NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 57

FACTORS INFLUENCING MODAL TRIP ASSIGNMENT

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NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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FACTORS INFLUENCING MODAL TRIP ASSIGNMENT

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

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

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

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

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

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

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FOREWORD

by Staff

Highway Research Board

This report will be of particular interest to the urban transportation analyst who is responsible for travel assignments among different transportation modes. The research involved identifying factors underlying choice of travel mode, determining the relationships of these factors, and developing a method of analysis and forecasting. The Chicago area was used extensively for this research because of the wide range in travel modes available.

One of the major problems in forecasting future transportation patterns is to determine how people will travel from their origin to their destination, particularly when they have a choice in transportation modes. With consideration being given to the installation of new rapid transit systems, improved bus services, and increased commuter train utilization for many of the major metropolitan areas, the problem of accurately predicting the trips such facilities will attract is very important in justifying their development and operation. One of the major objectives of providing these improved mass transportation systems is to aid existing mass transit service to the extent that it will free congested highway facilities. Therefore, the mass transportation service must compare favorably to the user with regard to travel time, cost, and comfort and convenience if the potential motorist is to be influenced into leaving his car at home, or at least at some suburban transit station.

The researchers of the Illinois Institute of Technology Research Institute initially reviewed the existing models for modal split analysis. They also studied the characteristics of the five metropolitan areas having rail rapid transit service in the United States. A multiple-mode transportation network was modeled to study the influence of a variety of factors such as travel time, monetary costs, levels of comfort, safety, and convenience. Then these factors were related to the user's socio-economic status expressed in family income, residential density, automobile availability, and travel distance. Data collected by the Cook County Highway Department in the Chicago area in 1956 were used extensively for a statistical discriminant analysis of modal choice. A more detailed study was conducted at IIT Research Institute in 1965 to further analyze the modal work-trip relationships, and two multiple regression equations were developed to express the percentage of trips on public transportation based on several independent variables. The factors cited as important in evaluating and selecting mode of travel are discussed further, based on the results of the 1965 survey.

This research shows that relatively uncomplicated modal assignment models can incorporate nearly all the predictive power inherent in an extensive set of independent variables. It is recommended that the variables found to be jointly most effective in the work presented in this report by further tested by others. Conclusions are presented concerning methods of statistical analysis and operations research that are particularly appropriate for this important area of transportation systems planning. In addition, areas requiring further research work are identified.

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ACKNOWLEDGMENTS

The cooperation and active assistance of many persons and organizations, indispensable to the accomplishment of the work reported herein, is acknowledged with gratitude. It is not feasible to name all who have contributed skills, information, and ideas. The following persons have been particularly helpful.

The staff of the Chicago Area Transportation Study made available large amounts of data from the home-interview, transportation-system, and land-use surveys carried out by CATS in 1956 and subsequent years. Discussions with E. Wilson Campbell, Director, John Howe, and Jere Hinkle were especially illuminating with respect to the problems of urban transportation planning, the interpretation of data, and methods of analysis.

The use of data from the 1956 transportation use study of the Cook County Highway Department was authorized by Leo Wilkie, Engineer of Transportation Research. Robert Gran, with CCHD at the time the study was made, aided in the interpretation of the survey design and the coded responses. Professor Paul Shuldiner and Harold Williamson, Jr., of Northwestern University, where the CCHD survey records were located, facilitated the copying of the punched-card file and coding manuals and explained a number of points that had arisen in their use of the data.

Walter Rainville, Director of Research, American Transit Association, generously made available 1960 data on transit operations in various cities of the United States from the files of the ATA. However, it was not possible, within the scope of the project, to carry out an intended analysis of the transit data in relation to corresponding highway data and data on work trips from the 1960 decennial census.

Within IIT Research Institute, the following members of the technical staff made substantial research contributions: Scott Cameron, Theodore Lewis, Clarence Moore, Janis Pettyjohn, Duncan Ewing, Michael Goodman, Robert Wheeler, Eugene Schwartz, James Sebastian, Ronald Lodewyck, Earl Nienhuis, Shirlee Ross, Mary Ellen O'Regan, Joseph Catrambone, Anthony Dundzila, and Patrick Gross. Many other staff members were involved directly and indirectly in the activities of the project. The cooperation of the IITRI staff as a whole was essential in carrying out the work-trip survey during stage 2 of the project. The evident time and care spent in answering a rather formidable questionnaire are worthy of special mention.

The following IITRI staff members were authors or coauthors of the indicated sections of the present report:

Chapter Two, "Survey of Modal Split Models," and Chapter Three, Scott Cameron.

Chapter Four, Janis Pettyjohn.

Chapter Six, Theodore Lewis.

Chapter Seven, "Extended Comparison of Reported and Computed Travel Times for Trips by Public Transportation," Michael Goodman.

Chapter Ten, Clarence Moore.

FACTORS INFLUENCING MODAL TRIP ASSIGNMENT

SUMMARY

This final report covers in detail the work accomplished under NCHRP Project 8-2, as conducted by IIT Research Institute. The research was performed in two stages during the period February 1, 1964, to July 31, 1966. During stage 1 (the first year) effort was directed principally to model formulation and application to existing data from urban transportation studies. During stage 2 (the following 18 months) the models were refined and tested by application to new data obtained specifically for the purposes of this project.

A bibliography of published material relating to modal assignment in urban transportation is included. This covers mathematical models for modal assignment, analyses of data on factors influencing modal choice, and selected collateral and background material.

A survey is presented of existing models and procedures for "modal split" in urban travel. The sources of the models, the methods used, and the factors explicitly incorporated are covered.

In model formulation in the present project emphasis is placed on treating the complex of travel facilities and the population of trip makers within a comprehensive and unified framework. This leads to the concept of a multimodal network in which the links can be of any modes and mixed-mode trips are accorded the same status as pure-mode trips. Utilization of the network, in the sense of user selection of modes and routes of travel, is assumed to depend, in a statistical sense, on functional relationships involving the multiple characteristics of both the users and the transportation facilities. Appropriate models, with whose aid main effects and interactions of selected variables can be determined, are provided by statistical theory. Analysis of variance, discriminant analysis, and multiple regression analysis are the principal statistical tools employed in the investigation. Estimates of the parameters quantifying the relationships must be derived and tested by analysis of empirical data.

Permission was granted to the project by the Chicago Area Transportation Study for use of data from the large-scale survey of the Chicago area carried out by them in 1956. These data include descriptions of the transportation facilities and land use of the area, as well as results of household interviews. A second source of relevant urban transportation data is the household-interview survey made by the Cook County Highway Department in the Chicago area in 1956. Permission for its use was granted by CCHD. CATS and CCHD household-interview data provide in part parallel, and in part complementary, information on modal choice.

Use was also made of selected data on urban travel from the 1960 U. S. decennial census, and of selected data on automobile ownership from the 1960-61 survey of consumer expenditures by the U. S. Bureau of Labor Statistics.

During the second stage of the project a survey of travel to and from work by employees of IIT Research Institute in Chicago was carried out. This survey was designed to provide data suitable for testing detailed hypotheses concerning modal choice developed earlier. Information was obtained, through the medium

of a questionnaire, on the facts of travel in a large urban area served by multimodal transportation facilities. Questions concerning advantages and disadvantages of modal alternatives, and factors motivating choice among them, were also asked. The data from the survey were supplemented by data on the transportation facilities available to the respondents.

Computer programs (for the IBM Type 7094 computer) were developed to accompish the following tasks: (1) Convert data describing the Chicago public-transportation and automobile networks from the format used by the Chicago Area Transportation Study to the format used by the Bureau of Public Roads, enabling application of BPR computer programs to Chicago-area data; (2) Construct a composite network for the Chicago area, incorporating both public-transportation and automobile subnetworks; (3) Build minimum-path trees from specified nodes in a network, employing a modified tree-building algorithm that minimizes the number of candidate links at each stage; (4) On either a link-by-link or overall basis, obtain descriptions of computed minimum paths between specified pairs of nodes; (5) Compute a measure of accessibility of all other zones from a given zone through a given network.

The five standard metropolitan statistical areas having rail rapid transit facilities in 1960—Boston, Chicago, Cleveland, New York, and Philadelphia—differ widely in age of the central city, geographical size and configuration, total population, population density, and the structure of the transportation network. Data from the 1960 U. S. census of population and housing show that the overall use of the major modes of urban travel (i.e., railroad, rapid transit, bus-streetcar, automobile, and walking) for the journey to work varied markedly over the five cities, particularly with respect to railroad and rapid transit on the one hand and private automobiles on the other. New York and Cleveland exhibit the sharpest contrast. Chicago occupies an intermediate position with respect to use of each of the major modes of urban travel.

Considering only the split between public transportation (railroad, rapid transit, bus-streetcar) and private automobiles, the pattern of variation in the proportion using public transportation to work as a function of several different worker characteristics, is quite similar from city to city. Characteristics for which this is true include annual earnings, occupation, age, sex, and race.

1960 data from the Bureau of Labor Statistics on car ownership per family in relation to (1) age of family head and (2) family income again show consistent city-to-city patterns.

The emergence of a considerable degree of uniformity from city to city in the way modal split and car ownership vary in relation to several different personal and family characteristics is strong evidence that reactions to travel opportunities are to some extent predictable phenomena.

Data on the main factors influencing choice of travel mode are presented and analyzed. These factors were specified in response to direct questions concerning motivation asked in the course of the CCHD home interviews. The responses apply to work trips in which automobile was either the actual or alternative mode of travel. Each person was asked to state only the main factor influencing the choice between modes; the relative influence of the many factors that might be considered by a single individual in making the modal choice was not ascertained directly. Considering the replies as a group, however, the relative frequencies with which the main factors or reasons were specified can be taken as an approximate measure of their importance in modal choice. On this basis the factors can be related to other items of information obtained during the interview. When this is done a number of significant conclusions can be drawn.

Travel time is in this set of work trips the factor most frequently stated to be decisive with respect to model choice. There is strong dependence on the nature of the modal choice, however. Where the choice was considered to be between automobile and railroad, about the same proportion of those who chose automobile and those who chose railroad gave time as the main reason (20 and 25 percent, respectively). Where the choice was considered to lie between automobile and rapid transit or bus, the proportion who used either of these forms of mass transit and gave time as the reason was very small (2 percent). In contrast, time was the main factor in the choice of a large proportion of those using automobiles (32 percent where rapid transit, 44 percent where bus was the best alternative). Time was more frequently specified by males (36 percent) than by females (25 percent) as the main factor in model choice. No statistically significant relationships were found between age or household income and the frequency with which time was stated to be the paramount factor in choice.

Comfort, like time, was more frequently given as the main factor in modal choice by automobile users than by mass transit users. About one-fourth of the automobile users said comfort was the main factor in choice, regardless of whether the best alternative was railroad, rapid transit, or bus. Among mass transit riders, comfort was cited as the reason for choice by about 13 percent of railroad commuters, but by a very small proportion of rapid transit and bus riders (about 1 percent). Comfort as the main factor in modal choice did not vary significantly with age. However, females mentioned comfort more frequently (29 percent) than males (19 percent). Also, the frequency with which comfort was mentioned tended to decrease with increasing income level.

Cost, including parking cost, was stated to be the main factor in modal choice by 42 percent of those taking public transportation, but by only a very small proportion (less than 1 percent) of those who used cars. No significant relationships were found between age, sex, or income and the frequency with which cost was stated to be the main factor in modal choice.

Car necessity was given as the main factor in the choice of means of travel by 25 percent of those who used cars. Almost all those who gave this reason were males; the proportion of persons citing this factor also varied depending on the form of mass transportation that was considered the best alternative (44 percent for railroad, 31 percent for rapid transit, and 23 percent for bus).

Less walking as the main factor in modal choice was almost entirely restricted to auto users, of whom less than 3 percent considered this of first importance. Fewer with bus as the best alternative cited this factor (2 percent) than with railroad or rapid transit (6 percent).

Parking unavailability (as distinguished from parking cost) was the main factor in modal choice for 11 percent of those who traveled to work by some form of public transportation.

The problem of predicting individual choice between use of public transportation and a private automobile for work trips on the basis of limited information about the worker and the transportation alternatives available to him was investigated by the method of statistical discriminant analysis. The items of information utilized in the construction of discriminant functions include age, sex, family size, income, type of dwelling, car ownership, distance from home to work, trip times by automobile and by public transportation, trip costs by automobile and by public transportation, and the particular mode of public transportation in question (railroad, rapid transit, or bus). The source of the data is the CCHD home-interview survey. Fourteen discriminant functions were developed using eleven different mathematical models and five different trip samples. All samples consist of morning peak-period trips to work for which an automobile was either the actual or the best alternative means of transportation. The samples differ in size and in criteria for completeness and consistency of reported information. The models differ with respect to the collection of variables included in the discriminant equations. Chosen mathematical transformations of the basic variables, as well as the basic variables themselves, were incorporated in the models in accordance with various hypotheses as to the way modal choice is influenced.

Each of the models tested provided discrimination between users of public transportation and users of private automobiles. The degree of discrimination did not vary from model to model nearly as much as was anticipated from the heterogeneity of the sets of variables. In the twelve cases in which the trip sample consisted of an equal number of automobile and transit trips, the proportion correctly classified by means of the discriminant function ranged from 60 to 78 percent. The expected proportion of trips that would be correctly classified by random assignment to the two modes with equal probability is 50 percent. Of the models tested, the more elaborate ones did not in general discriminate appreciably better than the simpler ones. The relatively simple model having the following five independent variables provided about as good discrimination as any of the models tested: household income, type of dwelling, number of passenger cars owned by members of the household, trip time by public transportation minus trip time by automobile, and trip cost by public transportation minus trip cost by automobile.

A detailed comparison of reported trips and corresponding computed paths in the Chicago metropolitan area was made. The reasons for undertaking the study were: (1) to compare trips through the transportation network, reported as actually having been made, with corresponding trips or paths computed from information descriptive of the network; (2) to compare the arterial and transit networks with respect to the relative agreement between reported and computed trips. The latter point is of particular importance with respect to modal trip assignment, because for this purpose it is advantageous to represent the spectrum of travel opportunities on a uniform basis. Travel time is the main trip characteristic investigated. Reported times came from samples of work trips: (1) trips by automobile, by railroad, by rapid transit, and by bus with destinations in the central area of Chicago (CATS data); (2) trips by the same four modes with origins in selected intermediate zones (CCHD data). Computed path information was derived from representations of the 1956 Chicago arterial and transit networks (developed by CATS) by application of a minimum-path algorithm. The agreement between average reported and computed travel times was good for automobile and bus trips. Computed times for rail trips (elevated-subway and computer railroad) were in general considerably longer than reported times. Reasons are given why close agreement between reported and computed times would not be expected, particularly for rail travel. For investigating effects of time differences on modal choice, the results suggest that simple adjustments of computed times can bring them sufficiently into line with reported times.

The results were negative in an investigation of the correlation between overall modal split and ratios of simple measures of accessibility by automobile and by public transportation. Values were computed for 580 zones in the Chicago area.

