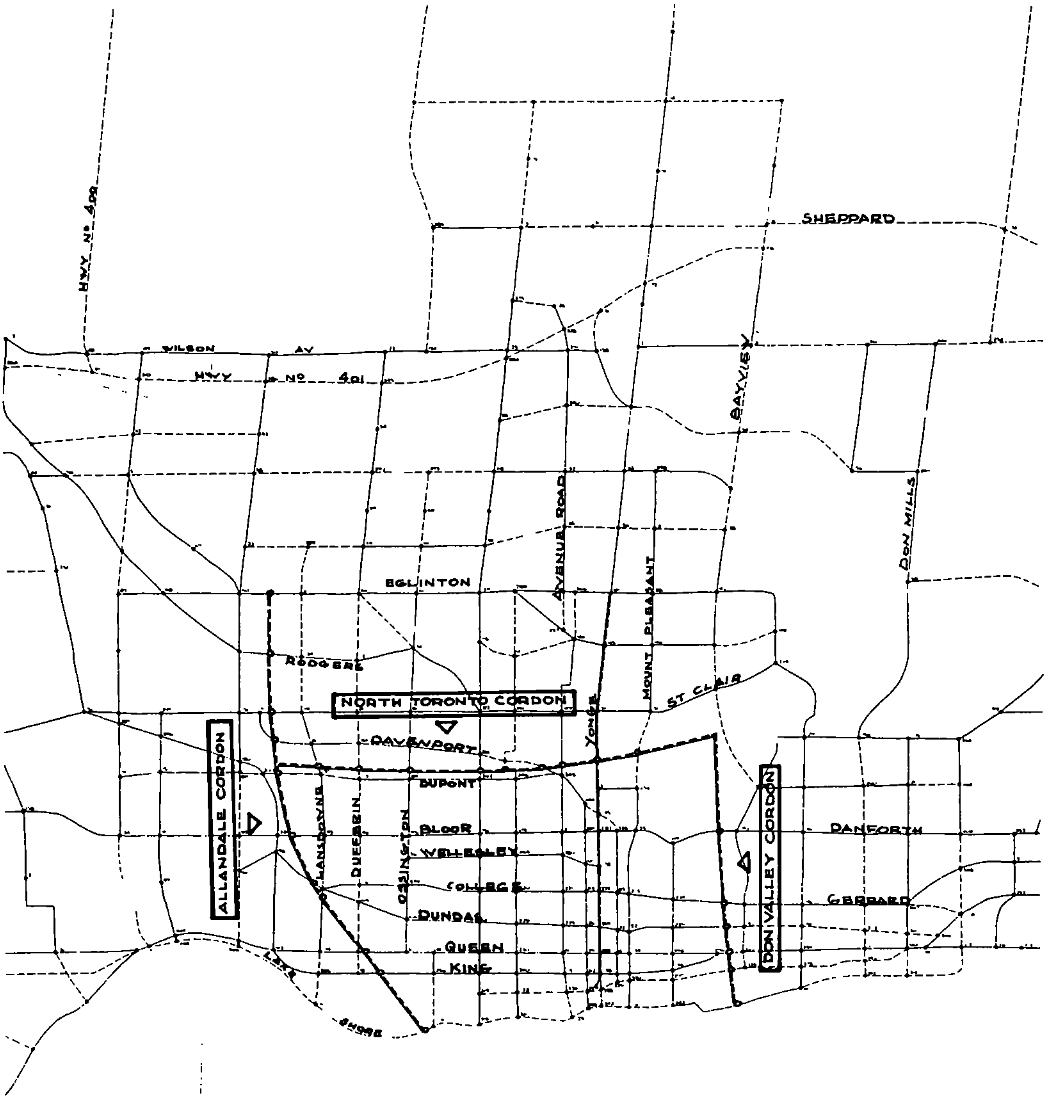


Figure 10. Transportation facility grid, Toronto, 1956.

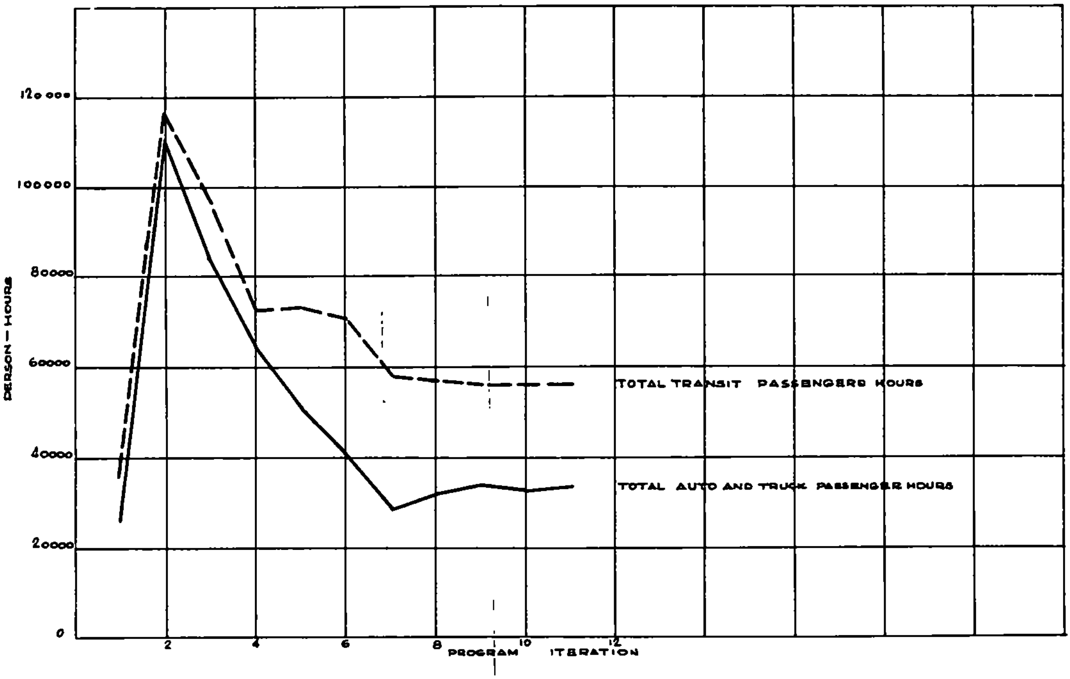


Figure 11. System cost chart for total time on roads.

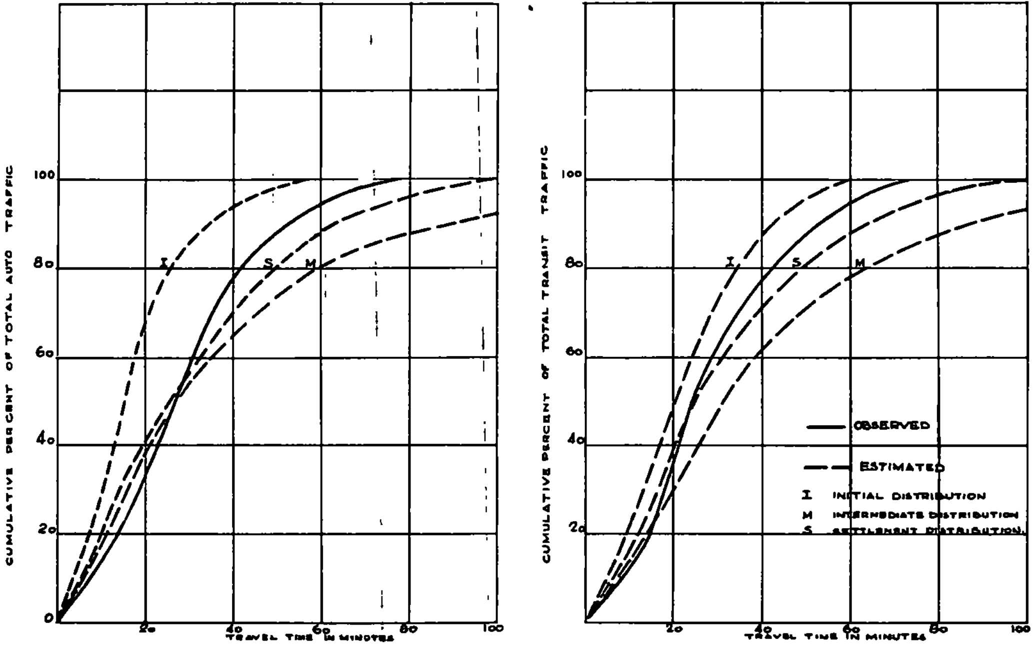


Figure 12. Trip distribution by travel time.

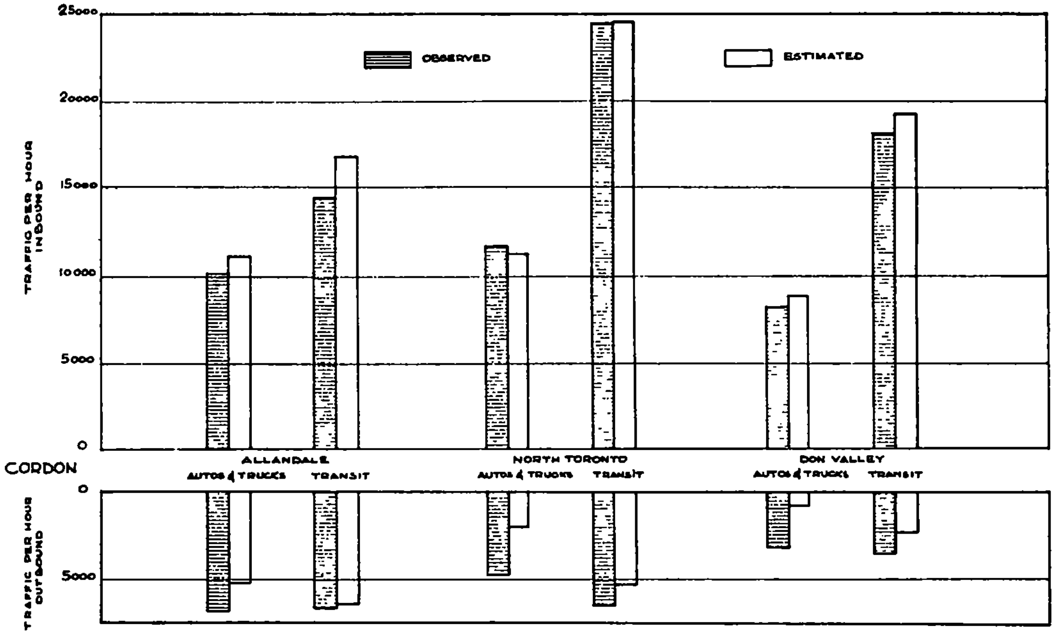


Figure 13. Total auto, truck, and transit passengers crossing cordon lines during AM rush hour, 1956.

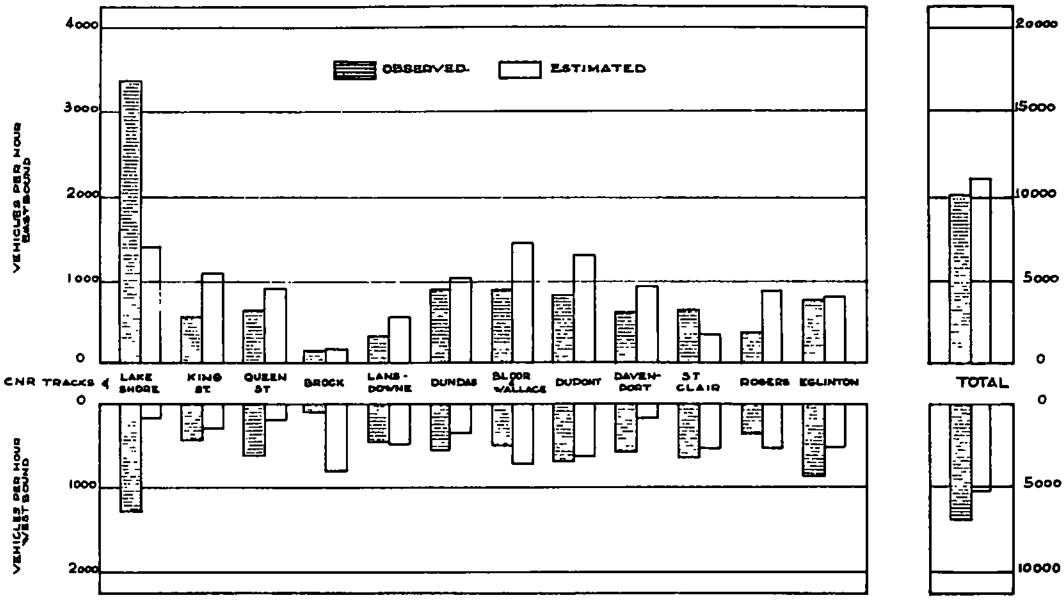


Figure 14. Automobile and truck flows crossing Allandale cordon during AM rush hour, 1956.

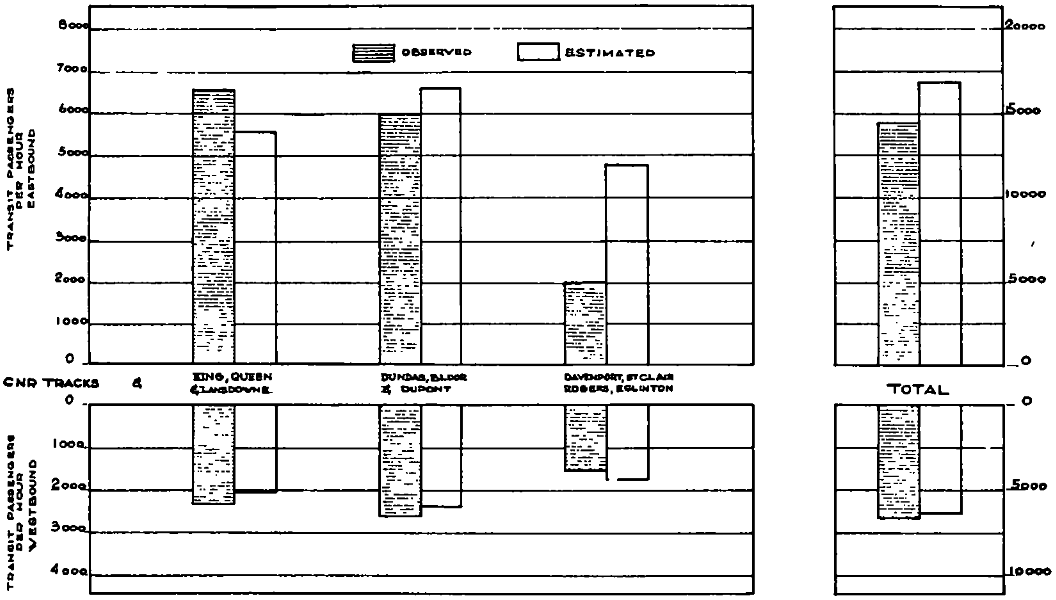


Figure 15. Transit passenger flow crossing Allandale cordon during AM rush hour, 1956.