IITRI Work-Trip Survey Results

The approximately 700 replies in the work-trip survey carried out at IIT Research Institute, located on the near south side of Chicago, provide a detailed factual description of the types of trips made together with relevant data on each person and household. The respondents also stated reasons why they travel as they do, and cited advantages and disadvantages of the types of trips of which they have experience, in response to questions of the free-response type. The responses were classified and coded after all the returns were in.

Home locations were coded geographically in terms of city or town, an *X-Y* coordinate system, and a zone system. Specification of the zones of residence and employment (the latter common to all trips in the survey) establishes a correspondence with the load nodes or zone centroids of the automobile and mass-transit network models developed by the Chicago Area Transportation Study. Equations were developed on a zone basis relating average reported times to the corresponding computed times. By this means it was possible to estimate travel times for alternative modes not reported by individuals. Average values of other trip characteristics were computed on a zone or distance basis to provide estimates in cases where alternative modes were not reported.

The following items of information concerning the person and the household are among those finally available for each of the cases in the survey: (1) sex, (2) age, (3) education, (4) salary level (one of four), (5) *X* and *Y* coordinates of residence, (6) zone of residence (one of about 600 covering the Chicago area), (7) city of residence, (8) length of time at present residence, (9) distance between home and access point for public transportation, (10) travel distance between home and work, (11) computed straight-line distance, (12) computed rectangular distance (sum of north-south and east-west distances), (13) whether or not the person is licensed to drive (drivership), (14) whether or not the person is a member of a car pool, (15) number of persons in the car pool (if applicable), (16) number of persons in the household younger than 16, (17) number of persons 16 or older, (18) number of persons in the household licensed to drive, (19) number of cars owned by members of the household.

The following additional items of information are among those finally available for each type of work trip (maximum of four) reported by each person: (1) trip type (defined by the combination of modes of travel used in the trip, where the possible modes are: walk, drive car, ride in car, bus, elevated-subway, commuter railroad, "other"); (2) proportion of trips to work and from work during a year that are of this type; (3) normal door-to-door travel time; (4) trip cost; (5) distance walked in the course of the trip; (6) number of transfers from one public vehicle to another; (7) time spent waiting for public vehicles; (8) probability of having a seat on bus, elevated-subway, and railroad trip segments (items 6, 7, and 8 apply to trips involving use of public transportation); (9) number of expressways and tollways used (in trip by automobile); (10) reasons why this type of trip may be necessary; (11) desirable features of this type of trip; (12) undesirable features of this type of trip.

The distributions of the individual variables, and the results of analysis of the variables considered jointly, are described in detail. Key findings are briefly summarized in the following.

A multiple-regression equation was developed, on the basis of survey data, which estimates the trips in which public transportation will be used (expressed as a percentage of all vehicular trips) as a function of several independent variables.

The variables included in the estimating equation are a subset of a considerably larger set of candidate variables. The selected variables are those which jointly are the most effective estimators of the values of the dependent variable. The independent variables tested, but not included in the equation, have little or no predictive power beyond that provided by the variables that are included.

The following variables are represented in the equation estimating proportionate use of public transportation: (1) age of the person, (2) whether or not the person is licensed to drive, (3) number of persons in the household who are licensed to drive, (4) number of passenger cars owned by members of the household, (5) straight-line distance between places of residence and work, (6) travel distance, (7) travel cost by car, (8) travel cost by public transportation, (9) travel time by car, (10) overall travel time by public transportation, (11) waiting time during trip by public transportation.

These variables were tested but are not represented in the estimating equation: (1) sex, (2) salary level, (3) length of time the person has lived at his present residence, (4) number of persons in the household younger than 16, (5) number of persons in the household 16 or older, (6) distance between home and nearest access point for public transportation, (7) rectangular distance between home and work, (8) walking time for the entire travel distance, (9) number of expressways used in trip by car, (10) distance walked during trip by public transportation, (11) number of transfers, and (12) seat probability.

The basic variables listed, both those included in and those excluded from the estimating equation, are in a number of instances represented by variables that are mathematical functions of the basic variables (e.g., squares, logarithms, differences, products, ratios).

The independent variables in the prediction equation account for 43 percent of the total sum of squared deviations of the dependent variable from its mean. Thus there remains a large residual variability in individual travel behavior which is not captured by even a fairly extensive set of variables characterizing the person, the household, the location, and the transportation alternatives that are available.

Factors cited in answering the free-response questions of the work-trip survey are presented in detail. Some of the main findings are as follows, in terms of contrasts between the alternative modes of travel.

Convenience is the general travel factor most frequently named, closely followed by travel time. On balance, both factors definitely operate in favor of travel by automobile as compared with public transportation; however, there is a greater contrast between the two general travel modes with respect to time than convenience. Weather is the general factor next in frequency of citation; bad weather is a leading factor necessitating use of public transportation, but exposure to weather is frequently cited as an undesirable feature of trips other than those by automobile. The three general factors cost, comfort, and effort or strain of travel occur about equally often as evaluative comments. Cost does not provide a clear-cut distinction between the major travel modes, being a relatively favorable aspect of walking trips, car-passenger trips, and elevated-subway trips, but a relatively unfavorable aspect of driving trips, bus trips, and railroad trips. The factor of comfort was considered a favorable aspect of travel by car, or combination of car and train, an unfavorable aspect of walking trips and trips by bus or combination of bus and elevated-subway. There is a sharp contrast between driving trips and other classes of trips on the basis of statements concerning the strain and effort of travel. This factor is a strongly negative aspect of driving. The factor of danger, or its opposite, safety, is less frequently mentioned than the other general factors that have been considered. From citation counts, railroad and elevated-subway travel are considered relatively safe, travel by car relatively unsafe, the middle ground being occupied by the remaining modes.

Other findings from the free-response data are briefly as follows. Unavailability of a car, or, contrariwise, special need for a car, were the most frequent factors constraining the trip maker to use public transportation or drive. The opportunity to read was a factor frequently and consistently given as favoring travel by rail. The factor of highway congestion was frequently cited as a negative aspect of commuting by automobile. Waiting, transferring, crowding, standing, and walking are, in order of decreasing frequency, the specific factors most unfavorable to use of public transportation.

Those persons who had switched from automobiles to public transportation for most commuting trips most frequently gave as the principal reason the effort and strain of driving and highway congestion. Those who had made the opposite switch most frequently gave lesser travel time and car availability as the reasons.

Composite Chicago Network

A composite network model (i.e., one including all modes of travel) was constructed covering the northern two-thirds of the Chicago area. Automobile, mass-transit, and mixed-mode minimum-time paths were generated. Adjustments of selected link values caused different types of trips to appear and also brought the computed times into good agreement with the travel times reported in the IITRI work-trip survey.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

This report covers work accomplished on NCHRP Project 8-2, entitled "Factors Influencing Modal Trip Assignment." Research in the present project was focused on personal travel—as distinguished from transport of goods—under conditions in which alternative modes of travel are available. Factors influencing choice of travel mode were studied in the context of urban transportation. By this is meant transportation that occurs primarily within rather than between, or outside of, urban areas.

The need for an adequate understanding of the factors at work in the utilization of multimodal transportation facilities within urban areas is particularly acute. This is not to deny that problems similar in kind exist in other fields of transportation. For example, in intercity travel airlines, highways, and railroads provide modal alternatives. However, the great and increasing degree of urbanization in the United States makes the planning of transportation facilities to serve the populations of large metropolitan centers a particularly urgent problem. Recognition of the importance of the problem at local, state, and national levels of government, as well as by private organizations, has led to extensive activity in collection and analysis of the present facts of urban transportation, conduct of transportation experiments under actual conditions, and investigation of alternative approaches to provision of future facilities. Among the basic decisions are those concerning the roles to be played by the various technologically feasible transportation modes.

There have been in the past, and continue to be, strongly divergent points of view on this question. However, it is now recognized more than ever before that intelligent planning requires careful consideration of the available alternatives in the light of present and projected demand and the factors that influence that demand. This is particularly true in a society which values freedom of choice on the part of its individual citizens. The subject of the present research is thus relevant to basic policy decisions affecting the travel opportunities made available to a large proportion of the nation's population.

It should be emphasized that the term "mode" as applied to travel or facilities for travel can be used in various senses. In general, the existence of two or more qualitatively different forms of travel is implied by the use of the term. The distinction may be broad, as between all forms of public transportation on the one hand and all forms of transportation by means of private vehicles on the other. At the other extreme, quite fine distinctions may be made; e.g., between various forms of public transportation (suburban railroad, rail rapid transit, bus, etc.), or even between varieties of each of these. Furthermore, the grounds for distinction can vary widely; for example, type of way (road vs rail), role of the traveler (driver vs passenger), manner of operation (scheduled vs unscheduled). What is meant by mode or modes in reference to transportation thus depends strongly on the context in which the words are used.

The use of the term "assignment" in the project title is interpreted to mean that trip demand must ultimately be related to the detailed networks, real or postulated, that are designed to serve the particular urban area in which the demand arises. If the results of research are to be of maximum benefit in the planning of future facilities they must be applicable to concrete situations. It is clearly insufficient to say merely that one mode is preferred or should be emphasized over another. The advantages and disadvantages of system alternatives that are actually competitive with one another will ultimately depend on the way in which the parts of the networks combine to form functional wholes with respect to the satisfaction of overall travel demand.

Factors that it is reasonable to suppose determine or influence user choice among the alternative modes and combinations of modes of travel that are typical of urban situations are numerous and heterogeneous. Various principles of classification may be applied. One classification of factors is in terms of the kind of entity underlying the variables or characteristics of interest: (1) the transportation network itself, which may be characterized by factors such as connectivity of links, and travel times and costs over alternative modes and routes; (2) the person or family unit as users of transportation facilities, characterized by factors such as age, sex, income, car ownership, and places of residence and employment; (3) the individual trip, characterized by factors such as purpose, length, and car availability; (4) the unit of land, characterized by factors such as residential and employment density, price of real estate, and distance from the center of the city. Another classification of factors is in terms of those that are relatively subjective, such as notions of relative comfort, convenience, and prestige, associated with various forms of travel, in contrast to relatively objective factors, such as distance, location of highways, and population density. Still another classification is in terms of the distinction between discrete variables, such as car ownership and modes of transportation, and continuous variables, such as age, income, and travel time.

The number and diversity of factors influencing modal choice make the problems of analysis and prediction in this area of transportation research truly challenging. The approach that has been taken to these problems, and the work that has been accomplished through formulation of conceptual models and application to urban transportation data, are set forth herein.

RESEARCH APPROACH

Basic Assumptions and Objectives

The following basic assumptions and objectives have provided the framework for the present research project:

1. The ultimate purposes of the research are to gain insight into the main factors which jointly influence the utilization of multimodal urban transportation facilities and to develop techniques of analysis and prediction by which the planning of future facilities may be aided. This is in contrast to a purely academic study of the subject.

2. The complex of transportation facilities, specifically including facilities differing in mode, should be considered as a whole—as a system—with respect to overall utilization. Cooperation as well as competition between modes should be taken into account in considering the uses to which the system may be put.

3. The diversity of possible modes and routes of travel in urban areas, and the freedom of choice on the part of both designers and users of transportation systems, give rise to a multiplicity of kinds of questions to which answers may be sought. There is a consequent need for a variety of problem models and solution methods applicable to urban situations actually existing or anticipated.

4. Technological innovation, and also creative imagination in the design and operation of facilities within existing technologies, have essential roles to play in the evaluation of future transportation systems. Methods of analyzing and predicting modal choice should be applicable, so far as possible, to situations differing widely in the transportation alternatives that are available or proposed and the demand that is to be satisfied.

5. It is unrealistic to expect that a high degree of precision is attainable in predicting individual behavior with respect to choice of modes and routes of travel, particularly in future or hypothetical situations. The variability and multidimensionality of human choice are facts of life. On the other hand, recognition of underlying factors that operate to produce roughly similar patterns of travel independently to some extent of time and place, even though such regularities are discernible only in the aggregate, provides the only solid foundation for long-range planning.

6. Estimates of the effects of important factors, considered jointly, on choices among alternative modes and routes of travel must be derived and tested by application of appropriate analytical methods to suitable data.

7. The long-range perspective is that public and private decisions on such matters as land use, home and work location, and design and utilization of the transportation system are mutually interacting. Therefore, in the ultimate planning process factors relating primarily to choice among transportation modes must be viewed in a broad context.

Plan of Investigation

The plan followed in the conduct of the project was predicated on the desirability of a balanced approach to the problem area in accordance with the preceding statement of basic assumptions and objectives. This implied that careful thought be given to selection and integration of research activities in view of the manifold possible lines of investigation. In particular, it was mandatory that correct emphasis be placed both on model formulation and on data acquisition and analysis in accordance with the alternation between the two that is characteristic of scientific inquiry.

The project was carried out in two stages, the distinction being both contractual and technical. During stage 1 (Feb. 1, 1964 to Jan. 31, 1965) data originating outside the project were used exclusively. During stage 2 (Feb. 1, 1965 to July 31, 1966) new data were gathered and used; at the same time, further use was made of pre-existing data. The following comments outline the concrete ways in which the research plan was carried into execution.

REVIEW OF PRIOR WORK

Various investigations have been carried out in the problem area with which this project was concerned, but little attempt seems to have been made to compare methods and results. Preparation of a bibliography on modal split, and a survey of modal-split models, are tasks that were undertaken early in stage 1 of the project.

SURVEY OF DATA SOURCES AND DATA ACQUISITION

Prior to the inception of the project, permission was granted by the Chicago Area Transportation Study (CATS) to use data from the large-scale surveys carried out by them in the Chicago area in 1956.

Other possible sources of existing data were explored. Included among these were surveys or censuses conducted by Federal agencies, by large-scale urban transportation study groups, and by smaller local organizations. An additional source of data from the Chicago area, the home-interview survey carried out by the Cook County Highway Department (CCHD) in 1956, was found to be available. After evaluation of the several possible sources of additional data with respect to a number of properties, including relevance, level of aggregation, and coverage of all the major modes of urban transportation, it was decided to use the CCHD data in conjunction with the CATS data for detailed analyses of travel in a large metropolitan area. The CCHD data include answers to a number of interview questions specifically concerned with travel alternatives and reasons for choice between modes. Inasmuch as the two surveys were made in the same year, the transportation network descriptions and land-use data developed by CATS provide a common frame of reference. Both the Chicago Area Transportation Study and the Cook County Highway Department gave their full cooperation in providing requested data.

Data on the journey to work in four metropolitan areas in addition to Chicago, obtained during the 1960 U.S. decennial census, were used for the purpose of making comparisons between these five cities with respect to aggregate travel patterns. A parallel use was made of data on automobile ownership for these same five cities in 1960-61, taken from the Survey of Consumer Expenditures by the U.S. Bureau of Labor Statistics.

During stage 2 of the project major effort was devoted to planning, executing, and analyzing a survey of travel between home and work by employees of IIT Research Institute in Chicago. The survey was designed to provide new data particularly relevant to the purposes of the present project. The survey questions were chosen after careful consideration of all the previous findings. The central aim was to test and validate relationships more or less strongly indicated in analyses of previous data. Because the new data came from the Chicago area, it was possible to relate them to network data developed by the Chicago Area Transportation Study.

MODEL FORMULATION

Model formulation proceeded from the following premises:

1. The individual trip in its entirety from origin to destination, possibly by way of specified intermediate points, is the basic unit of travel. This should not be lost sight of, even though aggregation or fractionation or simplification of trips may be necessary in treating trip populations.

2. Mixed-mode trips (i.e., trips composed of segments differing in mode) are of importance in their own right. This point of view contrasts with the usual concept of a "modal split," which leads to an assignment of trips to one or another mode exclusively.

3. For purposes of transportation planning it is usually the case that actual assignment of trip demand distributions to particular networks must be carried out in order to obtain sufficiently detailed information for rational decisions among design alternatives.

4. To provide an adequate description of the travel opportunities actually available in many situations, and in particular the opportunity of making mixed-mode trips, it may be advantageous to construct a composite network; i.e., a single network which includes the links belonging to the different modes as well as cross links by which transfer from one mode to another can be accomplished. Construction of a composite network is also a prerequisite for investigating the dynamic interaction among modes, as when trips or portions of trips can shift from one mode to another depending on the relative degrees of congestion prevailing in the alternative paths.

5. Construction of composite networks places a premium on efficient computational methods for carrying out large-scale trip assignment.

6. Various characteristics of the transportation network and various characteristics of the users interact in the selection of modes and routes.

7. Estimates of the effects of important factors, considered jointly, on choices among alternative modes and routes must be derived from actual data by suitable statistical methods.

8. The analysis of factors influencing travel decisions

must ultimately be grounded in specific information concerning decision makers, the travel options open to them, and the decisions actually made.

9. Direct but relatively subjective information provided by travelers concerning factors influencing their decisions can be a useful complement to relatively objective but indirect information.

10. Although highly aggregated data usually are not amenable to the same kind of detailed analysis as data on individuals, no inconsistency is to be expected between conclusions based on the two kinds of data when properly interpreted.

COMPUTER PROGRAMMING

Stored-program computing equipment is an indispensable tool for analysis of the large quantities of data typical of urban transportation studies. The programs themselves, when expressed in a suitable language, can provide a medium of communication for detailed computational procedures and algorithms. In the performance of computational tasks, existing programs have been utilized where applicable. Computer programs developed in the course of the project for data preparation and for implementation of mathematical methods have been fully documented (see Appendix C).

DATA ANALYSIS

The central purpose in the data analyses that have been undertaken was to investigate basic questions concerning factors that may reasonably be supposed to have important influence on modal choice. These questions have operational meaning only in terms of the confrontation between specific models and methods on the one hand and concrete data from actual urban situations on the other. The need to answer some basic questions led to analyses of selected items of data from different sources and at different levels of aggregation.

One question concerns the extent to which Chicago, which is the primary source of detailed data for this project, is comparable to other U.S. cities having a similar mix of urban transportation facilities. Are there characteristics common to the travel patterns of the various cities, or is each city essentially unique? Aggregate data from the U.S. Bureau of the Census and the U.S. Bureau of Labor Statistics on each of five cities were analyzed for the purpose of providing evidence on this question.

A number of questions concerning choice among specific modal alternatives as viewed by users of the transportation network were explored using data from the home-interview survey conducted by the Cook County Highway Department in 1956. Both relatively subjective and relatively objective factors were analyzed. Discrete frequency distributions in the form of contingency tables were analyzed to determine relationships between modal choice and relatively subjective factors. Predictability of individual choice between major modes of transportation, given relatively objective information concerning the network and the user, was investigated by application of the method of statistical discriminant analysis. Several different sets of variables were tested as predictors of choice.

Relative travel time is the factor most frequently specified in the CCHD data as exerting the predominant influence on modal choice. Travel time is also the usual criterion in shortest-path computations. The question of the degree of correspondence between the two kinds of time estimates is of basic interest from the point of view of models in which travel time enters as a variable. A comparison was made between travel times computed from data describing the 1956 Chicago network and corresponding travel times reported during home interviews. Reported times for sample automobile, railroad, rapid-transit, and bus trips were taken from both CATS and CCHD data.

The concept of relative accessibility of spatially distributed activities to an urban population by way of alternative modes of travel has led to use of accessibility ratios as predictors of modal split in a number of recent studies. Results of computing a measure of this type from Chicago data are presented.

Results of the work-trip survey made during stage 2 of the project are first presented in terms of characteristics of the respondents and the spectrum of kinds of trips reported. The 41 different types of trips, each defined by a unique combination of modes of travel, were combined into ten trip classes. Summary values characterize the different classes: number of trip reports, weighted frequency of occurrence, average reported travel distance, travel time, cost, etc. Factors stated to be determinative with respect to type of trip taken, or to be favorable or unfavorable, were listed and the frequency of citation was given by trip class. Individual factors were grouped into more general factors—travel cost, time, convenience, comfort, safety, etc.—and comparisons were made between trip types on the basis of relative frequency of factor citation. Reasons why persons had switched, one way or the other, between predominant use of the private automobile and predominant use of public transportation for work trips were analyzed in a similar manner. Statistical frequency distribution functions have been fitted to survey data on travel distance, travel time, and proportion of trips utilizing public transportation. Correlations have been established between travel times reported in the survey (zone means) and times computed from CATS network data. Regression equations also have been developed relating reported and computed times. Additional correlations are presented between travel times and distances, between different reported times, and between different computed times. Proportionate use of public transportation has been examined in relation to selected variables taken one at a time: sex, age, salary level, car drivership, car ownership, distance from home to public transportation, and overall travel distance. Finally, proportionate use of public transportation has been analyzed within the framework of multivariate regression analysis, with testing of a relatively large number of independent variables.

The question of the feasibility of a composite network for a large urban area has been explored by construction of such a network covering a major portion of the Chicago area. Results of minimum-path computations are reported.

CHAPTER TWO

REVIEW OF PREVIOUS WORK

BIBLIOGRAPHY

A bibliography of literature relevant to problems of modal trip assignment is given in Appendix A. Separate sections contain (a) publications concerned primarily with models for, and analysis of data on, modal split in urban transportation, (b) previous bibliographies, and (c) background and collateral material.

SURVEY OF MODAL SPLIT MODELS

Various approaches that have been taken to the problem of modal trip assignment are surveyed in this section. Although no claim of exhaustive coverage is made, the approaches described are considered representative in the sense that they exemplify the major methodological differences as well as the kinds of data utilized.

In nearly all of the work reviewed the geographic area of concern is partitioned into a number of zones between which all trips of interest are assumed to take place. Within this framework, however, two rather different approaches to the "modal split" may be distinguished. One approach assumes that by some method of trip distribution the interzonal flows (i.e., the number of trips which take place between each pair of zones) are given, whereas the other approach assumes only that the number of trips generated by each of the zones is given.

In the case in which the interzonal flows are given, the modal split results in a collection of fractions, one for each pair of zones. In each instance this is to be interpreted as the proportion of trips, having the specified origin and destination, which is to be assigned to the mass transportation facilities. Such a split is referred to as a "trip split." In the case in which only the trips generated by each zone are given, a modal split results in a smaller collection of fractions, one for each zone, each of which is to be interpreted as the proportion of all the trips having that zone of origin which will make use of the mass transportation facilities. Each split is refrered to as an "origin split."

The following presents a brief description of each of the modal split models. Salient features are compared in Table 1.

Chicago Area Transportation Study

The technique employed by the Chicago Area Transportation Study (*1, 2, 3, 4*) to estimate the use of the mass transportation facilities in the planning year (1980) was essentially as follows. The number of mass transit trips terminating in the central business district (CBD) in 1980 was projected to be approximately equal to the number of such trips in the survey year (1956). This forecast was based on a number of factors, including the current trends in utilization of mass transit to the CBD, plans for urban development within and around the CBD, and parking facilities in the CBD. The 1980 trips to the CBD from all other zones were then assumed to take place at rates (CBD-oriented trips per unit population) proportional to the 1956 rates. The constant of proportionality was adjusted to yield the anticipated number of trips. The non-CBD-oriented mass transit trips were estimated, for each zone, as the fraction of non-CBD trips which would employ mass transportation on the basis of a forecast of car ownership within the zone. The relationship between car ownership and mass transit use was based on the 1956 survey data.

Pittsburgh Area Transportation Study

The approach to the forecasting of mass transit use taken by the Pittsburgh group (*5, 6, 7, 8*) was similar to that employed in Chicago. It differed primarily because of the fact that during the survey year no rapid transit system existed in Pittsburgh. The fraction of transit trips in each of three categories (CBD-oriented trips, school trips, and non-school local trips, was established by means of estimating equations involving car ownership, residential density, and distance from the CBD. The effect of a rapid transit system on the number of CBD-oriented trips was taken into account by employing a somewhat different estimating equation that had the effect of diverting some of the auto CBD trips to the mass transit system. In this way the properties of the proposed mass transit network had at least some effect on the estimated flows.

Schofer and Voorhees

The model developed by Schofer and Voorhees (*9*) is similar to that used by CATS and PATS in that it is basically an origin split but different (for both mass transit and automobile) in that the properties of the network are strongly involved. The central idea is that of an accessibility ratio. Each zone has associated with it a measure of the relative accessibility of that zone to all other zones by means of the mass transit network and the highway network. The fraction of trips originating in each zone which employs the mass transit system is then estimated by means of that zone's accessibility ratio. To improve the estimates, the trips originating in each zone are stratified by trip purpose and by the income of the trip maker, and separate relationships between accessibility and transit use are employed for each of the stratified groups. The method has been applied to Washington, D.C., data.

TABLE 1

SUMMARY OF MODAL SPLIT MODELS

CHARACTERISTIC	CHICAGO (CATS)	PITTSBURGH (PATS)	SCHOFER-VOORHEES	PENN–JERSEY	RAND	TRAFFIC RES. CORP.	UPSTATE NEW YORK	PUGET SOUND	WARNER
I. Type of model:									
A. Splits trips						X	X		X
B. Splits origins	X	X	X	X	X			X	
II. Factors explicity involved in model:									
A. Network characteristics:									
1. Accessibility ratio			X	X				X	
2. Miles of bus service					X				
3. Travel time ratio						X	X		X
4. Travel cost ratio						X			X
5. Excess time ratio						X			
6. Present flows	X								
B. Person or family characteristics:									
1. Income			X		X	X		X	X
2. Car ownership	X	X		X				X	
3. Family size, composition					X				X
4. Sex					X				X
5. Age									X
C. Trip characteristics:									
1. Purpose		X	X		X		X		
2. Car availability						X		X	
3. Length						X		X	
D. Zone characteristics:									
1. Residential density	X		X				X		
2. Employment density			X						
3. Concentration of workers				X					
4. Distance from CBD	X								
5. Price of land				X					

Penn-Jersey Transportation Study

The technique proposed by the Penn-Jersey Transportation Study (*10*) is again similar to those previously discussed in that it is an origin split. It operates as follows. All trips are stratified into four categories: (1) home to work from residence, (2) work to home from non-residence, (3) other than work trip from residence, and (4) other than work trip from non-residence. In the case of categories 1 and 3 the fraction of transit trips is estimated as a function of the automobile ownership within the zone, the residential density within the zone, and the accessibility ratio associated with the zone of origin. Trips in categories 2 and 4 are handled in a similar fashion, but in this case the independent variables are the zone's accessibility ratio and the employment density.

RAND Corporation

The RAND Corporation (*11, 12*) has studied the general problem of modal distribution as a part of their program for development of a model for the growth of an urban area. The model for prediction of modal split was based on Detroit data and took the form of a linear estimating equation which estimated the percentage of transit trips from each zone as a linear function of six independent variables: (1) percentage of the zone's workers belonging to families having more than two members, (2) mean income of the zone's workers, (3) cost of residential space in the zone, (4) percentage of the zone's workers belonging to families with a single wage earner, (5) percentage of the zone's workers that are male, and (6) number of coach-miles of bus service within the zone. The coefficients determined by linear regression techniques succeeded in explaining about 83 percent of the variance.

Traffic Research Corporation

The Traffic Research Corporation (*13, 14, 15, 16, 17, 18, 19, 20*) has developed a model which is different from those mentioned previously in that trips rather than origins are split between the mass transit and road networks. The general approach is to estimate the fraction of interzonal trips which will employ the mass transit system as a function of the ratio of travel times over the two alternative networks, the ratio of the travel costs, the ratio of excess times (excess time is defined to be time spent other than in vehicular travel; e.g., waiting for public vehicles, walking to parking, waiting to unpark), the economic status of the trip maker, and the purpose of the trip. It should be noted that in order to employ such a technique some other technique must have already been employed to determine the total interzonal trip flow. The model has been applied in Toronto and Washington, D.C.

Upstate New York Transportation Studies

A technique has been proposed by the Upstate New York group (*21*) in which a transit utilization factor is estimated for each pair of zones based on car availability for the trip (as distinguished from car ownership), the travel time ratio, and the travel cost ratio as estimated for a fixed-fare mass transit system by the distance between zones. Trip origins are distributed into interzonal flow estimates by means of an intervening opportunities approach employing the road network alone and then a second time employing the mass transit network alone (augmented by synthetic terminal links where required). The transit utilization factors are then employed to obtain a final estimate of interzonal flows by using the transit use factor in taking a weighted average of the previously computed interzonal flows.

Puget Sound Regional Transportation Study

The modal split procedure proposed by the Puget Sound Regional Transportation Study (*22*) is based on the model advanced originally by Schofer and Voorhees, in which the central concept is that of the accessibility ratio. The PSRTS model, however, represents a refinement of the Schofer-Voorhees model, at least in the form in which the Schofer-Voorhees model was applied in the Washington, D.C., area, in that the concept of a "household characteristic factor" is introduced. The household characteristic factor is estimated on the basis of variables measuring the automobile availability and residential density in the originating zone and is employed as a correction or adjustment factor to the modal split as previously estimated on the basis of the accessibility, income, and trip-purpose variables.

Warner

The problem of modal choice has also been studied by Warner (*23*), whose models deal with more specific modal choices than simply mass transportation versus private auto. In fact, he has developed a series of models relating to the choice between auto and commuter train, auto and city mass transit, train and city mass transit, etc. In each case an estimating equation is developed by linear regression techniques for predicting the fraction of trips which will employ each of the alternative modes being considered. Although the parameters involved in the estimating equations depend on which of the choices is being considered, they are all selected from the following: cost ratio, time ratio, family income, family income per driver, drivers per car, sex of driver, trip length, and age of driver. The data used in this study came from the sample survey carried out by the Cook County Highway Department in 1956 and reported by Plummer, Wilke, and Gran (*24*).

Adams

Adams (*25*), of the Bureau of Public Roads, has developed a model which should be distinguished from any of the others previously discussed in that it predicts the fraction of all trips in an urban area which will make use of the mass transportation facilities. The output of the model for a given city is thus a single fraction. The Adams model involves many factors not explicitly considered in the other models; e.g., factors relating to the geographic shape of the urban area (such as the mean distance of the commercial and industrial land from the CBD), general economic factors, and transit service ratios). Various mathematical transformations of the variables are used. Values of the parameters of the estimating equation were derived by statistical analysis of data on 16 U.S. cities. The model has been tested by comparing its estimates of the overall transit-use ratios in an additional set of cities with the actual ratios.