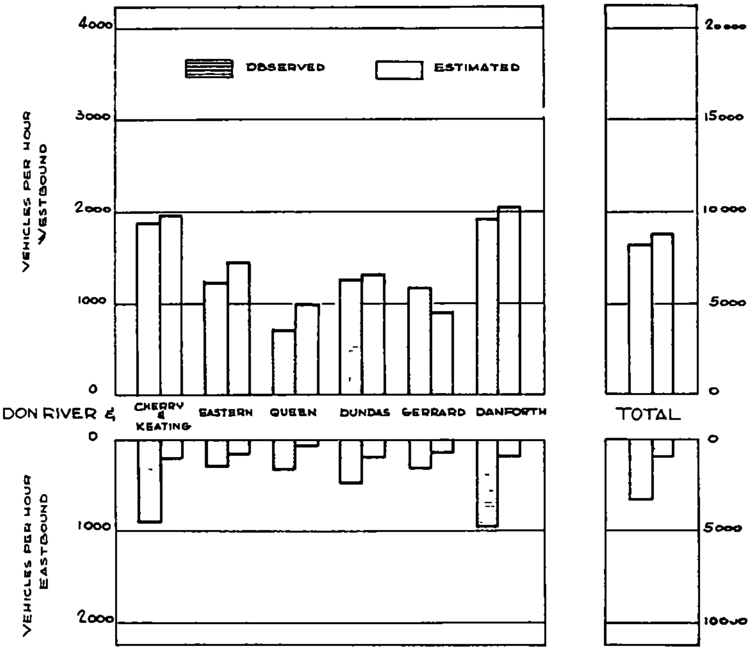


Figure 16. Automobile and truck flow crossing Don Valley cordon during AM rush hour, 1956.

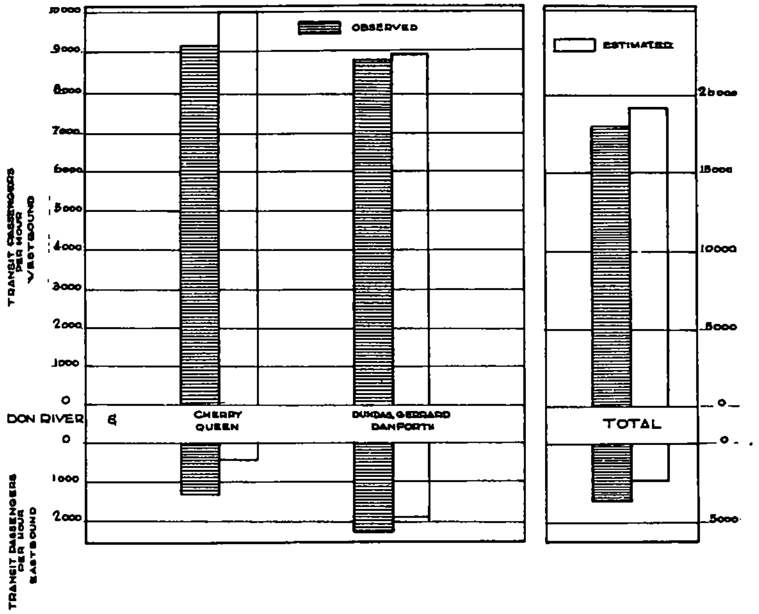


Figure 17. Transit passenger flow crossing Don Valley cordon during AM rush hour, 1956.

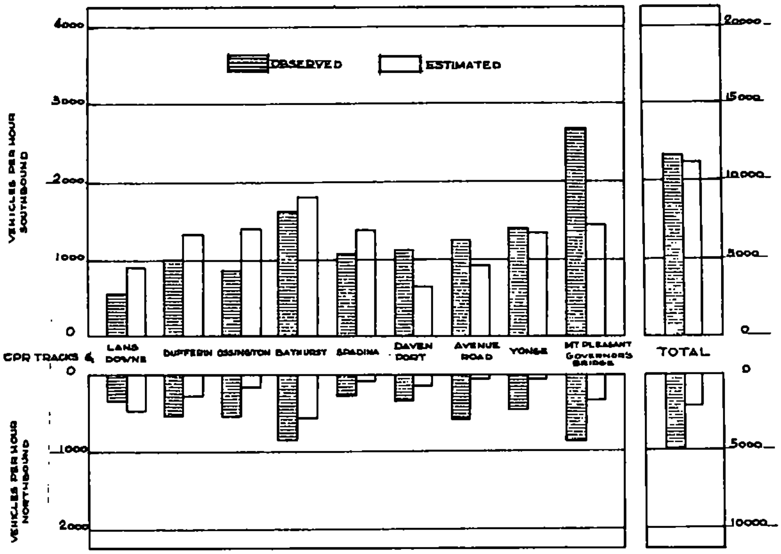


Figure 18. Transit passenger flow crossing North Toronto cordon during AM rush hour, 1956.

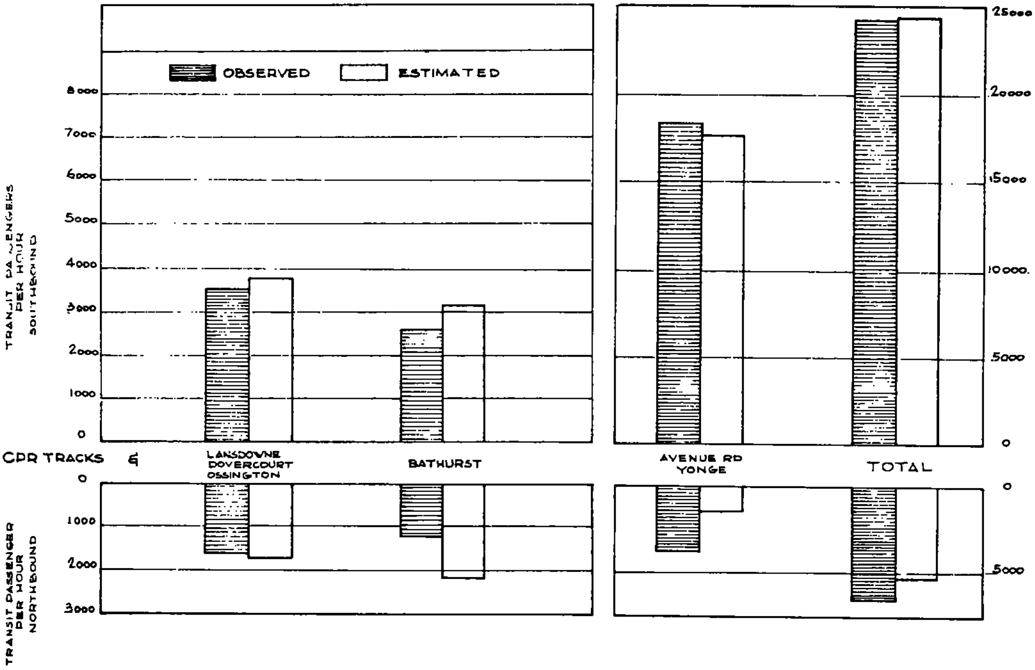


Figure 19. Transit passenger flow crossing North Toronto cordon during AM rush hour, 1956.

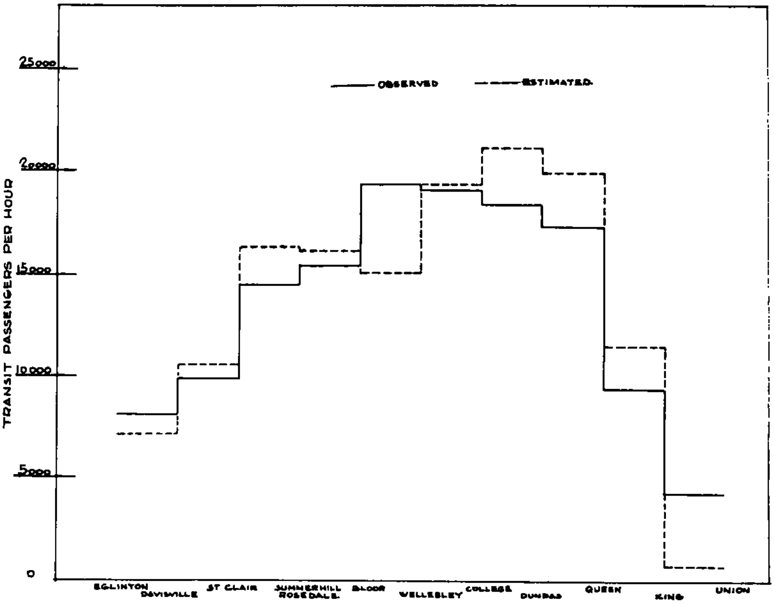


Figure 20. Total passenger flow of Toronto subway, northbound and southbound, during AM rush hour, 1956.

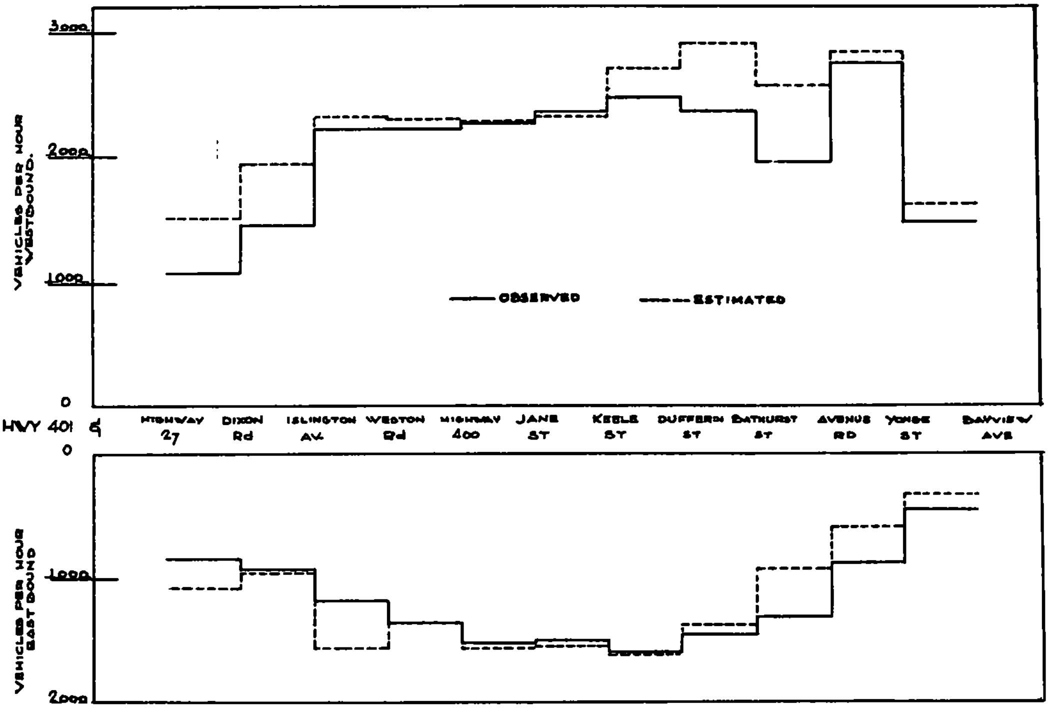


Figure 21. Eastbound and westbound flow of vehicles on Toronto bypass, Highway 401, during AM rush hour, 1956.

cordon line east of the CBD of Toronto. These graphs show excellent agreement for the large volumes inbound. Also, the modal split produced acceptable estimates for the inbound transit volumes. However, the outbound volume was greatly underestimated. This is apparently caused by errors in the input information for trip generation and attraction rather than in the modal split. Further analysis is pending. Figures 18 and 19 show the volumes of vehicles and transit passengers crossing a cordon line north of the CBD of Toronto. This cordon line is also crossed by the Toronto Subway for which the flow of passengers is shown in Figure 20. The discrepancies at Wellesley and Union Station are caused by the zoning of the area under study and could be rectified by subdividing the adjacent zones. These instances clearly show an unexpected sensitivity for coarseness in zoning and coding of street capacities. Figure 21 shows the vehicular flow on the Toronto Bypass, Highway 401, in both directions. The estimates are in reasonable agreement with the observed data.

CONCLUSION

The application of capacity restraints and the resultant feedback in a large-scale traffic forecasting model has given promising results in reproducing historic data. Although further research is necessary to imporve the various functions incorporated, the traffic forecasting model can realistically produce the travel behavior of the population in a given transportation system and given land-use plan.

REFERENCES

1. Cherniak, N., "Measuring the Potential Traffic of a Proposed Vehicular Crossing." ASCE Trans. Vol. 106 (1941).
2. "Highway Capacity Manual." U. S. Bureau of Public Roads (1950).
3. Trueblood, D. L., "Effect of Travel Time and Distance on Freeway Usage." HRB Bull. 61, 18-37 (1952).

4. Reilly, W. J., "The Law of Retail Gravitation." Filsburg Publishers, N. Y. (1953).
5. Beckmann, M., McGuire, C. B., and Winsten, C. B., "Studies in the Economics of Transportation." Yale University Press (1956).
6. "Highway Traffic Estimation." Eno Foundation (1956).
7. Dantzig, G. B., "The Shortest Route Problem." Operations Res., 5:270-3 (1957).
8. Moore, E. F., "The Shortest Path Through a Maze." Internat. Symposium on the Theory of Switching, Harvard Univ. (1957).
9. Bevis, H. W., "A Model for Predicting Urban Travel Patterns." Jour. Amer. Inst. of Planners, 25:No 2, (May 1959).
10. Booth, J., and Morris, R., "Transit vs Auto Travel in the Future." Jour. Amer. Inst. of Planners, 25:No. 2 (May 1959).
11. Calland, W. B.,"Traffic Forecasting for Freeway Planning." Jour. Amer. Inst. of Planners, 25:No. 2 (1959).
12. Voorhees, A. M., "A General Theory of Traffic Movement." Inst. of Traffic Engineers (1955).
13. von Cube, H. G., Desjardins, R. J., and Dodd, N., "Assignment of Passengers to Transit Systems." Traffic Engineering, 28:No. 11 (Aug. 1958).
14. Griffith, B. A., and von Cube, H. G., "Evaluation of Alternative Subway Routes." Proc. ASCE, Jour. City Planning Div. (May 1960).
15. Sagi, G., "Theoretical Traffic Volume and Timing Studies." Traffic Engineering, 30:No. 8 (May 1960).
16. Hall, E. M., and George, S., Jr., "Travel Time—An Effective Measure of Congestion and Level of Service." HRB Proc., 38:511-529 (1959).
17. Berry, D. S., "Field Measurement of Delay at Signalized Intersections." HRB Proc., 35:505-522 (1956).
18. Charlesworth, G., and Paisley, J. L., "The Economic Assessment of Returns from Road Works." Proc., Inst. of Civil Engineers, Vol. 14 (Nov. 1959).
19. Smeed, R. J., "Theoretical Studies and Operational Research on Traffic and Traffic Congestion." Bull. Internat. Inst. Statistics, 36:No. 4 (1958).
20. May, A. D., Jr., "A Friction Concept of Traffic Flow." HRB Proc. 38:493-511 (1959).
21. Rothrock, C. A., and Keefer, L. E., "Measurement of Urban Traffic Congestion." HRB Bull. 156, 1-13 (1956).
22. May A. D., Jr., and Wagner, F. A., Jr., "Headway Characteristics and Interrelationships of the Fundamental Characteristics of Traffic Flow." HRB Proc., 39:524-547 (1960).
23. Webb, G. M., "Freeway Capacity Study 1955." Progress Report, State of California, Department of Public Works, Division of Highways (1955).
24. Trautman, D. L., et al., "Analysis and Simulation of Vehicular Traffic Flow." Inst. Transportation and Traffic Engineering, Univ. of Calif., Research Report 20 (Dec. 1954).
25. Gardner, E. H., "The Congestion Approach to Rational Programming." HRB Bull. 249, 1-22 (1960).
26. Keese, C. J., Pinnell, C., and McCasland, W. R., "A Study of Freeway Traffic Operation." HRB Bull. 235, 73-132 (1959).
27. Malo, A. F., Mika, H. S., and Walbridge, V. P., "Traffic Behavior on an Urban Expressway." HRB Bull. 235, 19-37 (1959).
28. Campbell, E. W., Keefer, L. E., and Adams, R. W., "A Method for Predicting Speeds Through Signalized Street Sections." HRB Bull. 230, 112-125 (1959).
29. Wynn, F. H., "Tests of Interactance Formulas Derived from O-D Data." HRB Bull. 253, 62-85 (1960).
30. Hill, D. M., and von Cube, H. G., "Notes on Studies of Factors Influencing Peoples' Choice of Travel Mode." A report prepared for Metropolitan Toronto Planning Board (July 1961).
31. Hill, D. M., and Dodd, N., "Travel Mode Split in Assignment Programs." HRB Bull. 347, 290-301 (1962).

32. Irwin, N. A., Dodd, N., and von Cube, H. G., "Capacity Restraint in Assignment Programs." HRB Bull. 297, 109-127 (1961).
33. Dieter, K. H., "Analysis of Traffic Flow in Large Source-Sink Systems." Paper, 3rd Annual Meeting, Canadian Operational Res. Soc. (May 1961).

Travel Mode Split in Assignment Programs

D. M. HILL, Research Analyst, Traffic Research Corporation, Toronto; and NORMAN DODD, Transportation Research Planner, Metropolitan Toronto Planning Board

•DURING THE PAST two years the Traffic Research Corporation of Toronto has been developing and testing an electronic computer "traffic prediction program" (Fig. 1). This is a basic, highly flexible, planning tool that is being used by the Metropolitan Toronto Planning Board to develop a transportation plan comprising road, transit, and rail commuter systems.

To be capable of estimating traffic movements on each system the traffic prediction program must contain a mechanism able to forecast the division of total O-D movements between each of the available travel modes.

This paper deals with the studies carried out to develop this mechanism—referred to as the travel mode split—its incorporation and operation in the traffic prediction program, and finally, the results achieved in the estimation of 1956 traffic movements.

Studies firstly disclosed the factors influencing people's choice of travel mode and their order of importance, and secondly, enabled the establishing of a mathematical model that would represent the mechanism at work when people are confronted with the choice of travel mode.

There are two primary travel modes—travel by public transportation in buses, streetcars, subways, and commuter trains, and travel by private vehicle in automobiles, taxis, and trucks. The distinction between the two modes is characterized by the free movement of the private vehicle, as opposed to that of public transportation which is bound to schedules and routes.

People are influenced by many factors in their choice of travel mode, such as relative travel time, economic motivations, and the regularity and convenience of service. Using regression analysis methods, the influence of each of the factors was investigated separately and trends in transit usage were established.

Once mass human travel behavior was sufficiently explained by various factors, a mathematical model (the travel mode split) was designed to duplicate present behavior. Assuming no changes in human motivations, one can justify its application to future conditions.

The model of travel mode split is an inseparable component of any traffic prediction program. Such a program should contain a direct feedback mechanism using capacity restraints to allow the resultant traffic flow patterns to affect all components of the traffic prediction program including the travel mode split.

The travel mode split was incorporated in a traffic prediction program. It was used to forecast intra-city O-D traffic flows for all modes across various screen lines and on major city roads in metropolitan Toronto for the period of 1956. Close agreements between estimated and observed flows were obtained in most cases.

FACTORS INFLUENCING PEOPLES' CHOICE OF TRAVEL MODE

People are influenced by many factors in their choice of travel mode. These factors will be characteristic of the relative travel time, the social-economic status of the population, the influence of relative costs on the population groups, and the regularity and convenience of service.

Investigations were conducted to establish trends in transit usage with each of these factors. Much of the primary information used in these investigations was obtained from O-D surveys.

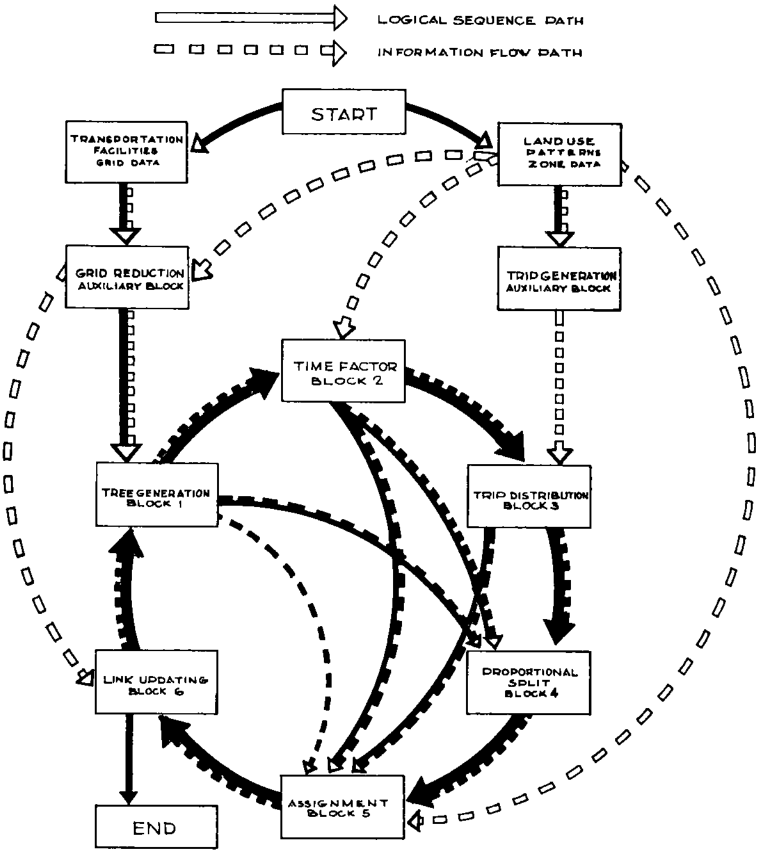


Figure 1. Traffic prediction program.

SOURCES OF INFORMATION

Surveys

Workers' Survey.—In the metropolitan Toronto area approximately 25 percent of establishments employing at least 30 people were surveyed in 1954. The questionnaire distributed was designed to establish the location of the worker's home, his place of employment and his mode of travel. Following the expansion of all reported trips and the processing of this information, a complete record was available of the total movements of this group of workers between zones by mode of travel.

Home Interview Survey.—Approximately 1 ½ percent of all households in metropolitan Toronto were surveyed in 1956. The interviews were conducted to obtain information about the number of persons per household, number of cars per household, and the occupants' travel behavior, i.e., how many trips were made by the occupants, the purpose of the trips, the mode of travel used, the place of departure and arrival, etc. By expanding the survey and processing of the results much information was available about such factors as population density, car ownership density, and trip characteristics.

Land-Use Survey.—Tables of 1956 existing land uses (in acres) were prepared from data derived from field surveys and aerial photographs. Land use was classified by such categories as residential (single dwelling units), residential (multiple dwelling units), hotels, commercial establishments, institutions, utilities, parking lots, transportation (railways), roads, open spaces, and vacant lands.

Some of the supplementary information was taken from the 1951 and 1956 Census Report of the Dominion Bureau of Statistics. In addition, information not available from the sources mentioned but essential for establishment of factors influencing people's choice of travel mode such as relative travel time and level of O-D transit service, was derived from transit schedules, transit route maps, and maps of the road layout. The data thus synthesized were carefully checked before implementation. The procedures of derivation used are discussed in their respective sections.

For the purpose of reducing the volume of survey data on hand the metropolitan Toronto area was subdivided into zones. The boundaries of the zones were made identical in all surveys so that they coincided with the zone layout used by the Dominion Bureau of Statistics.

For the purpose of further simplification a "center of gravity" was established for each zone, thus all trips are recorded as trips to and from fixed points—the centroids of the zones. Using a grid superimposed on the city map the centroids of zones were assigned coordinates where the X-axis of this coordinate system was taken parallel to the direction of the main east-west streets. This is especially justified in cities with a rectangular road layout.

There is a small sampling error inherent with a high percent sample, consequently the workers' survey is used in the regression analysis to establish most trends in transit usage. The other surveys are used to supply the necessary supplementary information.

STUDIES OF FACTORS

The relative importance of factors identified from the survey data is described in detail in the subsequent paragraphs. Only the major factors are mentioned, such as time, economic motivations, regularity and convenience of service. Other factors were eliminated from further investigations, once shown to be highly correlated with the major factors.

Travel Time

People are conscious of time elapsing while traveling, consequently they are likely to choose the mode of travel that keeps this time to a minimum. The choice may be related to the difference between travel times of the two modes; however, such an approach overlooks the relative importance of this difference as travel time increases. For example, a 10-min difference between travel times of 10 and 20 min is more critical than between travel times of 20 and 30 min. At this time the best approach seems to be to represent the time difference as a percentage of one of the travel times. This is equivalent to saying people's choice of travel mode is related to the ratio of the travel times.

Travel times for the O-D movements reported in the workers' survey were not available. Consequently, steps were taken to estimate the travel times by mode from each zone centroid to all other centroids. Knowledge of the relationships between travel speeds and prevailing traffic flows was implemented to estimate rush hour travel times by auto for each O-D worker movement. Travel times on the public transportation facility (not including waiting or transfer times) were based on scheduled speeds as recorded by the Toronto Transit Commission for rush hour service in operation in the metropolitan Toronto area on October 24, 1955.

To establish stable trends of travel behavior, a systematic grouping of all observations is necessary. The grouping of information tends to eliminate extraneous influences, and discloses the primary influence of a selected factor. The system of grouping requires that the entire spectrum of time ratio be divided into ranges, each of fixed length.

On grouping observations in this manner, the average transit share of all person-trips was calculated for each group and plotted on graph paper with the average travel

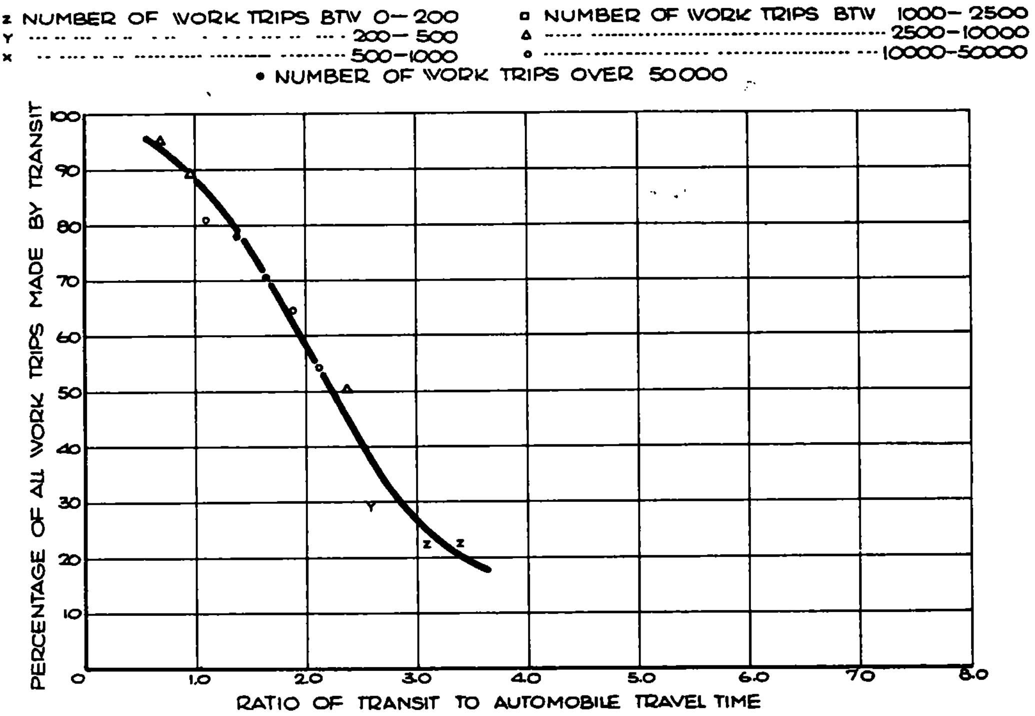


Figure 2. Transit share of work trips related to travel time ratio.

time ratio. A curve was drawn through the plotted observations to show the predominant trend in transit usage.