CHAPTER THREE

GENERAL MODEL OF A MULTIPLE-MODE TRANSPORTATION NETWORK WITH USE INFLUENCED BY A VARIETY OF FACTORS

The concept of a multiple-mode passenger transportation network with use subject to influence by a variety of factors is discussed here in abstract terms. The general model presented in this chapter provides a conceptual framework for the analyses of concrete data which follow.

STRUCTURE OF A MULTIPLE-MODE OR COMPOSITE NETWORK

It is in one sense a truism to state that every individual selects a means and a path for the accomplishment of each trip which minimizes his total expected cost for that trip. The term "cost" is used here in a generalized sense that reflects all the advantages and disadvantages of the person's travel alternatives as he sees them. The variation in behavior among individuals may be explained by a number of factors, including ignorance of the actual characteristics of the various alternative modes and routes and, perhaps more importantly, differences in the manner in which trip costs are determined. Thus, in assigning a population of trips to a network having certain characteristics in terms of expected travel time over the various links, expected dollar cost, and various levels of comfort, safety, convenience, etc., the implicit formula by which each member of the population measures total cost must be available in order that the actual travel choices of individuals correspond with the "minimum cost" or "shortest path" assignment. Although such a microscopic approach to trip assignment is clearly impractical, the stratification of trip demand into some reasonable number of categories within each of which cost is measured by a particular formula, and an assignment of the members of each category by means of an appropriate "shortest path" procedure deserves consideration as a realistic means for solving assignment problems. Such stratification could be based on economic and other factors associated with the trip makers, such as car availability, zone of residence, and trip purpose.

Next, consideration is given to the design of a network to which the members of each category of network user could be assigned by means of a shortest-path algorithm. The network must represent the entire spectrum of travel opportunities. One approach to the design of such a network is indicated in Figure 1, which is made up of three major subnetworks together with an interconnection network. The three subnetworks are intended to overlap geographically in that the nodes w_1, d_1, and m_1 represent the same general location within the actual transportation network, as indicated by their common subscript.

Although the costs incurred by the users of links may take many forms, for convenience in illustrating the concept of the composite network it is assumed that the total cost of a trip to an individual is given by the sum of the travel time cost (i.e., trip duration valued at some rate which depends on user category) plus direct out-of-pocket costs (i.e., automobile operating costs, parking fees, bus fares, etc.) An individual will then be assigned to the path through the network that minimizes his total cost. With respect to Figure 1, costs are associated with each of the links in the following way. The costs associated with the links in the walking subnetwork are established by elapsed time considerations (i.e., are roughly proportional to geographical distance), whereas the links which connect the walking network to the mass transit network include both the average waiting-time cost and the transit fare on the mass transit system, which is assumed to be a fixed-fare system. The costs associated with the links in the mass transit network then reflect primarily elapsed time. The transfer from the mass transit system to the walking network has essentially zero cost. The costs within the driving network are based on automobile operating costs and travel time considerations, whereas the transfer to the mass transit system involves parking fees, time, and the mass transit fare, plus a term related to the mass transit waiting time. Transfers to the walking network from the driving network, on the other hand, are penalized only for parking time and fees. It should be noted that the transfer from the mass transit system to the driving network is not possible (assuming home-to-work trips).

Within the subnetworks the links without arrows are intended as links on which travel is possible in either direction. The costs associated with travel in the two possible directions may, however, be different. The directed links in the interconnection network are, of course, intended as one-way links.

In assigning a trip between a particular O-D pair it is assumed (at least for some categories of users) that a car

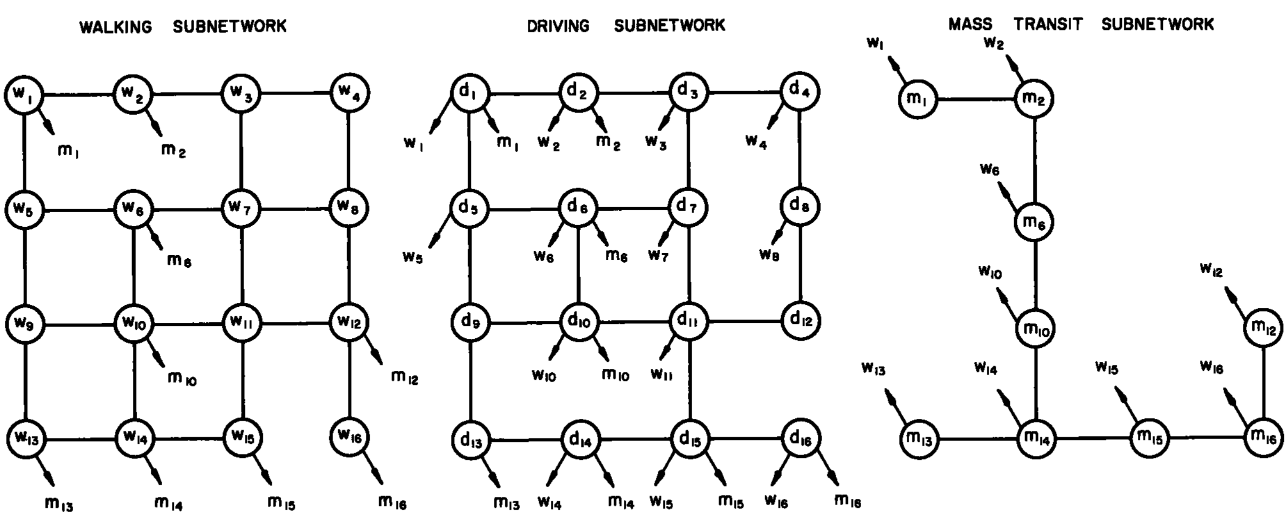

Figure 1. Mixed-mode network.

is available at the point of origin so that at this point and at this point only, the transfer from the walking subnetwork (containing the origin) to the driving subnetwork is possible. The trip destination is also taken to lie on the walking subnetwork, so that if the car is to be used the parking problem must be solved.

Although the network of Figure 1 is highly idealized, it illustrates the concept of assigning trips in terms of the entire transportation network rather than making an initial modal split that confines trip assignments entirely to disjoint subnetworks.

TRIP ASSIGNMENT SUBJECT TO THE INFLUENCE OF A VARIETY OF FACTORS (VECTOR-COST ASSIGNMENT)

This section describes a procedure whereby the parameters of a "vector-cost" assignment model may be estimated on the basis of individual behavior in the selection of routes over a network of travel opportunities. The vector-cost assignment model is one in which each network user is assigned to his least-cost route through the network; however, in contrast to other least-cost assignment procedures, the cost associated with any link in the network depends on certain characteristics of the individual contemplating the possible utilization of the link in carrying out his trip. In particular, it may be thought of as associating with each link in the composite network (i.e., a network composed of links representing both public and private means for travel) a sequence of numbers representing various aspects of the general costs or discomforts associated with the traversal of the link. Thus, the link connecting node i to node j can be described by the numbers $d_1^{i-j}, d_2^{i-j}, \ldots, d_n^{i-j}$ where, for example, d_1^{i-j} measures the actual cost in dollars associated with traversal of the link, d_2^{i-j} is the travel time, d_3^{i-j} is an index of the physical discomfort, d_4^{i-j} is an index of the safety hazard, etc. The notation D^{i-j} is used to represent the entire vector consisting of the components $d_1^{i-j}, d_2^{i-j}, \ldots, d_n^{i-j}$.

An individual traveler contemplating a trip over the composite network is also characterized by a vector of n components, in this case denoted by $s_1^k, s_2^k, \ldots, s_n^k$, where s_1^k is a measure of the sensitivity of the kth individual to dollar costs, s_2^k his sensitivity to travel time, etc. The symbol S^k is used to represent the vector $s_1^k, s_2^k, \ldots, s_n^k$. The cost which the kth individual associates with the link i–j in selecting his least-cost route from origin to destination is defined as $c_k^{i-j} = S^k \cdot D^{i-j}$, in which $S^k \cdot D^{i-j}$ is the usual dot product; i.e.,

$$c_k^{i-j} = S^k \cdot D^{i-j} = \sum_{x=1}^{n} s_x^k d_x^{i-j} \tag{1}$$

To apply such an assignment model to the prediction of actual route selections it would be necessary, of course, to make estimates of the sensitivity factors associated with network users in various categories. It is assumed that the information which might be available for the prediction of the sensitivities would be certain objective user characteristics, such as the user family income, residential density in his zone of residence, and automobile availability. Let these objective user characteristics be denoted by the vector U^k $(= u_1^k, u_2^k, \ldots, u_m^k)$, where the components of U^k are the objective user characteristics, except that $u_1^k = 1$, which is so defined for subsequent notational convenience. Next, assume that there has been established a series of linear predictors whereby the user's sensitivity factors may be predicted from the objective user characteristics; i.e.,

$$s_x^k = \sum_{y=1}^{m} a_{xy} u_y^k = A_x \cdot U^k \tag{2}$$

for $x = 1, 2, \ldots, n$. Thus, one finally obtains

$$c_k^{i-j} = \sum_{x=1}^{n} (A_x \cdot U^k)\, d_x^{i-j} \tag{3}$$

where the expected cost of the link i–j to the user k is now expressed in terms of objective characteristics of the user and the link. The model is then the foregoing framework plus the set of numbers a_{xy} for $x = 1, 2, \ldots, n$ and $y = 1, 2, \ldots, m$.

Consider next how estimates of the numbers a_{xy} might be formed from a body of data giving the objective characteristics of a sample of network users, the objective characteristics of the links, and the actual paths selected by the users in the sample. First, however, some additional notation is defined. Let Eq. 1 be rewritten in the form

$$c_k^{i-j} = A \cdot Z(i\text{–}j, k) \tag{4}$$

in which A is a vector consisting of all the values a_{xy}, and $Z(i\text{–}j, k)$ is a vector having components $u_y^k d_x^{i-j}$ for all positive integers $x \leq n$ and $y \leq m$. The cost of a path p to user k is defined as the sum of the costs of the links of which the path is composed; i.e.,

$$c_k^{p} = \Sigma_{i-j\epsilon p}\, c_k^{i-j} = \Sigma_{i-j\epsilon p}\, A \cdot Z(i\text{–}j, k) \tag{5}$$

Next, $Z(p,k)$ is defined as follows:

$$c_k^{p} = A \cdot \Sigma_{i-j\epsilon p}\, Z(i\text{–}j,k) = A \cdot Z(p,k) \tag{6}$$

If $p^*(k)$ is the actual path selected by the user k,

$$c_k^{p^*(k)} \leq c_k^{p(k)} \tag{7}$$

in which $p(k)$ is any path through the network having an origin and destination identical to those of $p^*(k)$. From this it follows that

$$A \cdot \{Z[p^*(k),k] - Z[p(k),k]\} \leq 0 \tag{8}$$

Although Eq. 8 is true for every path $p(k)$, it seems reasonable that Eq. 8 would contain information relevant to the vector A only if the path $p(k)$ to which it refers is in some sense reasonably competitive with the path $p^*(k)$. Because the major interest is in the distribution of travel over competitive modes of travel, it is proposed to select for each sample k a competitive path, say $p^a(k)$, which is, for example, the least travel time path employing an alternative mode of transportation (i.e., public transportation if k was an auto user, the auto network if k was a user of public transportation. Thus, for each user in the sample one obtains a relation of the form

$$A \cdot [Zp^*(k),k] - Z[p^a(k),k] \leq 0 \tag{9}$$

and the problem is reduced to that of finding the vector A which gives the best possible agreement with Eq. 9. A number of statistical techniques exist for estimating the vector A. One of these, construction of linear discriminant functions, was applied to data from the 1956 survey of transportation use by the Cook County Highway Department, as discussed in Chapter Seven. A somewhat different method, multivariate regression analysis, was applied to data from a survey carried out as part of the present project, as discussed in Chapter Nine.

CHAPTER FOUR

COMPARISON OF AGGREGATE PATTERNS OF TRAVEL TO WORK AND CAR OWNERSHIP IN FIVE CITIES

THE JOURNEY TO WORK, CENSUS DATA

To provide a larger perspective on the relative use of various modes of urban travel in the United States than is possible from examination of data from a single city, and to investigate relationships between selected population characteristics and modal split in a variety of urban settings, some overall comparisons with respect to travel mode were made between Chicago and four other large U.S. cities—Boston, Cleveland, New York, and Philadelphia. These are the five U.S. cities having rail rapid transit (elevated-subway) facilities in 1960. In that year questions on the principal mode of travel for the journey to work were asked of persons falling within the 25 percent sample of the decennial census of population. The answers to these questions, when related to other items of census information, describe aggregate travel patterns in the various urban areas of the country on a uniform basis.

Data on the principal mode of transportation for journeys to work in the Boston, Chicago, Cleveland, New York and Philadelphia Standard Metropolitan Statistical Areas (SMSA's) are given in Table 2. The numbers of workers using each mode in each SMSA are Census estimates based on the 25 percent sample of the 1960 census of population (*26*). The principal mode of travel was asked with reference to the week immediately preceding the date of enumeration. If more than one mode was used in daily travel, the principal mode was that used for the greatest distance. If different modes were used on different days, the principal mode was that used most frequently.

The percentages of workers in each SMSA who were classified in each of the nine modal categories also are given in Table 2. For each of the five SMSA's, the percentages of workers who used railroad, rapid transit, bus (including streetcar), or car as the principal mode of travel, or who walked to work, are plotted in Fig. 2.

There are some striking differences as well as similarities in the aggregate travel patterns of the five urban areas. New York is unique in the high proportion of workers (36.7 percent) using rapid transit and the low proportion (29.9 percent) using private automobile for the journey to work. The city with the next highest proportion of workers using rapid transit is Boston (12.6 percent) and the city with the next lowest proportion of workers using automobiles is Chicago (54.6 percent). Cleveland is at the opposite extreme from New York in having the lowest proportion of workers (0.6 percent) using rapid transit in 1960—and the highest proportion (68.5 percent) using automobiles. The proportion of workers traveling by railroad was again highest in New York (5.9 percent) and lowest in Cleveland (0.2 percent). Boston, Chicago, and Philadelphia lie between the extremes of New York and Cleveland and, on the whole, are relatively homogeneous in the proportions of workers who used automobiles and also rail facilities (either railroad or rapid transit) for the journey to work. The percentages of workers using automobiles in Boston, Chicago, and Philadelphia are 59.8, 54.6, and 56.0, respectively. The percentages of workers using rail facilities are 14.5 in Boston, 12.5 in Chicago, and 9.2 in Philadelphia. Bus use for trips to work was less variable over the five cities: Cleveland, Chicago and Philadelphia are clustered at the upper end of the range (20.7, 19.2, and 18.3 percent, respectively, of trips to work were by bus), whereas New York (12.8 percent) and Boston (9.6 percent) are at the lower end. The proportion of persons walking to work was relatively invariant from city to city, ranging from 10.8 percent in Boston to 6.3 percent in Cleveland.