The observations are coded according to the number of person trips reported for each group observation. Because extraneous influences are more likely submerged in large groups than in small groups, group observations reporting a large number of person trips tend to be more reliable than groups reporting a small number and naturally the curves should agree closely with these reliable observations (Fig. 2).

Economic Motivations

In choosing a mode of travel people consider the relative costs of travel. However, the importance of cost is related to people's economic status, which at this time is considered best measured by family income. One expects that people of low economic status are more conscious of travel costs than people of higher economic status who can afford more expensive modes. For changes in travel costs (such as increases in transit fares) people are likely to choose a new mode of travel, because either they find traveling by their present mode is now too expensive or both modes are equivalent in terms of cost and they are now more conscious of other factors, such as relative travel time and the regularity and convenience of service.

Neither income statistics nor comparative travel costs for each mode of travel were reported with the workers' survey. However, steps were taken to provide this information.

The census report of the Dominion Bureau of Statistics for the year 1951 was reviewed. The review provided information about the median incomes of male and female workers residing in each zone. Although worker's income had increased with rising standard of living between 1951 and 1954, one is justified in assuming that workers during 1954 still received the same income relative to their neighbors' income. The 1951 income scales, uniformly graded up to 1954 standard of living, were considered representative of people's economic status in 1954. Consequently, the worker population of each urban zone was assigned an economic indicator with a range of values from 0 to 35 depending on the median income recorded in each zone.

Figure 3 shows the relationship between the transit share of work trips and the economic indicator for the worker population. The observations are coded according to the number of person trips. Also, the fitted line agrees closely with the heavily weighted observations.

The influence of the relative travel cost is considered connected with the economic indicators. Measurements of the relative cost of travel were made subsequent to a review of the following sources of information:

1. Public transit zone maps and fare tables.
2. "Economic Evaluation of Traffic Networks," by G. Haikalis and H. Joseph. The review provided estimates of the operating costs of an automobile based on speed and distance of travel. The operating cost was set equal to the sum of the running and accident costs. Running costs included gas, oil, and maintenance expenses. High accident costs at low speeds of travel were expected to be representative also of travel discomfort experienced at these low speeds.
3. Annual reports of the Parking Authority of Toronto. The review provided a record of parking charges in zones serviced by off-street parking lots. Relationships established from such data showed that parking costs increased as the demand for parking exceeded a given supply. These relationships were used to determine parking charges in other zones.

Regression analysis was conducted to correlate changes in transit usage with the travel cost difference. Trends were disclosed that were approximately coincident with similar trends in transit usage for changing levels of the economic indicator. Constant increments of costs were shown to cause changes in transit usage that could be

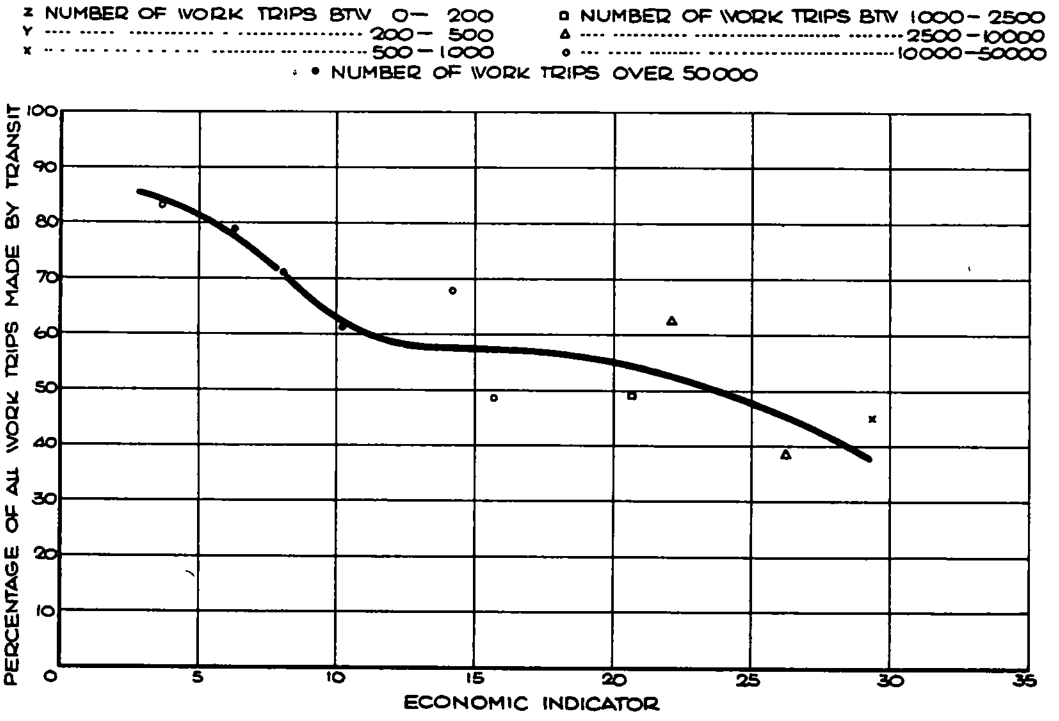


Figure 3. Transit share of work trips related to economic indicator.

explained by a constant increment in the economic indicator. These findings supported the deduction that people of a set economic status alter their travel behavior when changes in costs of travel occur, so that their behavior duplicates that of people of a different economic status. Consequently, it was concluded that the influence of changes in relative cost of travel would be reflected by a linear adjustment in the established economic indicator of the worker population.

Regularity and Convenience of Service

The private vehicle offers a more luxurious and convenient mode of travel than does public transportation, particularly by eliminating lengthy waiting periods and walking times. However, waiting periods and walking times are important considerations when using transit because they reflect the level of service offered on the public transportation facility. People tend to measure the regularity and convenience of public transportation service in terms of the time spent in addition to traveling, such as walking from the trip origin to the station, waiting time at the station, transfer time between route changes, and walking time from the station to the trip destination.

The following steps were taken to calculate these measurements:

1. Waiting Times. —The waiting time at a station is set equal to one-half the scheduled headway time of the public transportation facility in a zone as recorded by the Toronto Transit Commission for rush-hour service on October 4, 1955.

2. Transfer Times. —It is reported that approximately 90 percent of subway passengers make at least one transfer, approximately 50 percent of all transit passengers make one transfer, and 10 percent of this number make two or more transfers. Despite the introduction of a small error, each O-D transit movement is recorded with one transfer. This transfer time is set equal to one-half the scheduled headway time of the public transportation facility in the destination zone.

3. Walking Times. —Although walking times were not reported in the surveys, there was sufficient information available, such as the number of miles of transit track, the average spacing between stations, and the number of acres of developed land in a zone, to make possible the computation of average walking times to and from transit stations. A few assumptions concerning first the location of transit lines with respect to the zone boundaries and secondly, people's walking behavior, were necessary for the estimation of these average walking times.

Because transit routes follow the rectangular road layout of the city, it was assumed that approximately one-half of the transit lines servicing a zone run north-south and the other half east-west. Also, one can assume that people tend to walk to the nearest transit station located on a transit route that runs parallel to their desired direction of travel.

If the north-south and east-west transit lines are evenly distributed throughout the same developed area, then the following formulas may be used to compute representative walking distances, and walking times, which people may experience in each zone.

The average distance walked in miles,

$$D = \frac{1}{3}\sqrt{d^2 + w^2} + \frac{d^2}{6w} \cdot \ln\left(\frac{\sqrt{d^2 + w^2 + w}}{d}\right) + \frac{w^2}{6d} \cdot \ln\left(\frac{\sqrt{d^2 + w^2 + d}}{w}\right)$$

in which

$d = \frac{1}{2} \times$ stop spacing, miles,

$w = \frac{A_D}{L_T} \times \frac{1}{640}$, miles,

A_D = number of acres of developed land,

= total land—vacant land—open space,

L_T = number of miles of transit track.

The average walking time in minutes,

$$T = \frac{60}{3} \times D \quad \text{(walking speed of 3 mph)}$$

The level of O-D transit service is measured by the sum of the walking plus waiting time in the origin zone, a transfer time, and the walking time in the destination zone.

Observations were grouped and plotted on graph paper. A curve was drawn through the grouped observations to show the relationship between transit usage and the changing levels of O-D transit service (see Fig. 4).

DEVELOPMENT OF TRAVEL MODE SPLIT MODEL

Knowledge of the order of magnitude of the factors that influence people's choice of travel mode is especially important if the mechanism at work in the travel mode split is to be adequately explained. The trends in transit usage now established indicate the relative order of magnitude of the influence of the three factors:

1. Relative travel time.
2. Economic indicator as recorded for the population (based on average travel costs).
3. Level of transit service between origin and destination.

To formulate a mathematical model for the purpose of projection of transit usage the relationships between these factors and the transit share of person trips are united into a single model. The expected trends in travel behavior are shown in Figure 5.

The following condition is satisfied by this model of travel mode split: Population groups indexed by a high economic indicator, place more emphasis on time and comfort than cost considerations. Other population groups with a low economic indicator possibly ignore time and comfort considerations to choose a mode of travel they can afford to use. This mechanism is duplicated in the model where transit usage by persons of high economic status is more elastic with changes in the travel time ratio than transit usage by persons of low economic status.

The transit usage of person movements reported in the workers' survey was strati-

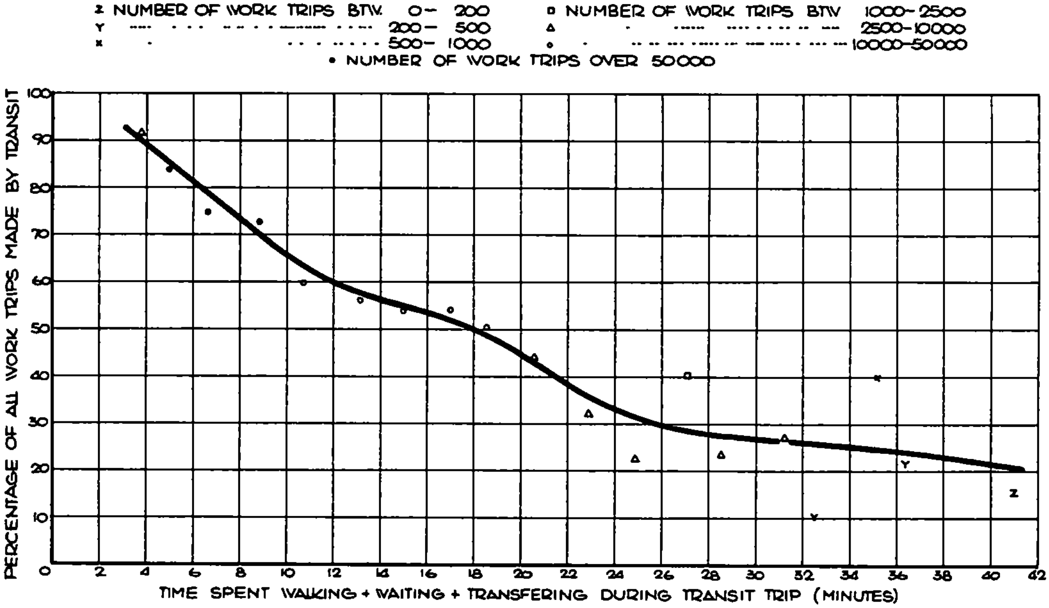


Figure 4. Transit share of work trips related to total walking and waiting times.

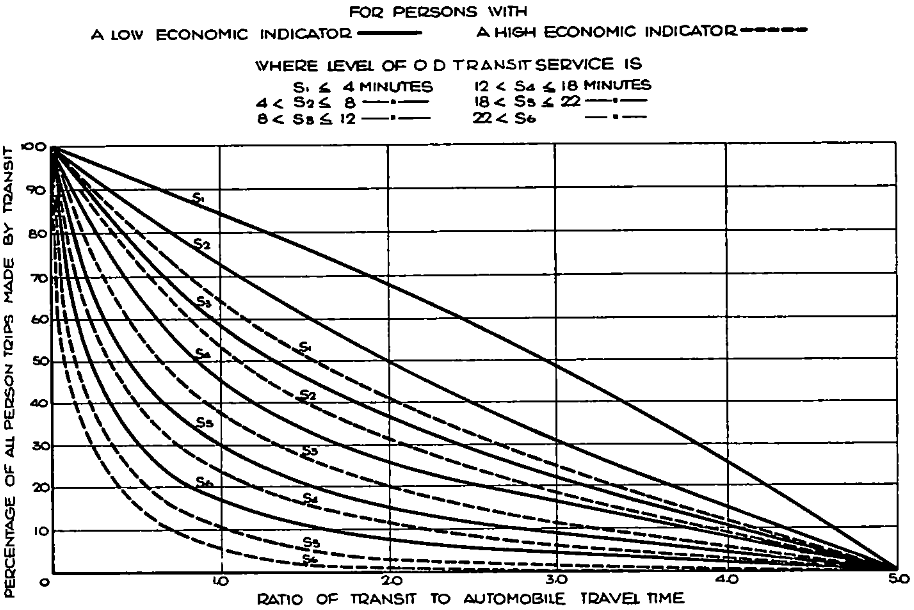


Figure 5. Model for forecast of transit share of person trips.