Numbers of persons, classified by various characteristics, who used, respectively, cars (private automobile or carpool) and public transportation (railroad, subway or elevated, bus or streetcar) for the journey to work in the five SMSA's in 1960 are given in Table 3. Four separate classifications of workers who used either a car or public transportation for the trip to work are presented, based on the following characteristics: (1) sex within race, (2) age, (3) occupation, and (4) individual earnings in 1959. As in Table 2, the data are based on the 25 percent sample of the 1960 U.S. census of population (*26*). For each group of persons having the specified characteristics and working in one of the five SMSA's, the percentage of those who used public transportation in the total of those who used either public transportation or a car for the trip to work is given in Table 3. These percentages are plotted separately in Figures 3 through 6 for the four worker classifications.

The aggregate proportion of public transportation use for work trips varies markedly from city to city—overall percentages derived by combining data of Table 3 are 65.0 for New York, 36.7 for Chicago, 32.9 for Philadelphia, 28.7 for Boston, and 23.9 for Cleveland—and each of the plots clearly reflects this fact. However, the parallelism between cities in the way public transportation use varies in relation to the selected worker characteristics is striking. This is particularly true for age, occupation, and income.

The proportion of workers using public transportation is consistently highest in the 14-24 age group, substantially lower in the 25-44 age group, and high again in those 45 or older (Fig. 4).

As shown in Figure 5, persons in sales, clerical, and kindred occupations used public transportation in each of the five cities to a considerably greater extent than did persons in professional and managerial occupations or persons in the remaining occupations. The professional and managerial group used public transportation the least.

Proportionate use of public transportation when workers are classified by annual earnings exhibits, again, a pattern that is repeated with minor variations from city to city (Fig. 6). There is a sharp drop in the proportion of workers using public transportation as earnings levels increase from \$2,000-3,999 to \$4,000-5,999 to \$6,000-9,999. This trend flattens out or even reverses at both ends of the range; i.e., in going from the \$4,000-5,999 level down to the ≤ \$1,999 level or in going from the \$6,000-9,999 level up to the ≥ \$10,000 level.

The general parallelism between cities in the pattern of modal split is also apparent when workers are classified simultaneously by sex and race (Fig. 3). A somewhat greater degree of irregularity is apparent in this compound classification than in the separate classifications by age, occupation, and earnings. Examination of the marginal distributions (i.e., classifying workers by age and sex separately) reveals that the main effects of these two factors

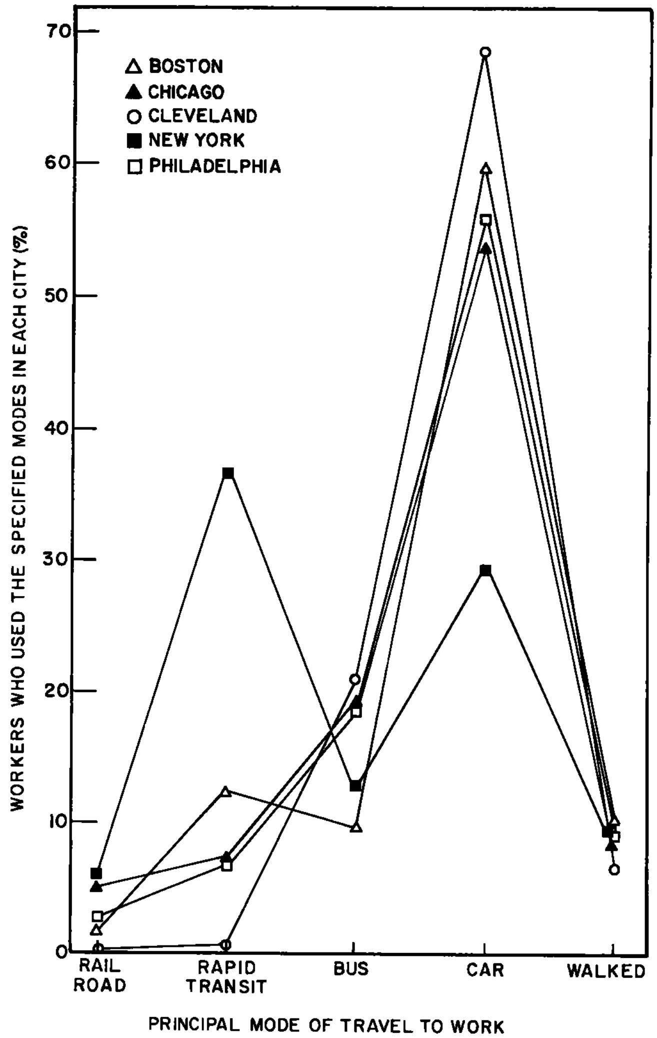

Figure 2. Comparison of journeys to work in five U.S. cities, by principal mode of travel. Based on 1960 Census data for SMSA's.

TABLE 2

PERSONS WORKING IN FIVE STANDARD METROPOLITAN STATISTICAL AREAS IN 1960, CLASSIFIED BY PRINCIPAL MODE OF TRAVEL FOR THE JOURNEY TO WORK[a]

PRINCIPAL MODE OF TRAVEL	BOSTON NO.	BOSTON %	CHICAGO NO.	CHICAGO %	CLEVELAND NO.	CLEVELAND %	NEW YORK NO.	NEW YORK %	PHILADELPHIA NO.	PHILADELPHIA %
Railroad	18,785	1.88	123,726	5.30	1,302	0.19	246,246	5.91	43,673	2.81
Rap. transit	126,053	12.63	167,975	7.20	4,376	0.63	1,530,402	36.73	99,564	6.40
Bus, str. car	95,732	9.59	447,678	19.18	143,079	20.73	534,707	12.83	284,739	18.32
Taxicab	4,979	0.50	7,285	0.31	1,054	0.15	32,343	0.78	3,766	0.24
Car	597,428	59.85	1,275,067	54.63	472,755	68.51	1,246,411	29.91	871,283	56.05
Walked	108,030	10.82	212,161	9.09	43,474	6.30	383,456	9.20	140,807	9.06
Worked home	27,949	2.80	56,880	2.44	12,285	1.78	108,384	2.60	80,853	5.20
Other means	9,475	0.95	22,048	0.94	6,697	0.97	48,256	1.16	17,979	1.16
Not reported	9,818	0.98	21,339	0.91	4,990	0.72	36,663	0.88	11,833	0.76
All	998,249	100.00	2,334,159	100.00	690,012	100.00	4,166,868	100.00	1,554,497	100.00

[a] Based on the 25 percent sample of the U.S. Census of Population.

on modal split are about equally variable over the group of five cities.

This comparison of the five U.S. cities (SMSA's) with rapid transit systems in 1960 shows that Chicago lies within the extremes in the percentage of workers using each of the major modes of transportation for the journey to work and exhibits typical effects of various factors on overall modal split.

CAR OWNERSHIP, BLS DATA

Relative use of public transportation and private automobiles for the journey to work in five standard metropolitan statistical areas having rapid transit facilities in 1960 (Boston, Chicago, Cleveland, New York, and Philadelphia) was investigated in the preceding section. A parallel investigation of car ownership in these five urban areas was carried out. The data, which derive from the 1960-61 survey of consumer expenditures by the U.S. Bureau of Labor Statistics (*27*), are given in Table 4. The sample units here are families (including single consumers) rather than individual workers. The size of the samples is much smaller than in the case of the census data, and sampling variability tends to obscure exact relationships. Nevertheless, the broad patterns of car ownership in the five metropolitan areas are clearly discernible.

In the BLS data "Chicago" actually refers to the entire urban part of the combined SMSA's of Chicago and Gary-Hammond-East Chicago. References to the other cities are to the entire urban parts of the corresponding SMSA's. The categories for each of the family characteristics listed in Table 4 have, so far as possible, been made to conform to the Census categories previously used in connection with the analysis of modal split by worker characteristics.

The numbers of families in the BLS samples for the Boston, Chicago, Cleveland, New York, and Philadelphia areas are 268, 371, 294, 448, and 313, respectively, and the corresponding overall percentages of sample families owning at least one car are 65.7, 70.6, 78.9, 50.2, and 62.3. For comparison, the percentages of occupied housing units with one or more cars based on 1960 census data for entire SMSA's (*28*), are as follows: 73.0 for Boston, 72.7 for the combined SMSA's of Chicago and Gary-Hammond-East Chicago, 79.8 for Cleveland, 53.2 for New York, and 71.9 for Philadelphia. New York thus had the lowest, and Cleveland the highest, overall proportion of car-owning families; Boston, Chicago, and Philadelphia fall within the extremes. This is in agreement with the relatively low proportion of workers in the New York SMSA who traveled to work by car, the relatively high proportion in Cleveland, and the intermediate proportions in the three other cities.

Percentages of car ownership also are given in Table 4 for the sample families classified separately by age and occupation of the head of the family, and by annual family income after taxes. Families in which the head was a member of the armed forces, or was unemployed or retired, have been excluded from the classification by occupation.

Percentages of car ownership in the five cities are plotted

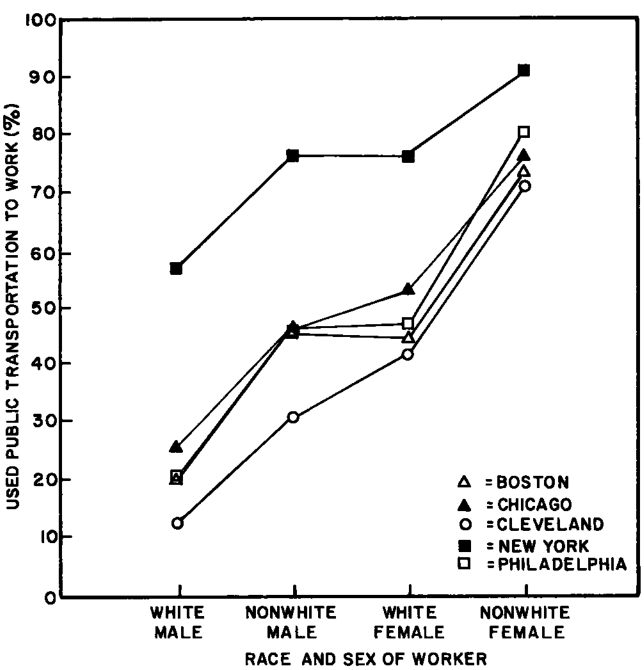

Figure 3. Modal split between use of public transportation and private automobiles for journeys to work in five U.S. cities, by race and sex. Based on 1960 Census data for SMSA's.

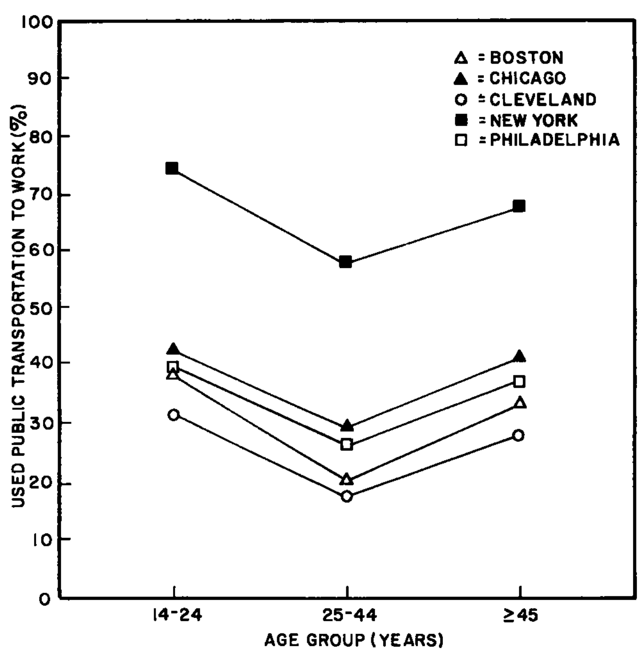

Figure 4. Modal split between use of public transportation and private automobiles for journeys to work in five U.S. cities, by age of worker. Based on 1960 Census data for SMSA's.

TABLE 3
PERSONS WORKING IN FIVE STANDARD METROPOLITAN STATISTICAL AREAS IN 1960, CLASSIFIED BY USE OF PUBLIC TRANSPORTATION OR A CAR[a] FOR THE JOURNEY TO WORK AS RELATED TO SEX WITHIN RACE AND AGE GROUP[b]

WORKER CHARAC-TERISTIC	BOSTON			CHICAGO			CLEVELAND			NEW YORK			PHILADELPHIA		
	NO. BY P.T.	NO. BY CAR	% BY P.T.	NO. BY P.T.	NO. BY CAR	% BY P.T.	NO. BY P.T.	NO. BY CAR	% BY P.T.	NO. BY P.T.	NO. BY CAR	% BY P.T.	NO. BY P.T.	NO. BY CAR	% BY P.T.
White male	110,946	440,891	20.10	317,488	918,244	25.69	48,522	339,328	12.51	1,243,552	948,988	56.72	160,468	624,897	20.43
White female	116,330	146,640	44.24	288,613	258,028	52.80	66,186	92,771	41.64	740,524	229,872	76.31	153,904	172,441	47.16
Nonwhite male	6,280	7,348	46.08	67,178	78,563	46.09	14,658	32,709	30.95	169,230	52,261	76.40	51,027	58,679	46.51
Nonwhite female	7,014	2,548	73.35	66,100	20,232	76.56	19.391	7,947	70.93	158,049	15,290	91.18	62,577	15,266	80.39
Age 14-24	47,578	74,934	38.83	122,615	159,812	43.41	26,981	56,812	32.20	347,608	115,067	75.13	70,640	103,613	40.54
Age 25-44	77,361	298,644	20.57	277,604	654,332	29.79	54,007	246,311	17.98	937,208	658,294	58.74	166,157	458,098	26.62
Age 45 or older	115,631	223,850	34.06	339,160	460,923	42.39	67,769	169,632	28.55	1,026,539	473,050	68.45	191,179	309,572	38.18

[a] Private automobile or car pool [b] Based on the 25 percent sample of the U.S Census of Population

TABLE 4
PERCENTAGE OF CAR OWNERSHIP AMONG SAMPLE FAMILIES RESIDING IN FIVE METROPOLITAN AREAS[a] IN 1960-1, CLASSIFIED BY AGE OF HEAD OF FAMILY, OCCUPATION OF HEAD OF FAMILY, AND ANNUAL FAMILY INCOME AFTER TAXES[b]

FAMILY CHARACTERISTIC	BOSTON		CHICAGO		CLEVELAND		NEW YORK		PHILADELPHIA	
	NO. OF FAMILIES	% OWNING CARS	NO. OF FAMILIES	% OWNING CARS	NO. OF FAMILIES	% OWNING CARS	NO. OF FAMILIES	% OWNING CARS	NO. OF FAMILIES	% OWNING CARS
Age of family head (yr):										
24 or younger	9	55.6	13	46.1	10	70.0	17	47.0	14	42.8
25-44	110	77.3	169	78.7	138	90.0	176	57.4	124	74.1
45 or older	149	57.7	189	65.1	146	69 9	255	45.1	175	56.0
Occupation of family head:										
Self-empl., salaried prof., officials	71	94.4	83	89.2	75	90.6	108	77.8	73	86.4
Clerical, sales	34	67.6	47	57.4	40	82.6	68	55.9	37	67.6
Other employed	102	66.6	180	77.2	126	82.6	194	47.4	123	66.6
Income after taxes ($):										
1,999 or less	23	4.3	24	4.2	25	32.0	40	0.0	36	2.8
2,000 - 3,999	43	11.6	67	35.8	36	55.6	79	11.4	58	31.1
4,000 - 5,999	62	71.0	83	69.9	68	75.0	110	47.2	76	75.0
6.000 - 9.999	99	87.8	139	89.3	119	93.3	150	70.0	105	80.0
10,000 or more	41	95.2	58	94.8	46	93.5	69	84.1	38	94.8

[a] All areas are Standard Metropolitan Statistical Areas except Chicago, which includes the two SMSA's Chicago and Gary-Hammond-East Chicago
[b] Data from the survey of consumer expenditures by the U. S Bureau of Labor Statistics.