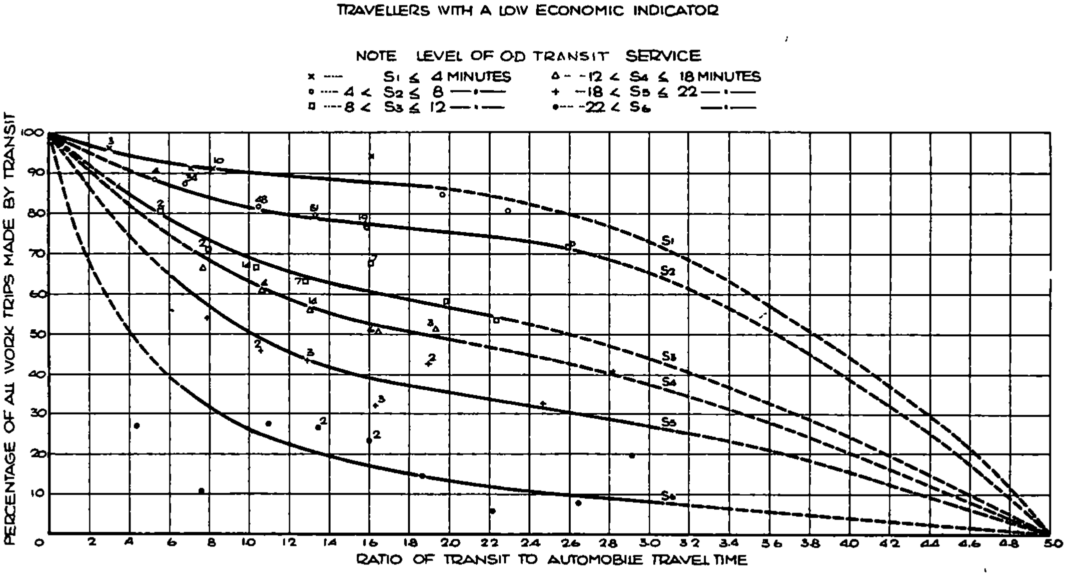


Figure 6. Transit share of work trips related to ratio of transit to automobile travel time.

fied by the economic status of the population and by levels of O-D transit service. Once the observations were stratified, transit usage was next correlated with the transit to automobile travel time ratio. The observations were assigned weights according to the number of person trips (unit = 1,000) grouped together for each interval of time ratio. Curves were drawn through the plotted observations to demonstrate the trends in transit usage (Figs. 6 and 7). Dotted lines are extrapolated beyond the range of observations to indicate the postulated trends.

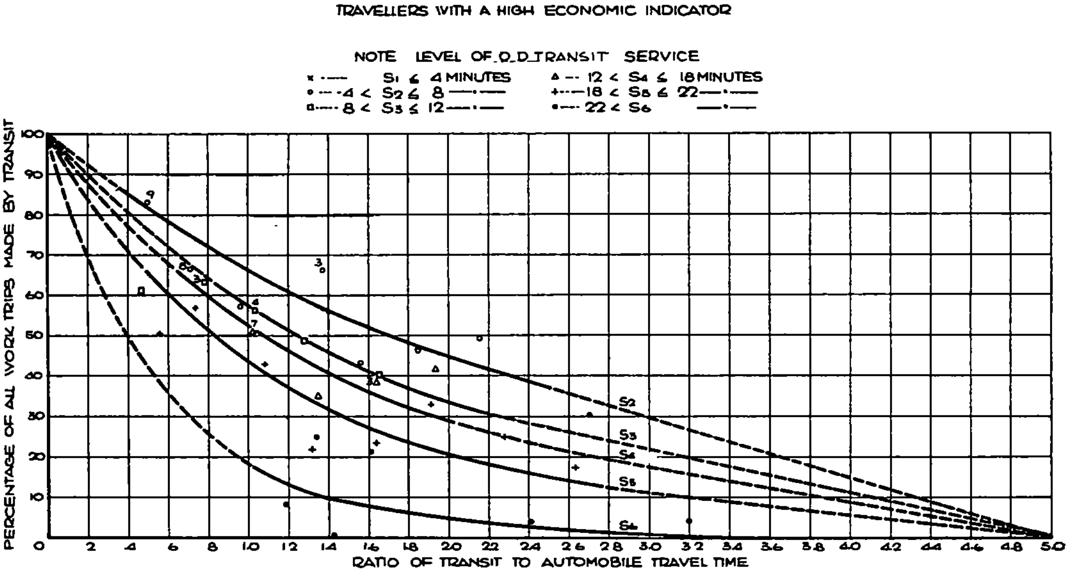


Figure 7. Transit share of work trips related to ratio of transit to automobile travel time.

Although these established trends are characteristic of work trips, further studies indicated that they approximately duplicate the behavior of people who make business, commercial, or school trips in autos or on transit during the rush hour.

The behavior of people making social trips appeared to differ from the behavior of people who make other types of trips.

In the analysis of the data of the home interview survey, social trips were less than 1 percent of total trips made during the morning rush hour and 3 percent of total trips made during the evening rush hour. If the model is used to determine the transit usage during the morning rush hour, the resulting discrepancy of calculating the transit share of social trips is negligible.

It is a well-known fact that estimates of traffic for the morning rush hour are more reliable than the traffic estimates for the afternoon rush hour, because of the predominance of work trips and the absence of other types of trips. It was concluded that curves for the estimation of the transit share of work trips (such as those shown in Figs. 4 and 5) will give accurate forecasts.

TRAVEL MODE SPLIT IN A TRAFFIC PREDICTION PROGRAM

The travel mode split model determines a realistic split of the O-D traffic between privately-owned vehicles and public transportation. Other components of the program calculate route assignment factors by travel mode to be used for assigning the O-D transit traffic to surface transit routes, subway routes, rail and bus commuter routes, likewise O-D vehicular traffic to local streets, arterial roads, and expressways.

The travel mode split is a component of the time factor block, one of the following six program blocks of the model:

Block 1	Tree generation
Block 2	Time factor
Block 3	Trip distribution
Block 4	Proportional split
Block 5	Assignment
Block 6	Link updating

Auxiliary blocks such as grid reduction block and the trip generation block are necessary to summarize land-use data and data characteristic of the transportation facili-

TRAVEL MODE SPLIT IN TIME FACTOR BLOCK

Thirty curves that describe the relationship between the transit share of traffic and the travel time ratio are expressed in table form for input to the time factor block. Each curve describes the transit usage of a specific population group for a specific level of transit O-D service. The population is divided into five groups where the first group are people of low economic status, and the fifth group are people of high economic status. There are six levels of transit O-D service, the first representative of very regular and convenient service, the sixth representative of irregular and inconvenient service.

To calculate the transit and/or vehicular share of O-D traffic for the AM rush hour the order of steps is as follows:

1. The economic indicator that is representative of the population residing in a home zone is linearly adjusted by a multiple of the travel cost difference for each O-D movement. The travel cost difference equals the sum of operating costs, accident costs, and parking charges minus the transit fare.
2. The regularity and convenience of service is measured by the sum of waiting, transfer, and walking times likely to be experienced in each O-D movement. The waiting time is set equal to one-half the average headway time of the transit facility in the origin zone. Walking times are calculated for both the origin and the destination zones, then added together. One transfer time is included, this is set equal to one-half the average headway time of the transit facility in the destination zone of the traffic.
3. Average O-D travel times are calculated for the vehicle mode and the transit mode. Transit O-D travel time is divided by the vehicular O-D travel time to form the travel time ratio.
4. The adjusted economic indicator and the level of O-D transit service specify the travel mode split table to be used. The travel time ratio then indexes the transit share of each O-D movement.

RESULTS OF A TRAFFIC ASSIGNMENT

The traffic prediction program was used to forecast total traffic via alternate modes for the historical period 1956 when traffic counts were made at various cordons, on major roads, and on surface transit and subway facilities. The results of this forecast are shown in some of the figures.

At the completion of eleven iterations (one initial, ten complete), stable traffic flow patterns resulted. During the first five complete iteration (2 to 6) new routes were generated, traffic was resplit, redistributed, reassigned, and travel times on links re-evaluated. In the final five iterations, (7 to 11) the program iterative cycle was complete with the exception that no further routes were generated. The first iteration provided an unrestricted assignment and an estimate of the ideal system cost; i.e., total time of persons, subject to ideal travel conditions (off rush hour), on roads in autos, in trucks, or on transit. The final iteration provided the traffic flows and system cost that would exist under peak-hour, congested conditions.

An analysis of results shows close agreement between total estimated and observed traffic crossing cordons, transit traffic crossing cordons via transit corridors, and transit traffic on the Yonge Street Subway. Most deviations between the observed and estimated counts are within day-to-day traffic fluctuations (10 to 20 percent).

CONCLUSIONS

The travel mode split with its ability to assess and reassess the division of traffic between alternative transportation systems is an essential component of any traffic prediction program. Consequently, the traffic prediction program simulates human behavior on roads. The sufficient accuracy of the results in the traffic assignment for a historical period warrants the model's application to transportation planning.

The scope of the model's application will widen as future research and experience is gained in the use of the model. Also, this research will undoubtedly result in further refinements of the program.

ties. The summarized data are then used as basic input data for the model. The sequence of information flow between each of the six blocks and between the six blocks and the auxiliary blocks is shown in Figure 1. A brief explanation is given here to explain the function of each block; a more detailed description can be found elsewhere (1).

Auxiliary Blocks

Grid Reduction.—The area to be studied is manually divided into zones. Land-use data of each zone such as population, the number of dwelling units, and car registration are attached to each node centroid.

Road and transit networks are represented by a detailed grid of links and nodes, where a link is the travel path between two adjacent nodes.

Trip Generation.—Relationships established from survey data are used by this block to estimate how many trips by purpose are made by the urban population during the AM rush hour. The output of the block provides an estimate of the traffic generated in each zone, and also of the traffic to be attracted to each zone.

Main Program Blocks

Tree Generation.—The tree generation block determines routes of travel and consequently travel times from each node centroid to all other node centroids. Up to nine routes for each origin destination pair may be generated.

Time Factor.—The time factor block determines the propensity to travel for various trip purposes from one zone to another zone (time factors). The transit share, and consequently the private vehicular share of traffic is simultaneously calculated for each O-D movement (travel mode split factors). Lastly, the proportion of private vehicular and/or transit traffic to be assigned to alternate routes of travel is calculated (route assignment factors). At this time, both the time factors and route assignment factors are functions solely of the travel time. The travel mode split factors are alone functions of several factors, one of which is time.

Trip Distribution.—The trip distribution block takes into account the time factors and also the opportunities offered for beginning and ending trips in each zone. Consequently, the block estimates by trip purpose how many people in total will travel from one zone to another zone.

The Proportional Split.—The proportional split block uses total O-D trip volumes of the trip distribution block, travel mode split factors, and route assignment factors to evaluate how many people will travel via each mode and on each alternative travel route from zone to zone.

Assignment Block.—The assignment block assigns the O-D split trips to each link of each route. This calculation provides estimates of traffic flows via each mode, on each link of the transportation network.

Link Update Block.—The link updating block uses the assigned link loads to evaluate the current travel time on each link of the grid. This evaluation is based on empirical formulas derived from speed vs traffic flow studies.

During successive iterations (6 complete blocks) of the program new travel routes are found, the traffic is resplit, redistributed, and reassigned. The information flow continues until stable traffic flow patterns are attained. The forecast in iterative steps is completed when the following observations are made:

1. There is little change in the system cost (total time spent traveling in autos or on transit).
2. There is little change in the distribution of the traffic (trip frequency remains stable).
3. There is little change in the traffic flows on all links of the transportation network.

Consequently, a series of program iterations duplicates human behavior as people will be influenced by changing travel conditions until they are content that their choice of route, travel mode, and trip destination is best among all possible choices.

REFERENCES

1. Irwin, N., and von Cube, H. G., "Capacity Restraints in Multi-Travel Mode Assignment Program." HRB Bull. 347, 258-289, (1962).
2. Adams, W. T., "Relationship of Use of Transit and Automobile in Urban Areas to Principal Factors Influencing That Use." U. S. Bureau of Public Roads (1959).
3. Trueblood, D. L., "Effect of Travel Time and Distance on Freeway Usage." HRB Bull. 61, 18-37 (1952).
4. von Cube, H. G., Desjardines, R. J., and Dodd, N., "Assignment of Passengers to Transit Systems." Traffic Engineering, 28:No. 11 (Aug. 1958).
5. Griffith, B. A., and von Cube, H. G., "Evaluation of Alternative Subway Routes." Jour. City Planning Division, Proc., ASCE, Vol. 86 (May 1960).
6. Quinby, H. D., "Traffic Distribution Forecasts Highway and Transit." Traffic Engineering, 31:No. 5 (Feb. 1961).
7. Schwartz, A., "Forecasting Transit Usage." HRB Bull. 297, 18-35 (1961).
8. Sutcliffe, E. D., "The Transit Planning Study Including Rapid Transit." A Study on Highway Planning Part II for Metropolitan Vancouver, British Columbia.
9. Irwin, N. A., Dodd, N., and von Cube, H. G., "Capacity Restraint in Assignment Programs." HRB Bull. 297, 109-127 (1961).
10. Mortimer, W. J., "Transportation Usage Study." Cook County Highway Department (Dec. 1957).
11. Haikalis, G., and Joseph H., "Economic Evaluation of Traffic Networks." HRB Bull. 306, 39-64 (1961).

A Survey of the Literature on Inter-Community Traffic

GEORGE T. MARCOU, Associate Professor of Community Planning,
Bureau of Community Planning, University of Illinois

• THE EASE of movement of people, goods, and ideas is a prerequisite to the proper functioning of modern society. Developments in highway, rail, and air transportation and in telephone, radio, and television communications are linking together communities and segments of communities despite their normal geographic separation.

In 1959, a research project was initiated by the Bureau of Community Planning of the University of Illinois and sponsored by the University, the Illinois Division of Highways and U. S. Bureau of Public Roads, to study one form of inter-community linkage (traffic) in one particular locale (east central Illinois) at one particular time (an average spring weekday in 1958) and between one central community (Champaign-Urbana) and the communities located around it.

The ultimate objective of this project is to relate inter-community traffic data between Champaign-Urbana and other communities in east central Illinois with the communities' population, economic, locational, and land-use data that are thought to be relevant to the traffic generated between them and Champaign-Urbana. These relationships are expressed in the form of statistical formulas or models.

SCOPE, PURPOSES AND PROCEDURES

One of the first tasks of the project staff has been to conduct a survey of the literature on inter-community linkage in general and inter-community traffic, in particular. The purposes of the literature survey have been the following:

1. To provide the project staff with general background and knowledge on inter-community linkage and traffic.
2. To identify from existing literature the current hypotheses essential to the development of an analytical framework to use in the project. The major emphasis in this survey has been on identifying the variables that past researchers have determined as affecting inter-community traffic, not on how these variables can be related to each other in a mathematical formula. This latter consideration will be covered in a subsequent report dealing with the form of the mathematical formulas that will be used in this project.
3. To relate these hypotheses to the present project.
4. To compile an annotated bibliography that could be of use in other projects dealing with inter-community traffic.