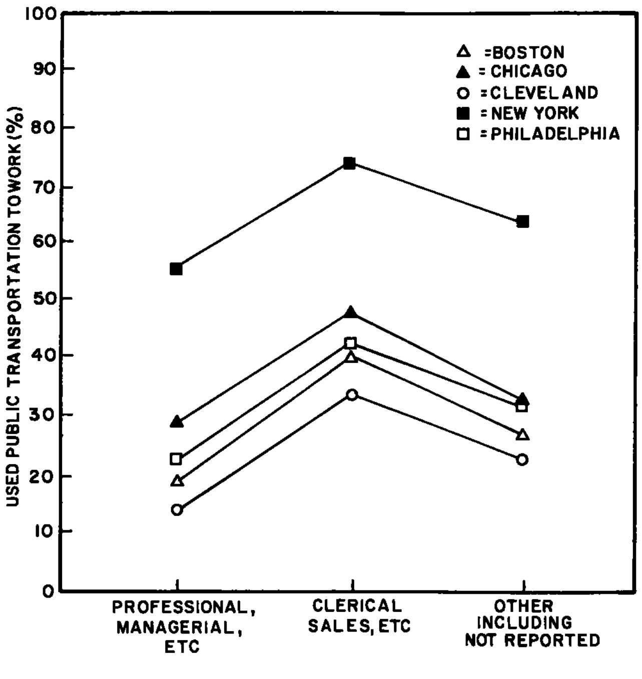

Figure 5. Modal split between use of public transportation and private automobiles for journeys to work in five U.S. cities, by occupation of worker. Based on 1960 Census data for SMSA's.

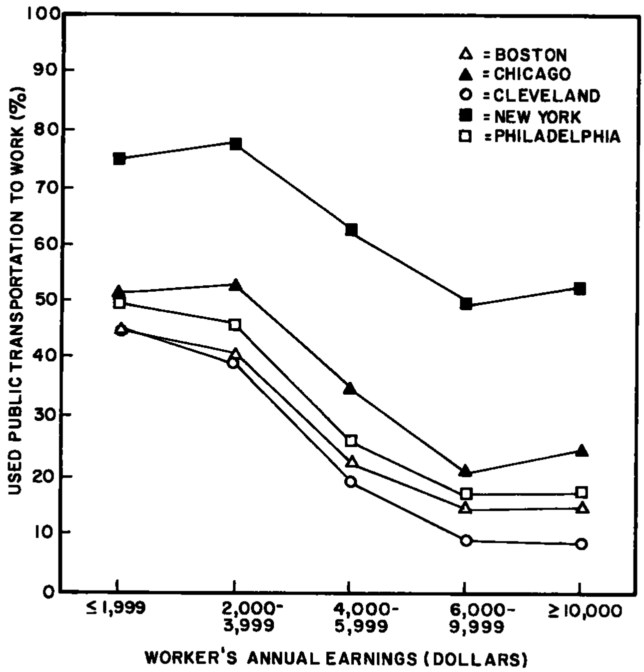

Figure 6. Modal split between use of public transportation and private automobiles for journeys to work in five U.S. cities, by individual earnings in 1959. Based on 1960 Census data for SMSA's.

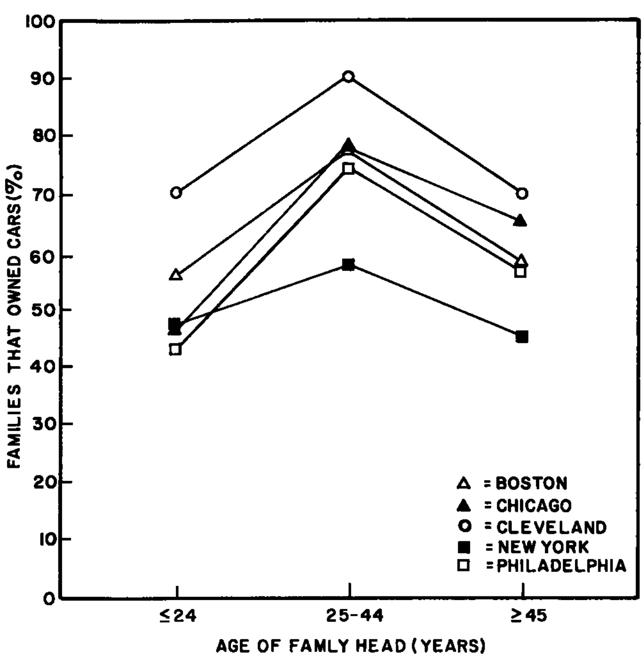

Figure 7. Car ownership by sample families in five U.S. cities, by age of family head. Based on 1960–61 surveys by the Bureau of Labor Statistics.

for each family classification in Figures 7, 8, and 9. The differences between cities as wholes in the percentage of car ownership among the sample families are, of course, reflected in these figures. The generally parallel pattern of variation from city to city in the proportion of sample families owning cars as a function of each of the selected factors (age of family head, occupation of family head, and family income) is apparent. Car ownership is consistently higher where the head of the family is in the intermediate age group (25 to 44 years) and lower where the head of the family is in the age groups either below or above this interval (Fig. 7).

Family income level and the frequency of car ownership are strongly related (Fig. 8). With the exception of Cleveland, less than 5 percent of families in the lowest income category (less than $2,000) owned cars in each city. On the other hand, with the exception of New York, roughly 95 percent of families in the highest income category ($10,000 or more) owned cars in each city. There is a sharp rise in the frequency of car ownership in each of the cities as income ranges upward through the intermediate levels.

Frequency of car ownership among sample families in the five cities exhibits a relatively weak and inconsistent relationship to the occupation of the family head (Fig. 9). Also, there is an apparent lack of agreement between the census data on modal split, reported in the preceding section, and the present data. The proportionate use of public transportation for the journey to work was in all cities higher among clerical and sales workers than among work-

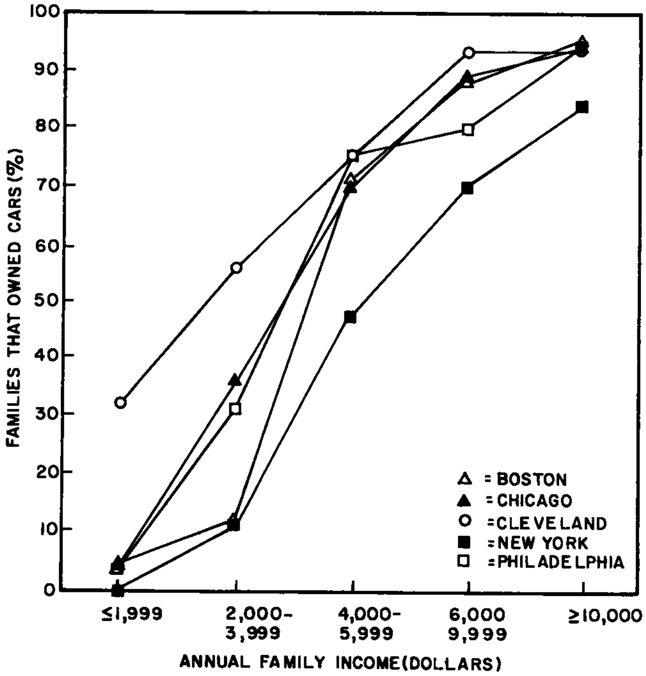

Figure 8. Car ownership by sample families in five U.S. cities, by family income after taxes. Based on 1960–61 surveys by the Bureau of Labor Statistics.

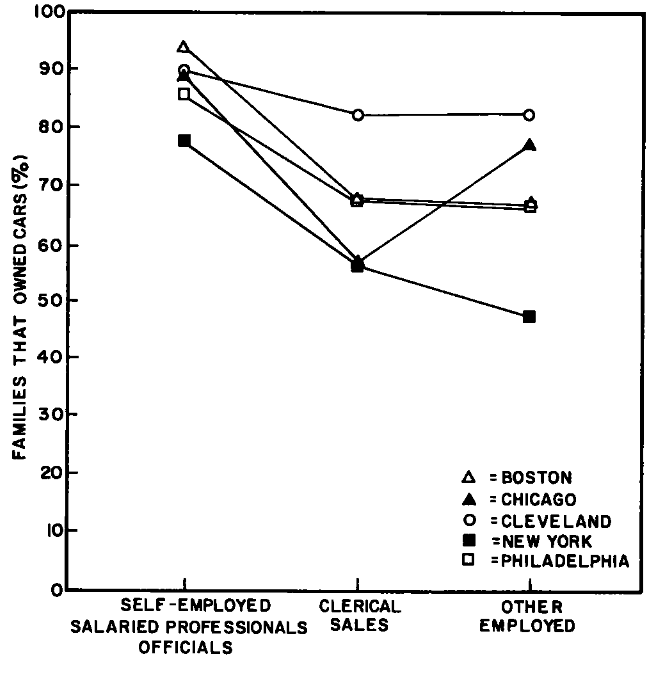

Figure 9. Car ownership by sample families in five U.S. cities, by occupation of family head. Based on 1960–61 surveys by the Bureau of Labor Statistics.

ers in either of the other two occupational categories; i.e., professional, managerial, etc., and "other" (the latter consists mainly of skilled, semi-skilled, and unskilled wage earners). However, the frequency of automobile ownership was somewhat higher among families in which the head was a clerical or sales worker than among families in which the occupation of the head was "other" in all cities except Chicago. Occupation (perhaps because of the location of the place of work) appears from these data to have an influence on the mode of travel that is to some extent independent of car ownership.

CHAPTER FIVE

ANALYSIS OF MAIN FACTORS CITED AS INFLUENCING CHOICE OF TRAVEL MODE

During home interviews conducted by the Cook County Highway Department in the Chicago area in 1956 information was elicited not only on actual trips made by adult members of households, but also on what they considered to be the best alternative means, or modes, of travel for these trips (*24*). Information is provided by the survey on the following points relative to individual assessment of travel opportunities: (1) the actual (or usual) and the best alternative mode of travel for a specified trip (mode is taken in the sense of principal mode when a trip is composed of multimodal segments); (2) duration or elapsed time of the trip for actual and alternative modes, together with a separate estimate of the difference between the two elapsed times; (3) in the case of work trips, the monetary cost of making the trip by the actual and alternative modes; (4) the single factor with most influence on the choice of travel mode. A further piece of information for work trips is the number of trips to and from work per week by automobile and by public transportation.

The modes of travel are distinguished as automobile driver, automobile passenger, taxicab, CTA bus, suburban bus, elevated or subway (rapid transit), and railroad. The categories for the single factor with most influence on choice of travel mode for the trip are: (1) cost, (2) comfort, (3) time, (4) walking, (5) parking not available, (6) parking too costly, (7) car necessary, (8) other. These categories were chosen in advance of the survey and presented as a set of alternative responses during the interviews.

For the purpose of investigating the influence on modal choice of several factors on which the CCHD data bear, the following subsample was selected from the complete trip file: work trips of persons who stated that for such trips a car was either the actual or the best alternative means of travel. The number of persons in this subsample (trip sample A) is 1,467. A reduced subsample (trip sample B, consisting of 1,300 or 1,304 trips) was formed by eliminating trips from sample A that were found not to contain information on income or were otherwise unsuitable with respect to factors under investigation.

The persons in sample A are simultaneously classified by the actual and alternative travel modes and by the main factor influencing the choice between them in Table 5. The mode "car" here includes both drivers and passengers. The preponderant mode of travel actually chosen for these work trips is car; 1,165 persons of 1,467 (79 percent) were automobile drivers or passengers. The proportion of persons choosing automobile is, however, strongly dependent on which of the three particular modes of public transportation is one member of the pair of candidate modes. Where the choice was stated to lie between automobile and railroad 51.1 percent of persons (71 of 139) chose automobile; where the choice was between automobile and rapid transit (elevated-subway) 67.4 percent (128 of 190) chose automobile; and where the choice was between automobile and bus 84.9 percent (966 of 1,138) chose automobile.

The overall frequencies with which the various reasons for choice of travel mode were specified vary greatly. Time was most frequently named as the single most important factor influencing modal choice: 34.0 percent of all persons (499 of 1,467) gave this response. The proportion of persons so responding was, however, far from uniform over the six combinations of actual and alternative modes given in Table 5. Considering first the division into automobile users and public transportation users, 41.0 percent of the former (478 of 1,165) said time was the most important factor in their choice, whereas only 6.9 percent of the latter (21 of 302) said so. A further breakdown of automobile users according to which mode of public transportation was considered the best alternative reveals significant heterogeneity. Of those automobile users who considered railroad the best alternative mode, 20 percent (14 of 71) gave time as the main factor in the choice; of those who considered rapid transit the best alternative, 32 percent (41 of 128) gave time as the main factor in the choice; whereas of those who considered bus the best alternative 44 percent (423 of 966) gave time as the main factor in the choice. Among those who used public transportation rather than automobiles, time was given as the main reason for choice by 25 percent (17 of 68) of those using railroad but by only 1.7 percent (4 of 232) of those using rapid transit or bus.

The second most frequently stated factor in modal choice was comfort. Overall, 21.0 percent of persons (308 of 1,467) gave this as the main factor influencing choice. As in the case of time, there is a high degree of asymmetry between automobile and public transportation users with respect to this factor. As a group, 25.4 percent (296 of 1,165) of those who traveled by automobile gave comfort as the main factor in modal choice as contrasted with 4.0 percent (12 of 302) of those who traveled by some form of public transportation. There is, however, with respect to comfort as a factor influencing choice, no statistically significant evidence of heterogeneity among automobile users dependent on whether the best alternative mode was considered to be railroad, rapid transit, or bus. The proportions of automobile users with these as the best alter-

TABLE 5

PERSONS FOR WHOM A CAR WAS EITHER THE ACTUAL OR THE BEST ALTERNATIVE MODE OF TRAVEL FOR WORK TRIPS, CLASSIFIED BY THE ACTUAL AND ALTERNATIVE MODES AND BY THE MAIN FACTOR INFLUENCING CHOICE BETWEEN THEM [a]

PRINCIPAL TRAVEL MODE		MAIN FACTOR IN CHOICE OF TRAVEL MODE (NO. OF PERSONS)								
ACTUAL	ALTERNATIVE	TIME	COST	COMFORT	WALKING	PARKING NOT AVAILABLE	PARKING TOO COSTLY	CAR NECESSARY	OTHER FACTORS	TOTAL
Car	Railroad	14	0	17	4	0	0	31	5	71
Car	Rapid transit	41	1	29	8	0	0	40	9	128
Car	Bus	423	5	250	18	0	0	223	47	966
Railroad	Car	17	19	9	1	6	7	0	9	68
Rapid transit	Car	2	22	0	0	10	16	0	12	62
Bus	Car	2	54	3	1	18	8	0	86	172
All		499	101	308	32	34	31	294	168	1467

[a] Cook County Highway Department data.

native modes who gave comfort as the reason for choice are, respectively, 24 percent (17 of 71), 23 percent (29 of 128), and 26 percent (250 of 966). The hypothesis that the proportion of automobile users giving comfort as the main reason for choice of travel mode is independent of whether the best alternative is railroad, rapid transit, or bus is tenable in terms of the present data ($\chi^2 = 0.67$ with 2 degrees of freedom; $0.7 < P < 0.8$). Among users of public transportation, comfort was the main factor in modal choice for 13 percent (9 of 68) of railroad commuters, but for only 1.3 percent (3 of 234) of those taking rapid transit or bus.