The concept of inter-community linkage is a broad concept that cuts across a number of disciplines and fields of study. The first effort in this survey was diverted towards identifying these disciplines and the literature available in these fields.

This was accomplished first by interviewing a number of University of Illinois faculty members from the fields of economics, business, planning, traffic engineering, communications, geography, government, and sociology. Lists of relevant reference works and literature were obtained during these interviews.

The items in the bibliography were then reviewed and abstracted. These annotated selected references are included in the Appendix. The body of this report consists of a review of the findings of the survey. Other reports in this project include "Description of Regional Traffic Patterns in the Champaign-Urbana Area," by George W. Greenwood, project investigator; "A Multiple Gravity System for a Study of Regional Inter-

Community Traffic," by Aly M. Shady, project statistician; George W. Greenwood, project investigator; and George T. Marcou, project supervisor; and a final report which is in preparation.

MEASUREMENT OF INTER-COMMUNITY LINKAGE

Four elements in the definition of linkage recur through the literature: the item that is moved, the two or more geographic areas between which this movement occurs, the channels through which the movement occurs, and finally, the purpose of this movement. All four elements of this definition are variable depending on the form of linkage.

The following are some examples taken from the literature surveyed:

1. The number of telephone calls exchanged between arbitrary selected cities (1).
2. The number of tourists entering the State of Washington by State of residence (1).
3. The number of downtown shoppers from various residential areas within a city (2).
4. The number of automobiles from different States entering Mount Rainier, Glacier, Yosemite, and Yellowstone National Parks (1).
5. The quantity of household goods moved by moving van between arbitrary selected cities (1).

These measures indicate that linkage involves the following:

1. Items that move or are moved; items of communication, people, vehicles, or goods.
2. Two or more geographic areas that are linked: parts of a city, cities, States, regional, statewide, or national facilities.
3. Channels through which linkage occurs: highways, railways, airways, or telephone lines.
4. Purpose or purposes for which linkage occurs: recreation, shopping, or all-purpose.

Linkage then can be broadly defined as a relationship between two geographic areas, involving the movement of items of communication, people, vehicles or goods between them, along certain channels and for certain purposes. A fifth element of definition, essential to measurement, is that of the time interval within which linkage is observed and measured.

The data obtained during the 1958 comprehensive origin and destination survey of the Champaign-Urbana area provide the following information for measuring inter-community traffic (a form of linkage) between Champaign-Urbana and the communities around it.

Items which move or are moved include the following:

1. The number of vehicle-trips produced by vehicles garaged in Champaign-Urbana and attracted by individual communities in east central Illinois.
2. The number of person-trips produced by Champaign-Urbana residents and attracted by individual communities in east central Illinois.
3. The number of vehicle-trips produced by vehicles garaged in individual communities in east central Illinois and attracted by Champaign-Urbana.
4. The number of person-trips produced by residents of individual communities in east central Illinois and attracted by Champaign-Urbana.

The two geographic areas linked are the Champaign-Urbana urban area on one hand and the population centers and rural zones surrounding Champaign-Urbana, on the other. Population centers include both incorporated and unincorporated communities that are identifiable by name. Rural zones have been defined for Champaign County. Both of these are referred to as communities.

The channels used in this case are the highways, roads, and streets that connect Champaign-Urbana to its surroundings.

The purposes for which inter-community traffic occurs have been categorized in the survey as "work, business, medical and dental, school, pleasure, shopping, eat meal, overnight, and all others." The total traffic linkage resulting from the summation of all trips is of course an "all-purpose" total.

The time increment for which these data are available is an average 24-hr spring weekday in 1958.

Some observations should be made regarding the scope of project IHR-69 in relation to other studies found in the literature:

1. The project deals with only two items of linkage: motor vehicles and their passengers.
2. One of the two geographic areas linked is always Champaign-Urbana.
3. The project deals with only one regional situation. Whether relationships derived from this project are applicable to other regional situations is open to question and testing.
4. The project deals with 1958 spring weekday traffic only and cannot take into account weekend or seasonal variations, or changes from one year to another.

MAJOR HYPOTHESES ADVANCED

The total traffic interchange between two communities may be regarded as the summation of two types of movement: trips produced by the first community and attracted by the second together with their return trips, and trips produced by the second community and attracted by the first, including return trips. A community's capacity to attract trips is not necessarily the same as its capacity to produce trips. For this reason, the literature survey was geared to identifying the variables that affect both trip production and attraction as well as those that affect trip production or trip attraction alone.

1. A community's capacity to produce trips to another community or to attract trips from that community is a function of the travel friction between them.

This is a widely accepted and well-demonstrated hypothesis based on the assumption that the greater the distance from a population center, the smaller the influence of that center (27, 28). Questions raised in the literature concern the ways of measuring travel friction or distance between communities.

Distance has been measured in terms of actual mileage or travel time. Distance has also been measured in terms of cost of travel including direct transportation costs such as the cost of motor fuel consumed or indirect costs resulting from delay or fatigue (3). Of these, time-distance appears to be the most appropriate to inter-community traffic studies because it can take into account factors that affect the movement of motor vehicles such as traffic congestion, road conditions, or topography.

The literature suggests that the impact of distance on the extent of inter-community traffic is not uniform. It is suggested that the distance factor itself is a variable that is affected by the size of population of communities linked, or by the magnitude of the distance involved (4). Another consideration regarding the variation in the impact of the distance factor is the difference in value placed by people on distance depending on the purpose of the trip (27). People are willing to travel longer distances for medical purposes, for example, than for shopping purposes, or for less frequent trips than for daily trips. Finally, there is a great likelihood that the impact of the distance factor will vary depending on whether trips produced or trips attracted are under consideration.

In project IHR-69, it is proposed that time-distance between Champaign-Urbana and other communities in east central Illinois be used as a measure of travel friction. It is also proposed that the diversity in the impact of distance on inter-community traffic be taken into account.

2. A community's capacity to produce or to attract trips is a function of its population size.

The assumption in this hypothesis is that the larger the population of a community, the greater its influence and the more likely it is to produce and attract trips (1, 28). This is also a widely accepted hypothesis whose validity has been demonstrated in a number of empirical studies. Population size has been used as a measure of a community's importance as a retail trade center (4) or as a center of absorption in migration studies (5, 6). It has also been used as an indication of a community's capacity to produce and attract trips in studies in Illinois, Michigan, and Washington (1).

But some researchers have criticized the use of population size as a measure of a community's traffic generation potential on the grounds that size alone does not reflect the social or economic structures of the community, factors that are believed to be of significance in traffic generation. In answer, some researchers state that population size is a reliable indicator of a community's economic importance. In other cases, population size has been modified by the addition of factors accounting for differences in the sex, education, and other characteristics of the population. Similarly, population size data has been supplemented with indexes of the community's economic structure, such as assessed valuation or banking resources.

There has been sufficient evidence advanced to demonstrate that population size in itself is a reliable enough index of a community's ability to produce and attract trips (1). In project IHR-69, population size as a measure of this ability will be tested. If it is found unreliable, it will be supplemented by other data pertaining to the community's structure.

3. A community's capacity to produce trips is a function of the extent of car ownership in the community.

This hypothesis is derived from recent investigations of the traffic generation of residential areas (2, 7, 8, 9, 27) and has found application in at least one inter-community traffic study in the State of New Jersey (10).

In these studies, the average number of cars owned per dwelling unit was found to correlate highly with residential trip production. Similarly, the total number of cars in a residential area was also found to correlate highly with the number of trips produced by the area.

This method of measuring a community's capacity to produce trips may be preferable to the use of population size, because the former gives an indication of population size as well as the ability of community residents to travel. The difference between using car ownership and population size is particularly important where the per capita car ownership is not uniform for all communities linked.

In project IHR-69 both car ownership and population size will be tested to determine their relative reliability as indexes of a community's ability to produce trips.

4. A community's capacity to produce or to attract trips varies from one purpose to another.

This recognizes that the degree of influence of a community over the surrounding area is not uniform for all functions performed by the community. The existence of a hierarchy of functions that a central city performs for its hinterland has been demonstrated in general studies (11) and in studies dealing with the Lansing, Mich., area (12), the Champaign-Urbana area (13), and the Springfield, Ill., area (14).

In this project, the extent of inter-community traffic is expected to vary with the purpose for which trips are made. Therefore, different mathematical models will have to be developed for each purpose. Because the pattern of inter-community traffic is likely to vary for each purpose, the variables that will be related to traffic are also likely to be different in each case.

5. A community's capacity to produce or to attract trips for any one person will vary within that purpose.

This hypothesis recognizes the difference between activities of a local and those of a regional nature, within any one purpose category. As an illustration, shopping for groceries has often been mentioned as an activity likely to take place within the community of residence; by contrast, shopping for apparel is an activity that may generate a large amount of regional traffic (9, 11, 13).

Most of the purpose categories in the Champaign-Urbana traffic survey are broadly defined and do not take into account these intra-purpose variations. It will be necessary to determine for each purpose category which activities are of a local nature and which are of a regional character. Two sources of information are available to assist in these determinations: the findings in the literature survey and the analysis of the types of establishments in Champaign-Urbana which attract regional trips for each purpose. Both of these sources will be used in the project.

6. A community's capacity to attract trips is conditioned by competition with other communities.

This recognizes the limitations put on a community's area of influence by competing communities, and the overlapping nature of community influence. This is taken into account in delimiting the primary regional labor markets and trade areas of communities (15).

In the literature, a procedure is established to define the point of equilibrium at which the influences of two competing communities are equal. This is accomplished through the use of population size and distance data. An adaptation of this procedure can be developed to measure competition as a variable in inter-community traffic. In project IHR-69 it is proposed to develop such a measurement and to incorporate competition as a variable in the inter-community traffic models.

7. A community's capacity to attract trips is a function of the "attractiveness" of the community with respect to the purpose of the trip.

How to allocate trips produced by residential areas to non-residential "attractions," or on what basis to distribute trips produced by one part of a community to all other parts has been the subject of a number of recent research activities (9, 10, 16).

The use of land area and building floor area classified by use have been suggested as units of traffic generation (17, 26). These measurements are not practical in this project because the cost and time involved in obtaining land-use and building floor area data for a large number of communities would be prohibitive. Other suggestions for measuring the "attractiveness" of an area with respect to the purpose for which trips are taken, are reviewed next under each purpose category.

A. Work purposes

The purpose "work" applies to trips made to the location of a person's place of employment (such as a factory, a shop, a store, or an office) and also to locations that must be visited in performing a normal day's work (18).

Migration and commuting studies indicate that "economic opportunity" is a major determinant of movement between communities (5, 6, 15). More specifically, the existence of a surplus of labor supply in one community coupled with an expansion in the economy of another community is a prime factor in causing a permanent (migration) or recurring (commuting) movement of workers from one community to the other. Also, in rural areas, farmers located around a community with an expanding economy will often work in that community for income not connected with their farms (12).

The number of workers employed in work places located within the community has been suggested as a measure of a community's capacity to attract work trips (9, 17). This number includes community residents as well as commuters. It would appear that the number of workers would be a more useful measure if it is related to the number of workers residing in the community, or in case this is not available, to the population of the community (29).

It has also been suggested that work places employing a substantial number of workers tend to attract the larger portion of community workers. There is some question as to the employment size level at which a work place ceases to be a local concern and becomes a work place of regional significance.

In project IHR-69, a series of tests will be undertaken to determine whether total employment, or employment in work places of various sizes is a better measure of a community's ability to attract work trips.

B. Business purposes

"Business" refers to trips made to complete transactions not considered part of a person's regular employment. Examples are trips to the bank to transact business, to the post office to mail a letter or package, and to an office to pay a bill (18).

This purpose category presents some difficulties. A business trip could conceivably be undertaken to any type of establishment or land use. Past research to establish a basis for measurement of business trip attraction is scarce and inconclusive. There are suggestions in the literature that business trips may be considered as shopping trips (9), but little evidence exists to warrant this.

One type of business activity (banking) is often referred to in the literature, as an activity as likely to be found in small communities as in central cities (11, 13, 14).

In this project many ways of measuring a community's ability to attract business trips will have to be tested. These may include the total number of establishments in the community, the number of selected establishments, or the number of types of establishments. To indicate the magnitude of activity of these establishments the size of their employment may also be used.

C. Medical and dental purposes

This is one of the more precisely defined purposes and refers to trips made for consultation about health with doctors and dentists (18).

The literature indicates that medical and dental services are predominantly found in the central cities and are tending toward centralization away from smaller communities (11, 13, 14). But no specific ways of measuring a community's capacity to attract trips for this purpose were found in the literature. Here again some testing is necessary. Among the measures that are available are the number of medical and dental professionals in the community, the number of beds in the community's hospitals and clinics, and the number of persons employed in these institutions.

D. School purposes

"School" refers to trips by students who are actually attending school. This includes public and private schools, universities, colleges, high schools, etc. (18).

Of the many types of institutions covered by this definition, only a few may be of regional significance. These include major private schools, technical schools, colleges, and universities.

Here again no specific measurement suggestions were found in the literature. Some measures to be tested include the number of students registered in these regional institutions or the number of teaching and non-teaching staff employed.

E. Pleasure purposes

"Pleasure" refers to cultural trips made to church, civic meetings, lectures, and concerts as well as trips to attend parties or to visit friends. Also included are trips made for golfing, fishing, movies, bowling, etc. (18).

This broad-purpose category includes trips to residential areas, to public and semipublic facilities as well as to commercial recreation establishments. Because no attempt has been made at differentiating between trips taken to these largely different types of facilities, little is known about their traffic-generating patterns (10).

Also, the rapid changes that are currently taking place in leisure-type activities tend to render obsolete much of the research that has taken place and to complicate the problem of measuring a community's capacity to attract pleasure trips.

Findings in the literature indicate a large degree of interdependence between rural areas, small communities, and central cities in regard to pleasure trips. Rural and small community residents are willing to travel some distance to patronize a central city's recreation facilities (13), yet they also attempt to decrease their social dependence on the central city by strengthening the role of local schools, churches, community centers, and civic organizations in the social sense (19). Similarly, central city residents seek to occupy their leisure time with activities that require large amounts of open space, seldom found within the confines of the city limits.

The lack of precise definition as to what constitutes a "pleasure" trip coupled with the high degree of interdependence of rural areas, small towns, and central cities in matters of recreation suggest that a meaningful measure of a community's ability to attract pleasure trips must rest on two premises. The first is that the variety of types of establishments that attract pleasure trips suggest that the measure would be of a composite nature taking into account both social and commercial recreation. Among the measures available to arrive at this composite measure are the resident population of a community, the number of public and semi-public institutions, and the number and employment of commercial recreation establishments of regional significance. The second premise is that when trips produced by Champaign-Urbana residents are under consideration emphasis will be placed on the types of recreation facilities located outside the twin cities which attract these pleasure trips. Similarly, when trips produced by residents of other communities are analyzed, emphasis will be placed on the types of establishment within Champaign-Urbana which attract these pleasure trips.

F. Shopping purposes

"Shopping" applies whenever a trip is made to do some shopping but also includes "window shopping" (without purchase), trips for repairs to automobiles, radios, etc., and for personal services such as haircuts, cleaning and pressing clothes, etc. (18).

Shopping practices have received a large amount of research. The existence of a heirarchy of types of goods in terms of the distance that consumers are willing to travel to make purchases and in the case of small communities, in terms of the percentage of goods purchased out of town, has been established in a number of studies (11, 13, 14, 20). These studies indicate that consumers from rural areas or small communities tend to purchase shopping goods (apparel and furniture) in the central city and convenience goods (food and drugs) either in the small community or in the central city.

Various ways of measuring a community's capacity to attract shopping trips are suggested in the literature, for convenience goods, the floor area in food stores and drug stores (9); for shopping goods, the floor area in apparel (2, 9); for all goods, or if the data are available by type of goods sold, dollar sales (17), and the number of business units (21).

In project IHR-69, the following types of data will be tested to measure a community's capacity to attract shopping trips: the total number of retail and service establishments by type of goods sold, their number, their employment and their retail sales volume in dollars.

G. Eat meal, overnight, and all other purposes

In terms of inter-community traffic analysis, these purpose categories are considered to be of little significance.

USES AND APPLICATIONS OF INTER-COMMUNITY TRAFFIC MODELS AND INFORMATION

Highway and Road Classification

Inter-community traffic data provide a basis for determining the functional use of highways and roads. They indicate to what extent a particular highway or road segment is of service to municipalities, unincorporated communities, rural townships, counties, the State, and the nation. They can therefore serve as a basis for assigning administrative responsibility for that segment to one or more units of government and to indicate joint interests that different units of government have in that particular segment. They also establish a basis for defining financial policy for construction and maintenance of highways and roads. Inter-community traffic analysis has been used for this purpose in Illinois, Michigan, and Washington (1, 22).

Regional Analysis and Planning

There is a need in the fields of regional analysis and planning to continually develop, test out, and refine fundamental relationships that give insight into the structure of regions. In turn these relationships form a basis for getting specific answers to problems of regional development (4). The relationship between communities, particularly in the light of the different functions performed by these communities, is an important area for further exploration.

To define an all-purpose planning region for a central city it has been suggested that the criteria include the city's retail trade area, the area from which the city draws its labor, the area over which its institutions, hospitals, theatres, clubs are used by the population of surrounding areas and communities (23). Inter-community traffic data can be used to define all of these areas.

In planning for regional land-use facilities such as shopping areas and industrial or employment centers, inter-community traffic data provide a basis for estimating the extent to which these facilities are needed and will be used by the population of the communities in the region, and in some measure for defining parking and circulation needs resulting from the development of these facilities. Inter-community traffic analysis can also be used in the formulation of policy in highway planning (24). For example, it can be used in locating, designing, and maintaining highways and roads that play or could play a key role in linking communities in the region, and in drawing the implication of alternative highway improvements on the inter-community structure of the region.

Community Analysis and Planning

One of the more significant results of inter-community traffic studies is the insight these give into a community's dependence on outside sources for the satisfaction of its daily or recurrent needs. This forms a basis for indicating to the private and public interests in the community the kinds of new services in which they should be able to compete successfully with other communities in the region and the types of existing activities that they should strengthen and maintain.

Impact Studies

Community linkage studies undertaken at various intervals and particularly after the development, expansion, or contraction of major local and regional facilities (new shopping centers, major parks, industries, Interstate highways) could form the basis for "before and after" studies to estimate the effect of these changes on the regional structure.

Inter-Community Traffic Models

At the present time, the most prevalent method of obtaining the traffic data necessary for regional or urban highway planning is through the long and costly process of undertaking origin and destination surveys (18).

Highway, city, and regional planners have recently been using traffic survey data to develop mathematical models that, as they are refined, may be used to approximate actual traffic movement. In a broad sense these models provide a more scientific approach to the development of highway and land-use policies (25).

Appendix

ANNOTATED SELECTED REFERENCES

1. MYLROIE, WILLA
"Evaluation of Intercity-Travel Desire"
Factors Influencing Travel Patterns (Washington: National Academy of Sciences, National Research Council, Highway Research Board Bulletin 119, 1956) pp. 69-92.

Highway travel between cities is expressed in formulas dealing with the "total desire" for travel. Measures take into account the desire for personal travel, and to a lesser degree, the desire to move goods from one center to another. General propositions discussed include (a) the larger the population of a center, the more influence it will exert; (b) the greater the distance from a population center, the less influence that center will exert; and (c) these two propositions can be combined into a mathematical form similar to the law of attraction between physical masses. A test made of origin and destination traffic data for 22 pairs of cities in the State of Washington indicates that a very high correlation exists between intercity traffic data and the square root of the product of the population of each pair of cities divided by the square of the distance between them.

2. VOORHEES, ALAN M., SHARPE, GORDON B. AND STEGMAIER, J. T.
Shopping Habits and Travel Patterns
Highway Research Board Special Report 11-B (Washington, D. C., 1955)

Many cities are adopting various means to accommodate the shopper better. To plan these improvements better a broader understanding of shopper habits can be beneficial. Among the relevant conclusions drawn by the authors are: Distance should not be the only criterion for measuring the extent of trade area, competitive land-use relationship should also be considered. The number of auto and transit shipping trips generated by a residential area is directly related to the automobile ownership. To predict traffic movements adequately it is necessary to separate the component parts of the particular land use that is likely to attract shoppers; i.e., how many square feet of floor area of convenience goods? apparel? etc.

3. LIEPMANN, KATE K.
The Journey to Work: Its Significance for Industrial and Community Life
(London, K. Paul, Trench, Trubner & Co., 1944)

In this work on commuting, the model of journey-to-work relationships between a central industrial area and subsidiary residential areas is thoroughly discussed. But other types of commuting patterns are also investigated, including movements between outlying areas of a metropolis. Commuting linkage can be measured in terms of financial cost, as indicated in Liepmann's discussion of the journey to work as an expenditure item both in the national economy and the budgets of individual families and business enterprises.

Liepmann's work perhaps is most significant in its early consideration of the nature of the community involved in commuting, and a classification of communities according to day-night populations is presented; places are therefore predominantly work or residence localities. The day-night dichotomy is related to "severance," the allegiance to two different communities on the part of commuters. This affects the economic characters of the communities involved, with, for example, day communities possessing few schools, food shops, churches, and other similar activities. Commuting linkage, in effect, results in the substitution of two specialized localities for one comprehensive community.

4. CARROTHERS, GERALD A. P.
An Historical Review of the Gravity & Potential Concepts of Human Interaction
Journal of American Institute of Planners Vol. XXII No. 2

Gravity and potential concepts of human interaction provide a basis on which to develop theories of urban structure and at the same time provide a basis with which data may be applied to aid in solving specific problems, thereby satisfying both the theorist and the practical planner. The interaction between two centers of population is said to vary directly with some function of the population and inversely with some function of the distance between the center.

Various people have used different means to measure this interaction. These means have included migration, retail trade, telephone calls, bus passenger movement, newspaper circulation and traffic volume.

Others contend that distance might be a greater influence on interaction than population; or that the impact of distance is not continuous but that intervening opportunities might cause a change in its effect. Still others have suggested relating the interaction to cost of traveling, the time necessary to travel the distance or the trip purpose and the size of the attracting influence.

5. BOGUE, DONALD J.
A Methodological Study of Migration and Labor Mobility: in Michigan and Ohio in 1947 (Oxford, Ohio: Scripps Foundation Studies in Population Distribution No. 4, 1952)

Bogue studies labor mobility in terms of migration from one county to another as well as change of industry and employer. Findings here pertinent to linkage reinforce the thesis that most long-term migration between different communities is related to variations in economic opportunities between localities.

6. HAWLEY, AMOS H.
"Intrastate Migration in Michigan: 1935-40"
(Ann Arbor: University of Michigan, Institute of Public Administration, Bureau of Government, Michigan Governmental Studies No. 25, 1953.)

Again the economic basis of migration is emphasized. A major tendency in Michigan migration is the movement from areas of extractive activities (farming, mining) to areas of fabricating industry.

7. NATIONAL COMMITTEE ON URBAN TRANSPORTATION
Procedure Manual Origin-Destination and Land Use

O-D studies have shown that the frequency of trips per family, the mode of travel and the purpose of trips are all related to car ownership per family. Also car ownership has the greatest impact as frequency of trips but car ownership also reflects other conditions; i.e., population density, average income, etc.

Recent research has developed a theory that trips starting from a point are pulled by land uses as by magnets. Units used to measure the size of the attractor should reflect the type of trip in question; i.e., work trips should relate to number of people employed.

8. DETROIT METROPOLITAN AREA TRAFFIC STUDY
Report on the Detroit Metropolitan Area Traffic Study, Part I - Data Summary and Interpretations, July 1955

Among the many significant findings in this comprehensive land-use traffic generation study is the determination of these variables that affect trips made by residents. Four variables were investigated: car ownership, population density, distance from the city center, and income. Car ownership was found to be the most reliable single predictor of residential traffic generation with a little additional accuracy gained by combining it with other variables. Similar results were obtained in a study of vehicular trip generation in Washington, D. C., using 1948 traffic data. This latter study is reported in:

William L. Mertz, Lamelle B. Hammer, "A Study of Factors Related to Urban Travel," by the Division of Highway Transport Research, Bureau of Public Roads. Public Roads, Vol. 29, No. 7 Washington, Government Printing Office, April 1957. pp. 170-174.

9. VOORHEES, ALAN M.
"A General Theory of Traffic Movement,"
1955 Proceedings (Institute of Traffic Engineers, 1955) pp. 46-56

The theory is based on the premise that all trips emanating from a residential area are "pulled" to various land uses in accordance with certain empirical values. The number of trips per day by purpose starting from a residential area are approximated. Of particular importance to inter-community linkage is the way the destination of these trips are distributed.

Trip destinations reflect the competition between existing land uses. The land-use attraction is expressed in different terms for different land uses and distance is a major factor. Research has shown that in applying this principle, the distance factor should be raised to some power depending on the type of trip.

TABLE 1

APPARENT FACTORS AFFECTING DESTINATIONS OF TRIPS STARTING FROM A RESIDENTIAL AREA

Purpose of Trip	Unit to Express "Size of Attractor"	Effect of "Distance Factor"
Work	No. of workers employed	D
Social	Dwelling Units	D^3
Shopping		
Convenience goods	Floor area in food and drugs	D^3
Shopping goods	Floor area in apparel	D^2
Business	--[1]	--[1]
Recreational	--[1]	--[1]
Other	--[1]	--[1]

[1] In light of existing research it is recommended that these trips be considered as shopping goods trips.

10. SCHMIDT, ROBERT E. AND CAMPBELL, M. EARL
Highway Traffic Estimation
The Eno Foundation for Highway Traffic Control, Sangetuck, Connecticut, 1956

The part of the report dealing with "inter-area travel formulas" reviews some of the more pertinent inter-city traffic models. These include a basic formula developed in New Jersey which states that the volume of traffic from area 1 to area 2 is a function of the number of motor vehicles registered in area 1, of the force of attraction which area 2 exerts on area 1 and of the total elapsed time to travel from area 1 to area 2. Another formula discussed is that developed by Mrs. Willa Mylroie of the University of Washington reported elsewhere in this bibliography (1).

11. LOOMIS, CHARLES P. AND BEEGLE, ALLAN J.
Rural Sociology: The Strategy of Change (Englewood Cliffs, N. J., Prentice-Hall, 1957)

Representative of the general texts on rural sociology, this book includes several discussions of the rural family's relations with the town. As to economic linkage, farmers generally travel to urban centers for purposes of clothing and home furnishings and for medical-dental services. Businesses in small, rural-oriented communities compete most successfully with city enterprises in the lines of food, farm feeds and supplies, banking services, and automobile and machinery service and repair.

Differences exist among farm groups as to social and business interaction with the urban community. Citing studies, the authors point out that owners of larger farms and estates—the high-prestige groups in rural areas—have much contact with friends and relatives in the city, often belong to city churches and other organizations, and maintain property and other business interests in town.

12. THADEN, J. F.
The Lansing Region and Its Tributary Town-Country Communities
(East Lansing: Michigan State College, Agricultural Experiment Station)
Special Bulletin 302, 1940

This study's objective is the determination of Lansing's "zone of influence," particularly for rural residents. This involves the determination for Lansing and other centers of community boundaries—the extent of trading and service areas—as determined by "the frequency and regularity of association between town and country people in each locality." Association is measured in economic terms (purchases of hardware supplies, banking services, newspaper circulation), high school education, and socio-religious-civic relationships. Measurement of the last kind of association includes determination of the proportion of rural residents serving on the boards of given urban center's government, social, business, educational, and religious institutions.

Thaden's community includes the "people in that local area, tributary to the center of their common interests and activities, where at least a majority of the people obtain the means of satisfying their daily and weekly needs and desires."

13. LINDSTROM, DAVID E. AND BANTZ, EARL C.
Changes in Preferred and Actual Social and Economic Service Centers in Champaign County, Illinois 1948-58 (Urbana: University of Illinois, Department of Agricultural Economics, 1958)

To determine the preferences of farmers for meeting places in a relatively large east central Illinois county, this study designates their centers for socio-economic services. Socio-economic activities investigated include education, church attendance, banking services, marketing of crops and livestock, movie attendance, medical-dental services, and purchases of hardware, groceries, machinery, furniture, clothing, and newspapers. The study concludes that farmers prefer to have more contact and business relations at their local neighborhood centers than at the larger centers. They value the "primary face-to-face type of association on the part of most of the people in the area not found in any other area of social contact."