The next most frequent factor in modal choice, advanced by 20.0 percent of all persons (294 of 1,467) (i.e., by 25.2 percent of car users (194 of 1,165)), was "car necessary." On the home-interview forms two of the possible responses listed are "car necessary for work" and "car necessary for return trip." The two categories are combined here. The frequency of this response varied considerably, depending on the nature of the mode choice. Those automobile users having railroad, rapid transit, and bus as the best alternative means of travel gave car necessity as the main factor in choice with these frequencies: 44 percent (31 of 71), 31 percent (40 of 128), and 23 percent (223 of 966), respectively.

Relative cost of travel by alternative modes was stated to be the main factor in choice considerably less often than relative time, relative comfort, or car necessity. Two of the possible main factors in mode selection listed on the interview forms are concerned with cost: "cost is less" and "available parking facilities too costly." The two factors are kept separate in Table 5. They are referred to herein individually as "trip cost" and "parking cost" and in combination simply as "cost." Trip cost was given as the main factor in choice by 6.9 percent of all persons (101 of 1,467) and parking cost by 2.1 percent (31 of 1,467). Cost as the main factor in modal choice was almost entirely restricted to users of public transportation. Only 6 of 1,165 automobile users (0.5 percent) gave cost (i.e., trip cost) as the main factor influencing choice. Combining persons for whom either trip cost or parking cost was the named factor, 41.7 percent of the users of public transportation (126 out of 302) said that cost most influenced their choice. There is evidence of some variation among persons choosing the three public transportation modes with respect to cost as the main factor: 61 percent of rapid-transit users (38 of 62) specified cost as compared with 38 percent of railroad users (26 of 68) and 36 percent of bus users (62 of 172). The ratios differ to a statistically significant extent ($\chi^2 = 12.41$ with 2 degrees of freedom; $0.001 < P < 0.005$). Examination of Table 5 indicates that the relatively large number of instances in which users of rapid transit gave parking cost as the main factor in mode choice is the cause of the nonuniformity.

The factors of the amount of walking required and parking unavailability were specified by comparatively few

TABLE 6

PERSONS FOR WHOM A CAR WAS EITHER THE ACTUAL OR THE BEST ALTERNATIVE MODE OF TRAVEL FOR WORK TRIPS, CLASSIFIED BY SEX WITHIN AGE GROUP AND BY THE MAIN FACTOR INFLUENCING MODAL CHOICE [a]

AGE GROUP (YR)	SEX	MAIN FACTOR IN CHOICE OF TRAVEL MODE (NO. OF PERSONS)								
		TIME	COST	COMFORT	WALKING	PARKING NOT AVAILABLE	PARKING TOO COSTLY	CAR NECESSARY	OTHER FACTORS	TOTAL
16 - 19	M	3	4	1	—	—	—	2	2	12
	F	2	2	4	—	—	—	1	9	18
20 - 24	M	27	5	18	1	1	—	12	6	70
	F	5	3	7	1	1	1	1	10	29
25 - 29	M	50	3	22	4	2	3	19	8	111
	F	9	2	9	—	—	—	—	10	30
30 - 34	M	70	8	34	3	3	1	41	5	165
	F	7	1	12	1	—	1	—	4	26
35 - 39	M	70	14	27	3	1	6	39	13	173
	F	11	3	9	—	1	—	1	6	31
40 - 44	M	49	9	29	5	6	3	38	5	144
	F	4	3	10	1	—	—	—	9	27
45 - 54	M	71	18	48	3	6	4	63	27	240
	F	14	5	7	1	1	1	1	9	39
55 - 64	M	47	11	24	2	4	8	36	17	149
	F	2	1	5	2	1	—	—	6	17
65 -	M	7	2	3	2	1	—	4	—	19
	F	—	—	—	—	—	—	—	—	0
All		448	94	269	29	28	28	258	146	1300

[a] Cook County Highway Department data.

TABLE 7

PERSONS FOR WHOM A CAR WAS EITHER THE ACTUAL OR THE BEST ALTERNATIVE MODE OF TRAVEL FOR WORK TRIPS, CLASSIFIED BY HOUSEHOLD INCOME LEVEL AND BY THE MAIN FACTOR INFLUENCING MODAL CHOICE [a]

HOUSEHOLD INCOME LEVEL ($)	MAIN FACTOR IN CHOICE OF TRAVEL MODE (NO. OF PERSONS)								
	TIME	COST	COMFORT	WALKING	PARKING NOT AVAILABLE	PARKING TOO COSTLY	CAR NECESSARY	OTHER FACTORS	TOTAL
2,000 - 3,000	7	0	1	0	0	0	1	1	10
3,000 - 4,000	28	4	30	1	1	1	3	9	77
4,000 - 5,000	67	16	33	2	4	4	23	13	162
5,000 - 6,000	88	22	60	12	5	5	49	25	266
6,000 - 7,500	106	23	55	3	7	5	58	31	288
7,500 - 10,000	80	15	42	6	7	5	52	35	242
10,000 - 15,000	49	10	43	5	4	6	43	25	185
15,000 +	24	5	6	0	1	2	29	7	74
All	449	95	270	29	29	28	258	146	1304

[a] Cook County Highway Department data.

people; 2.2 percent of all persons (32 of 1,467) specified walking as the main factor in modal choice and 2.3 percent (34 of 1,467) specified parking unavailability. Only 2 persons who used public transportation gave as the reason that less walking was required. Among automobile users as a group, 2.6 percent (30 of 1,165) gave this reason. When the group is broken down by best alternative mode, however, there is evidence of variation: 6 percent of those with railroad and also with rapid transit as the best alternative mode (4 of 71 and 8 of 128, respectively) gave less walking as the main factor in favor of the automobile, but only 2 percent of those with bus as the best alternative (18 of 966) did so.

A joint classification of persons in trip sample B by age, sex, and the main factor influencing choice of travel mode is presented in Table 6; a separate classification jointly by household income and the main factor influencing choice is presented in Table 7.

Statistical (χ^2) tests failed to show any significant relationships between age group and the proportion giving any of the following as the main factor in modal choice: time, comfort, car necessity, cost, or walking. Also, no significant relationships were revealed between sex and the proportion of persons giving cost or walking as the main factor.

The proportion of males who gave travel time as the main factor in mode choice, 36.4 percent (394 of 1,083), was significantly higher than the proportion of females, 24.9 percent (54 of 217). On the other hand, the proportion of females who gave comfort as the chief factor was significantly higher than the proportion of males who did so (29 percent of females (63 of 217) as compared with 19 percent of males (206 of 1,083).

The factor "car necessity" was cited almost exclusively by males. Only 1.8 percent of females (4 of 217) cited this factor, as contrasted with 23.4 percent of males (254 of 1,083).

Analysis of the data given in Table 7 does not show statistically significant relationships between household income level and the frequency with which interviewed persons gave either time or cost as the main factor in modal choice. There are significant relationships, however, between income level and the frequency with which both comfort and car necessity were the responses. The proportions of persons in seven income categories who considered comfort and also car necessity as the main factor in modal choice are given in Table 8. The frequency with which car necessity is stated to be the main factor increases with increasing income level, whereas the reverse is true of comfort.

TABLE 8

PROPORTION OF PERSONS GIVING "COMFORT" AND "CAR NECESSITY" AS MAIN FACTOR IN MODAL CHOICE AS RELATED TO HOUSEHOLD INCOME LEVEL [a]

HOUSEHOLD INCOME LEVEL ($1,000)	TOTAL PERSONS	PERSONS GIVING COMFORT AS MAIN FACTOR IN MODAL CHOICE		PERSONS GIVING CAR NECESSITY AS MAIN FACTOR IN MODAL CHOICE	
		(NO.)	(%)	(NO.)	(%)
< 4	87	31	35.6	4	4.6
4–5	162	33	20.4	23	14.2
5–6	266	60	22.6	49	18.4
6–7.5	288	55	19.1	58	20.1
7.5–10	242	42	17.4	52	21.5
10–15	185	43	23.2	43	23.2
> 15	74	6	8.1	29	39.2
All	1304	270		258	

[a] Cook County Highway Department data.

CHAPTER SIX

STATISTICAL DISCRIMINANT ANALYSES OF MODAL CHOICE

Relationships between actual choices as to mode of transportation and a number of variables that could reasonably be expected to be predictive of such choices were investigated by applying the technique of statistical discriminant analysis to data from the home-interview survey carried out in the Chicago area in 1956 by the Cook County Highway Department (*24*). Factors explicitly indicated by the persons interviewed to be of greatest importance in their modal choices were analyzed in Chapter Five. The variables considered in this chapter refer to relatively objective data.

The method of discriminant analysis as originally developed by Fisher (*29*) and subsequently elaborated (*30, 31*) is directed at the problem of classification of individuals into two or more groups. That linear function of a set of variables characterizing the individuals is found which in a certain sense best discriminates between the members of the different groups. In the present context there are two groups to be discriminated—persons using private automobiles and persons using public transportation for trips to work. The variables characterizing the individuals are such properties as age, type of dwelling, and distance from home to work. For each person it is also known, as a result of the interview, whether an automobile or public transportation was actually used for these trips. The objective is to find a linear combination of the variables (or specified functions of the variables) that will permit accurate classification of individuals into automobile and public-transportation users. The coefficients of the discriminant functions are computed by techniques of calculation similar to those used in multiple regression analysis. The "distance" between the known groups, as defined by the difference in mean values for constant within-group variance, is maximized. The classification of individuals is then carried out as follows. Associated with a discriminant function (in the case of discrimination into two groups) is a unique boundary value or point. The function is evaluated for each individual from knowledge of his particular combination of characteristics. Depending on whether the value of the function is below or above the boundary value, the individual is classified as belonging to one group or the other. The number of errors of classification among individuals for which actual modal choice is known is thus a measure of the degree of discrimination achieved.

Discriminant analyses were carried out using several different sets of predictive variables and also different samples of trip data. The variables used in the construction of the various discriminant functions are defined in Table 9. Values of some of the variables are taken directly from the raw survey data (basic variables); other variables have been defined in terms of specified mathematical functions of the original or basic variables.

The five samples of trip data used in the construction of discriminant functions are described in Table 10. Each sample includes a set of trips in which private automobile was the principal mode and a different set of trips in which some form of public transportation was the principal mode. All trips in all five samples are work trips: (1) that began between 6:00 AM and 9:30 AM (morning peak period), and (2) for which there was a choice between use of a private automobile and public transportation. Trips are included from both cluster and cross-section portions of the survey. It was discovered that in a surprisingly large number of instances the reply to the question, "Is a car necessary in your work?", was "Yes." Trip sample 3 differs from 2 in that trips are excluded if this response was made. Trip sample 4 also excludes trips with associated zero values for time or cost estimates. This was necessary to avoid division by zero where time or cost ratios were included in the set of variables. Trip sample 5 contains an enlarged number of automobile trips; all trips were screened with particular care for consistency of information.

The 14 discriminant functions given in Table 11 have numerical coefficients calculated from the indicated samples of trip data. The variables of each discriminant function were chosen on the assumption that collectively they would provide good discrimination.

Cases 2, 3, and 4 of Table 11 involve the same set of variables, but three different samples of trip data. This set of variables was specifically suggested by the vector-cost assignment model discussed in Chapter Three. Time difference, X_{15}, and cost difference, X_{16}, between alternative journeys to work by public transportation and by private automobile are treated as predictive variables for actual choice of mode in conjunction with the cross products of these variables with automobile ownership, X_1, and income, X_3. The cross products alone (X_{25}, X_{26}, X_{27}, and X_{28}) are the variables in case 1.

The number of passenger cars owned by members of the household to which the worker belongs, X_1; the type of dwelling in terms of single-, double-, or multiple-family occupancy, X_2; household income, X_3; and the cross products between type of dwelling and cost difference, X_{29}, and between type of dwelling and time difference, X_{30}, are introduced as additional variables in case 5.