14. SANGAMON COUNTY REGIONAL PLANNING COMMISSION
Land Use Plan, Sangamon County, Illinois Regional Plan Report No. 2, Dec. 1959

Knowledge of where farm families go for various services and activities is important as a guide for physical planning and the determination of functions that the various communities serve. Functions have been divided into the following four groups:

I. Extremely Centralized
   purchase of furniture
   purchase of clothing

II. Tending Toward Centralization
   patronage of Doctors
   patronage of Dentists
   recreation outlets

III. Balanced -- Central and Local
   purchase of groceries
   banking services
   farm equipment centers

IV. Highly Localized
   Church attendance
   Community centers
   Grain sales

Control of the location of functions in group I is largely removed from the farmer. Group IV functions are those over which the farmer has complete control. The two middle groups II and III are pivotal groups over which the farm family could exert control.

15. WILCOCK, RICHARD C. AND SOBEL, IRVIN
Small City Job Markets: The Labor Market Behavior of Firms and Workers (Urbana: University of Illinois, Institute of Labor and Industrial Relations, 1958)

Commuting and migration are treated as they affect the size, composition, and behavior of local labor markets in these two studies. The central point of a labor market is visualized as a "magnet" attracting persons from surrounding towns and countryside. The outer limits of a geographical labor market—the commuting distance—is defined by the distance in terms of time, cost, and space relative to other centers of employment, and the distance workers are willing to commute daily. The radius of the market of a medium-sized Illinois city is put at 20 mi; actually more than 90 percent of the persons working in the center of the market commute 20 mi or less (one-way). Generally expanding employment in a labor market results in a great amount of in-migration and commuting over longer distances.

16. FRATER, THOMAS J.
"Forecasting Distribution of Interzonal Vehicle Trips by Successive Approximation" Proceedings of the 33rd Annual Meeting, Highway Research Board, Washington. National Academy of Sciences, National Research Council, 1954, pp. 376-84.

The procedure explained in the article "is based on the premise that if the character and growth conditions of traffic zones are known, or can be predicted, it is possible to estimate with equal dependability the total trips which will be made to and from each zone and the distribution of those trips in interzonal travel." Two data compilations are suggested as essential tools: a regional economic development plan to determine growth and change in each traffic zone and origin and destination traffic data by zone for a given date. Two essential premises in this method are that the volume of traffic will reflect the relative attractiveness of that movement in competition with other possible movements, and that distance is an essential variable.

17. HAMBURG, JOHN R. AND SHARKEY, ROBERT H.
Determination of Land Use Categories (Chicago Area Transportation Study, 1958)

This report presents, describes, and discusses the relative merits of various ways of measuring establishments as traffic generators. It discusses the use of dollar volume of sales as a measure of the traffic generation of commercial establishments, employment by work place location for industrial land, residential population location and density for residential areas, landareas classified by use, and building floor area classified by use. Having selected the last two as measured to be related to trips, the authors develop a system for classifying establishments and land use for traffic generation and its purposes.

18. DEPARTMENT OF COMMERCE, BUREAU OF PUBLIC ROADS
Manual of Procedures for Home Interview Traffic Study (Revised edition, October, 1954)

This manual covers the procedure for undertaking a comprehensive origin and destination traffic survey in urban areas. It covers the collection of field data, the evaluation of survey accuracy, coding, punching, computations, and tabulations.

19. SCHAFFER, ALBERT
"A Rural Community at the Urban Fringe,"
Rural Sociology, Vol. 23 (September, 1958), pp. 278-85

This study of a rural school district in the vicinity of two urban centers deals with the problem of "boundary maintenance," the preservation of the rural social system in resistance to change brought on by the outside world. In essence, boundary maintenance is a force contrary to linkage.

The rural comminity's ties to the outside—and particularly to the urban centers—

include part-time employment of farm operators in cities, migration to the outside, individual social contacts, and general social and governmental controls imposed from the outside. Boundary maintenance is enforced by the preservation of family farms keeping family groups together, expansion or rural socio-recreational activities by churches and schools, and greater organizational activities on the part of other groups. But though the direct physical contact with the outside is kept to a minimum, the rural community maintains an indirect social linkage with the outside by adopting many patterns of city life.

20. CONVERSE, P. D.
A Study of Retail Trade Areas in East Central Illinois
U. of I. Bulletin Business Studies No. 2

This study deals with the shopping practices of consumers, and shows that the distance a person travels to shop is dependent on the goods being purchased. Goods purchased less frequently and more expensive goods generally cause buyers to travel farthest (women's coats, dresses, hats and shoes).

21. WHITNEY, VINCENT H.
"Economic Differences Among Rural Centers" American Sociological Review, Vol. 12 (February, 1947), pp. 50-7

Criticizing the practice of characterizing all non-urban places (under 2,500 population) as agricultural service centers, Whitney emphasizes differences in structure and role among rural communities. Three kinds of places are identified: agricultural villages, primarily farm service and trade centers; industrial villages; and suburban villages, handling urban residential overflows. These communities are also categorized by the degree to which their trade and service establishments depend on business outside the locality. Locational factors and the the number of business units are used as factors predictive of linkage.

22. ILLINOIS DEPARTMENT OF PUBLIC WORKS
Classification of Illinois Highways. (Springfield, 1951)

A classification system for Illinois highways was needed to provide a basis for delegating responsibility for roads to different levels of government. The scheme presented here emphasizes the functional use of the highway, determined by the economic natures of the populated places that are linked. According to populations of trade areas, banking resources, newspaper circulation, and assessed valuation of immediate trade areas, all municipalities are assigned one of six economic ratings—ranging from metropolitan to minor marketing centers—indicating each community's "ability to generate and attract traffic." Each highway segment in the state is then classified according to the importance of the communities it links.

23. WIRTH, LEWIS
The Metropolitan Region as a Planning Unit
Community Life and Social Policy pp. 301-313

"The search for an all-purpose planning area may be as futile as the search for the Holy Grail, but the search for an approximation to such an area is the categorical imperative of the planner." Tentative criteria that might be used in developing an empirical basis for defining such an area might be:

1. The area from which the city draws many of its basic-raw materials.
2. The retail and wholesale trade areas.
3. Areas from which the community draws its labor supply.
4. Areas over which urban institutions (hospitals, schools, churches, theaters, clubs) are used by suburbanites.
5. Extent of urban land uses.
6. Area of continuous urban population density.

24. PERLOFF, HARVEY S.
Regional Research and Highway Planning
Highway Research Board Bulletin No. 190
Urban Research in Highway Planning

The knowledge and techniques of regional analysis can help the activities of highway units in six ways:

1. Location and design of highways by analyzing changes resulting from alternatives.
2. Pinpointing economic impact of various types and elements of highways.
3. Development of transportation system concepts and system services.
4. Interpretation of O-D data, and other highway research activities that lead to formulation of policies.
5. Clarifying the types of issues raised at public hearings.
6. Sharper definition of other types of problems involved in highway planning and research, particularly in relating highway development to developments in the economy and society.

25. VOORHEES, ALAN M.
The Nature and Uses of Models in City Planning
Journal of the American Institute of Planners Vol. XXV No. 2

Mathematical formulas can be developed that express travel behavior and forecast land patterns. These tools are generally more precise than the previous methods of analyzing facts on population distribution, employment, economic factors, social patterns, and travel habits and using them for preparing land-use and transportation plans. With these new tools the planner is able to predict with a fair amount of accuracy the consequence of government policies on land development; he can also use them to evaluate the impact of improved transportation services, the extension of sewer and water systems, new zoning laws, etc. These new techniques make it possible for the planner to estimate traffic volumes and patterns resulting from different arrangement of land uses or from various transportation solutions.

The use of these models can help the planner:

1. Understand factors that influence land development and traffic patterns.
2. Provide a better factual basis for plans.
3. Evaluate and test alternative plans.
4. Develop more realistic plans.

26. HARPER, B. C. S. AND EDWARDS, H. M.
"Generation of Person Trips by Areas within the Central Business District" Traffic Origin-and-Destination Studies (Washington: National Academy of Sciences, National Research Council, Highway Research Board Bulletin 253, 1960), pp. 44-61

The authors report on an investigation of the relationship between floor space in use (classified under: retail, service-office and manufacturing-warehousing) in central business districts and the number of person destinations in the area for an average 24-hr period (obtained from O-D surveys). A statistical regression technique was used to determine this relationship for the CBD's of seven central cities in standard metropolitan areas of over 250,000 population in 1950. Results indicate that the number of people attracted to an area in a city's CBD apppears to be closely related to the amount of floor space being used for various purposes in that area. Also, the similarity of equations for the various CBD's investigated indicates that in all these floor space attracts people to the center at approximately the same rate.

27. WYNN, F. HOUSTON AND LINDER, C. ERIC
"Tests of Interactance Formulas Derived from O-D Data" Traffic Origin-and-

Destination Studies (Washington: National Academy of Sciences, National Research Council, Highway Research Board Bulletin 253, 1960), pp. 62-85.

The validity of interactance formulas was tested by the authors using O-D data for the St. Louis, Mo.; Kansas City, Mo.; and Charlotte, N. C.

Major findings relevant to inter-community traffic include:

1. Median family income, vehicle ownership, population density, and relative decentralization are the most significant factors in traffic generation of residential areas.
2. Results in these tests corroborate the inverse relationship between the number of trips exchanged between a pair of zones and the driving time between them.
3. Results also corroborate the hypothesis that the impact of the distance factor on trip interchange varies with the purpose of the trip, being smaller, for "work" and "social" trips than for "commercial" (includes "personal business," "medical-dental," "shopping," and "eat meal") or "school" trips.

28. LYNCH, JOHN T.; BROKKE, GLENN E.; VOORHEES, ALAN M. AND SCHNEIDER, MORTON
"Panel Discussion on Inter-Area Travel Formulas" Traffic Origin-and- Destination Studies (Washington: National Academy of Sciences, National Research Council, Highway Research Board Bulletin 253, 1960) pp. 128-138.

Members of the panel discuss the pros and cons of three methods of forecasting travel patterns between areas: the growth factor method (which projects present travel pattern forward on the basis of anticipated growth in different areas), the gravity model (which states that the travel between areas depends on their attractive power and the distance between them) and the model developed by the Chicago Area Transportation Study (which is based on the premise that total travel time from a point is minimized subject to the condition that every destination point has a stated probability of being accepted if it is considered). The advantages and disadvantages of each method as discussed by the panelists include:

1. Growth Factor Method.—Disadvantages: there are difficulties caused by interzone volumes of zero; it cannot be used effectively to estimate travel patterns that would result from significant changes in land use (residential to industrial) or in transportation facilities (a new rapid transit system); it is expensive to apply and relatively inflexible; it is more applicable to short-term than to long-range projections. Advantages: a good degree of accuracy; it makes possible the projection of future traffic volumes by direction during peak hours; it takes unique travel patterns into consideration.
2. Gravity Model.—Disadvantages: unless weighing factors are applied, the model cannot take into account differences in social or economic patterns; it is basically a concept borrowed from applied physics not evolved from human behavior; it loses validity over an unlimited or undefined range of the distance variable. Advantages: it has merit in predicting travel between cities; it is sensitive to changes in travel time between zones; it takes competition between land uses into consideration; it appears to be applicable in different areas at different times; it is easy to understand and to apply and it is adaptable to computer programing.
3. The Chicago Model.—Disadvantages: the number of trips received at a zone do not necessarily agree with the number provided; there are some difficulties in obtaining parameters for future or unknown situations. Advantages: it is based on a concept that seems logical; it can be easily computed; it is independent of zonal or regional boundaries; its computations compare favorably with actual data.

29. HOWE, ROBERT T.
"A Theoretical Prediction of Work-Trip Patterns"

Traffic Origin-and-Destination Studies (Washington: National Academy of Sciences, National Research Council, Highway Research Board Bulletin 253, 1960) pp. 151-165

This paper presents a theory for predicting work-trip patterns based on principles of electrostatics. Given the distribution of workplaces and that of the residences of workers in a bounded region, it illustrates two methods (by successive partial assignments and by correction factors) of allocating workers to workplaces. These methods are based on a model which relates the probability of movement from one zone to another to the number of workers residing in the first zone, to the number of jobs available in the second zone and to the distance between zones. The paper illustrates the adaptation of this model to a hypothetical community and to the Cincinnati metropolitan area.

30. BEVIS, HOWARD W.
"Forecasting Zonal Traffic Volumes"
Traffic Quarterly, Volume X, Number 2, April 1956

Following a review of previous methods of forecasting zonal traffic volumes, the author presents a method developed by the Detroit Metropolitan Area Traffic Study. The Detroit method is based on the premise that the factors affecting the distribution of trips throughout an area include the relative attractiveness of the zonal interchange and the friction in making the interchange relative to all other interchanges. In the model, attractiveness is defined in the concept of probability interchange volume which is the interchange volume to be expected if the friction were equal for all interchanges. The relationship between actual interchange volume and probability interchange volume measures the amount of friction for any one particular interchange. On the assumption that the amount of friction remains relatively equal through time, future zonal interchange volumes can be predicted on the basis of the projected growth for the different zones in the area; that is on the basis of the projected changes in relative attractiveness for the various zonal interchanges.

31. BROKKE, G. E., AND MERTZ, W. L.
"Evaluating Trip Forecasting Methods with an Electronic Computer"
Travel Characteristics in Urban Areas (Washington: National Academy of Sciences, National Research Council, Highway Research Board Bulletin 203) pp. 52-75.

The results of two O-D surveys for Washington, D. C. taken in 1948 and in 1955 are used by the authors to test out the relative efficiency of three ways of forecasting traffic based on the "Growth Factor" method; and to illustrate the use of electronic computers in this evaluation. The methods tested are the average factor method, the Detroit method and the Fratar method. The authors report that these are equally accurate provided each is carried through a sufficient number of successive iterations. In these tests, the authors report that the second approximation of the Fratar method was of maximum accuracy whereas more approximations were needed with the other two methods. In discussing computer use, the authors discuss the need for an electronic computer, the selection of the computer, and the preparation of the program for the computer.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.