The variable X_{17} appearing in cases 7, 11, and 13 is intended as a possible discriminator of different levels of comfort and convenience in the three modes of public transportation. This proxy variable is defined as the absolute value of the difference between the index number of the mode actually used in the work trip and the index number of the best alternative mode. For this purpose the

TABLE 9

VARIABLES USED IN CONSTRUCTION OF DISCRIMINANT FUNCTIONS

VARIABLE	DEFINITION
X_1	Number of passenger cars owned by members of household
X_2	Type of dwelling (1, single-family; 2, two-family; 3, multiple-family)
X_3	Category of total household income (0, \$0-1000; 1, \$1,000-2,000; 2, \$2,000-3,000; 3, \$3,000-4,000; 4, \$4,000-5,000; 5, \$5,000-6,000; 6, \$6,000-7,500; 7, \$7,500-10,000; 8, \$10,000-15,000; 9, 15,000 and up)
X_4	Number of persons 16 years or older who are members of household
X_5	Age category of trip maker (1, 16-19 yr; 2, 20-24 yr; 3, 25-29 yr; 4, 30-34 yr; 5, 35-39 yr; 6, 40-44 yr; 7, 45-54 yr; 8, 55-64 yr; 9, 65 yr or older)
X_6	Sex of trip maker (0, male; 1, female)
X_7	Distance from origin to destination (miles)
X_8	Principal mode of travel utilized (1, automobile; 2, train; 3, el-subway; 4 bus)
X_9	General mode of travel utilized (—1, automobile; 1, transit—i.e., train, el-subway, or bus)
X_{10}	Best alternative mode of travel (same indices as X_8)
X_{11}	Cost of trip by mode utilized (\$0.10 units)
X_{12}	Cost of trip by best alternative mode (\$0.10 units)
X_{13}	Time duration of trip by mode utilized (10-min units)
X_{14}	Time duration of trip by best alternative mode (10-min units)
X_{15}	Time difference (time duration of trip by transit minus time duration of trip by automobile, in 3-min units with sign)
X_{16}	Cost difference (transit cost minus auto cost, or $X_{16} = X_9\ (X_{11} - X_{12})$)
X_{17}	Mode difference (transit mode minus auto mode, or $X_{17} = \lvert X_{10} - X_8 \rvert$
X_{18}	Logarithm (base 10) of age code ($X_{18} = \log_{10} X_5$)
X_{19}	Logarithm (natural) of distance ($X_{19} = \ln X_7$)
X_{20}	Relative cost (if $X_9 = 1$, $X_{20} = \ln (X_{12}/X_{11})$; if $X_9 = -1$, $X_{20} = \ln (X_{11}/X_{12})$)
X_{21}	Relative time (if $X_9 = 1$, $X_{21} = \ln (X_{14}/X_{13})$; if $X_9 = -1$, $X_{21} = \ln (X_{13}/X_{14})$)
X_{22}	Income per person where transit cost exceeds auto cost (if $X_{16} < 0$, $X_{22} = \ln (X_3/X_4)$; if $X_{16} \geq 0$, $X_{22} = 0$)
X_{23}	Income per person where auto cost exceeds transit cost (if $X_{16} > 0$, $X_{23} = \ln (X_3/X_4)$; if $X_{16} \leq 0$, $X_{23} = 0$)
X_{24}	Competition for cars within households (if $0 < X_1 < X_4$, $X_{24} = [X_4 \log_{10} (X_3/X_4)]/X_1$; otherwise, $X_{24} = 0$)
X_{25}	Cars times cost difference ($X_{25} = X_1\ X_{16}$)
X_{26}	Cars times time difference ($X_{26} = X_1\ X_{15}$)
X_{27}	Income times cost difference ($X_{27} = X_3\ X_{16}$)
X_{28}	Income times time difference ($X_{28} = X_3\ X_{15}$)
X_{29}	Type of dwelling times cost difference ($X_{29} = X_2\ X_{16}$)
X_{30}	Type of dwelling times time difference ($X_{30} = X_2\ X_{15}$)
X_{31}	Cars times mode difference ($X_{31} = X_1\ X_{17}$)
X_{32}	Type of dwelling times mode difference ($X_{32} = X_2\ X_{17}$)
X_{33}	Income times mode difference ($X_{33} = X_3\ X_{17}$)
X_{34}	Principal mode of travel utilized, with revised bus index (1, automobile; 2, train; 3, el-subway; 6, bus)
X_{35}	Best alternative mode of travel, with revised bus index (same indices as X_{34})
X_{36}	Mode difference; i.e., transit mode minus auto mode, with revised bus index ($X_{36} = \lvert X_{35} - X_{34} \rvert$)
X_{37}	Cars times mode difference, with revised bus index ($X_{37} = X_1\ X_{36}$)
X_{38}	Type of dwelling times mode difference, with revised bus index ($X_{38} = X_2\ X_{36}$)
X_{39}	Income times mode difference, with revised bus index ($X_{39} = X_3\ X_{36}$)

following modal indexes were assigned: 1, private automobile; 2, train; 3, elevated-subway; and 4, bus. This particular set of indexes was chosen as a rough approximation of the relative discomfort and inconvenience likely to be encountered in the use of the modes. The variables X_{31}, X_{32}, and X_{33}, which appear in cases 7, 9, 10, 11, 12, and 13, represent interactions between variable X_{17} and the variables X_1, X_2, and X_3 for car ownership, dwelling type, and family income, respectively.

The variables of case 8 (X_6 and X_{15} through X_{24}) are those found by Warner (*23*) to have the most explanatory value among a larger number which he investigated in his study of modal choice. Warner used the same body of data as that drawn upon here (the CCHD 1956 household survey), but considered choices between particular pairs of modes rather than between private automobile on the one hand and all forms of public transportation on the other.

In cases 9 through 12 of discriminant analysis (Table 11) a set of nine cross-product terms is included among the variables. These cross products represent interactions between three user characteristics (automobile ownership, income, and type of dwelling) and three network characteristics (differences in time, cost, and comfort, the latter by proxy as explained previously) between alternative routes of contrasting mode from a given origin to a given destination. Only the nine interaction terms appear in the equation of case 9. In cases 10, 11, and 12 one additional term appears—the simple cost, time, and "comfort" differences, respectively.

In case 13 the set of variables is identical with that of case 7, but the trip samples differ. The set of variables in case 14 is the same as in cases 7 and 13 with the exception that revised variables X_{36}, X_{37}, X_{38}, and X_{39} are used in place of previous variables X_{17}, X_{31}, X_{32}, X_{33}, respectively. The difference is that the latter variables are defined as functions of the variables X_{34} and X_{35} rather than the variables X_8 and X_{10}. The variables X_{34} and X_{35}, which are associated with actual and alternative modes of travel, take on values 1, 2, 3, and 6 for automobile, train, rail rapid transit, and bus, respectively, whereas the corresponding variables X_8 and X_{10} take on values 1, 2, 3, and 4.

The computations for the 14 cases were carried out using a discriminant-analysis program written at the University of California (*32*).

Statistical properties of the discriminant functions of Table 11 are given in Table 12, including mean values of the discriminant function for transit trips and auto trips, $\bar{Z}_1$ and $\bar{Z}_2$, respectively. The Mahalanobis distance, D^2, is the quantity maximized in the process of computing the coefficients of the discriminant functions and is, as previously stated, a standardized measure of the degree of separation achieved between the two subpopulations from which the discriminant function is derived. The variance ratio, F, for degrees of freedom associated with the numerator and denominator, respectively, is used to test the hypothesis that there is no difference in the mean values of the variables in the two populations. The probabilities, P, of Table 12 correspond to the values of F for the given degrees of freedom on the assumption of normal distributions of the variables. Except for the first two cases, the tests show a high degree of statistical significance ($P < 0.001$).

The comparative performance of the discriminant functions was tested in another way, by using the mean, Z^*, of $\bar{Z}_1$ and $\bar{Z}_2$ as a boundary point such that any observation having a value $Z \geq Z^*$ is classified as a trip by public transportation and any observation having a value $Z < Z^*$ is classified as a trip by private automobile. The results of classifying the sample observations in this way are presented in Table 13, in which the two types of classification errors (i.e., classifying what was in fact an auto trip as a trip by public transportation, and classifying what was in fact a trip by public transportation as an auto trip) are enumerated separately and combined, the latter also being expressed as a percentage of the total number of trips in the sample.

Table 13 also provides a lower limit on the total number of classification errors in the sample data that can be realized given the discriminant function of Table 11 and the freedom to select any value of Z as the boundary point. The minimum error total was found by searching through the values of Z, considering these as possible boundary points, and summing the resulting type 1 and type 2 errors. The minimum error total over all possible boundary points is in all cases not far below the error total using Z^* as the boundary point.

The percentage of classification errors using Z^* as the boundary point shows a surprisingly small range over the first 12 cases, considering the diversity of models and sample sizes. On the criterion of percentage error, case 6, in which (except for case 1) the number of predictive variables is a minimum, actually exhibits one of the best levels of discrimination (23.6 percent errors). The variables of case 6 (automobile ownership, type of dwelling, income, time, and cost differences between modes) are also close to the raw data in the sense of minimum complexity of mathematical transformation.

In cases 13 and 14 the degree of discrimination is markedly better than in the first 12 cases. This appears to be due primarily to the difference between trip sample 5 and the other trip samples rather than to differences between models. This conclusion is based on the fact that the mathematical model is identical in cases 7 and 13, although the trip samples differ, the model being applied to trip sample 3 in the former case and to trip sample 5 in the latter. The value of D^2 (Mahalanobis distance) is 4.05 in case 13 as compared with 2.03 in case 7. The latter is the largest value of D^2 among the first 12 cases. The percentage of classification errors is 14.3 in case 13 as compared with 22.3 in case 7. The degree of discrimination achieved in case 14 is about as good as in case 13. The value of D^2 is 4.06 and the percentage of classification errors is 14.8. Particular care was taken in selecting trip sample 5 to eliminate all trips with apparent coding errors or inconsistensies. This sample also differs from the others in that the number of automobile trips is larger than the number of transit trips by about a factor of 2.

TABLE 10

TRIP SAMPLES USED IN CONSTRUCTION OF DISCRIMINANT FUNCTIONS [a]

TRIP SAMPLE	DESCRIPTION
1	25 Auto trips and 25 transit trips; sample used primarily to check computational procedures
2	235 Auto trips and 235 transit trips
3	235 Auto trips and 235 transit trips; trips excluded where a car was stated to be necessary in person's work
4	180 Auto trips and 180 transit trips; trips excluded where a car was stated to be necessary in person's work or there were zero cost or time estimates
5	298 Auto trips and 142 transit trips; "car necessary" trips excluded; all doubtful cards removed (e.g., other than 1-4 in Col. 10, other than 0 or 1 in Col. 14, transit riders who said car was necessary, etc.)

TABLE 11
DISCRIMINANT FUNCTIONS

CASE	TRIP SAMPLE	DISCRIMINANT FUNCTION WITH COEFFICIENTS OF THE SPECIFIED VARIABLES CALCULATED FROM SAMPLE DATA
1	1	$Z = -5.4 \times 10^{-4} X_{25} + 7.74 \times 10^{-3} X_{26} - 8.7 \times 10^{-4} X_{27} - 9.7 \times 10^{-4} X_{28}$
2	1	$Z = 8.05 \times 10^{-3} X_{15} - 1.70 \times 10^{-2} X_{16} + 2.44 \times 10^{-3} X_{25} + 7.55 \times 10^{-3} X_{26} + 2.88 \times 10^{-3} X_{27} - 3.13 \times 10^{-3} X_{28}$
3	2	$Z = -6.7 \times 10^{-4} X_{15} - 4.5 \times 10^{-4} X_{16} + 6 \times 10^{-5} X_{25} - 3.5 \times 10^{-4} X_{26} + 2 \times 10^{-5} X_{27} + 1.2 \times 10^{-4} X_{28}$
4	3	$Z = -1.3 \times 10^{-3} X_{15} - 7.5 \times 10^{-4} X_{16} + 8 \times 10^{-5} X_{25} - 4 \times 10^{-4} X_{26} + 4 \times 10^{-5} X_{27} + 2.3 \times 10^{-4} X_{28}$
5	3	$Z = -2.89 \times 10^{-3} X_{1} - 6.3 \times 10^{-4} X_{2} + 1.02 \times 10^{-3} X_{3} - 9.9 \times 10^{-4} X_{15} - 8.6 \times 10^{-4} X_{16} - 8 \times 10^{-5} X_{25} - 8 \times 10^{-5} X_{26} + 1.0 \times 10^{-4} X_{27} + 1.1 \times 10^{-4} X_{28} - 4 \times 10^{-5} X_{29} + 2 \times 10^{-5} X_{30}$
6	3	$Z = -2.76 \times 10^{-3} X_{1} - 4.0 \times 10^{-4} X_{2} + 1.00 \times 10^{-3} X_{3} - 3.2 \times 10^{-4} X_{15} - 3.4 \times 10^{-4} X_{16}$
7	3	$Z = 4.9 \times 10^{-4} X_{1} - 1.79 \times 10^{-3} X_{2} + 5 \times 10^{-5} X_{3} - 9.0 \times 10^{-4} X_{15} - 7.8 \times 10^{-4} X_{16} - 2.36 \times 10^{-3} X_{17} + 0.0 \times 10^{-4} X_{25} - 1 \times 10^{-5} X_{26} + 9 \times 10^{-5} X_{27} + 1.0 \times 10^{-4} X_{28} - 5 \times 10^{-5} X_{29} - 2 \times 10^{-5} X_{30} - 1.29 \times 10^{-3} X_{31} + 4.8 \times 10^{-4} X_{32} + 3.4 \times 10^{-4} X_{33}$
8	4	$Z = 5.12 \times 10^{-3} X_{6} - 5.32 \times 10^{-4} X_{18} + 8.93 \times 10^{-4} X_{19} + 4.20 \times 10^{-3} X_{20} + 5.53 \times 10^{-3} X_{21} + 2.09 \times 10^{-3} X_{22} + 7.72 \times 10^{-3} X_{23} - 6.67 \times 10^{-5} X_{24}$
9	3	$Z = -3.10 \times 10^{-5} X_{25} - 3.70 \times 10^{-5} X_{26} - 9.03 \times 10^{-6} X_{27} - 1.07 \times 10^{-5} X_{28} - 1.36 \times 10^{-4} X_{29} - 1.25 \times 10^{-4} X_{30} - 1.11 \times 10^{-3} X_{31} - 3.19 \times 10^{-4} X_{32} + 2.93 \times 10^{-4} X_{33}$
10	3	$Z = -5.4 \times 10^{-4} X_{16} - 1.0 \times 10^{-5} X_{25} - 3.0 \times 10^{-5} X_{26} + 4.0 \times 10^{-5} X_{27} - 1.0 \times 10^{-5} X_{28} - 5.0 \times 10^{-5} X_{29} - 1.4 \times 10^{-4} X_{30} - 1.14 \times 10^{-3} X_{31} - 2.5 \times 10^{-4} X_{32} + 3.3 \times 10^{-4} X_{33}$
11	3	$Z = -2.23 \times 10^{-3} X_{17} - 4.0 \times 10^{-5} X_{25} - 5.0 \times 10^{-5} X_{26} + 0.0 \times 10^{-4} X_{27} + 0.0 \times 10^{-4} X_{28} - 1.3 \times 10^{-4} X_{29} - 1.4 \times 10^{-4} X_{30} - 1.03 \times 10^{-3} X_{31} - 9.0 \times 10^{-5} X_{32} + 4.0 \times 10^{-4} X_{33}$
12	3	$Z = -1.28 \times 10^{-3} X_{15} - 3.0 \times 10^{-5} X_{25} - 0.0 \times 10^{-4} X_{26} - 0.0 \times 10^{-4} X_{27} + 1.4 \times 10^{-4} X_{28} - 1.4 \times 10^{-4} X_{29} + 8.0 \times 10^{-5} X_{30} - 1.14 \times 10^{-3} X_{31} - 4.5 \times 10^{-4} X_{32} + 1.9 \times 10^{-4} X_{33}$
13	5	$Z = 1.02 \times 10^{-3} X_{1} - 7.33 \times 10^{-3} X_{2} - 1.90 \times 10^{-4} X_{3} + 3.1 \times 10^{-4} X_{15} - 1.01 \times 10^{-3} X_{16} - 1.133 \times 10^{-2} X_{17} + 2.3 \times 10^{-4} X_{25} - 9 \times 10^{-5} X_{26} + 4 \times 10^{-5} X_{27} - 2 \times 10^{-5} X_{28} - 2.0 \times 10^{-4} X_{29} - 3.9 \times 10^{-4} X_{30} - 7.3 \times 10^{-4} X_{31} + 2.75 \times 10^{-3} X_{32} + 7.4 \times 10^{-4} X_{33}$
14	5	$Z = 1.43 \times 10^{-3} X_{1} - 5.12 \times 10^{-3} X_{2} - 1.08 \times 10^{-3} X_{3} + 9 \times 10^{-5} X_{15} - 1.06 \times 10^{-3} X_{16} + 2.5 \times 10^{-4} X_{25} - 2 \times 10^{-5} X_{26} + 5 \times 10^{-5} X_{27} - 2 \times 10^{-5} X_{28} - 2.0 \times 10^{-4} X_{29} - 3.4 \times 10^{-4} X_{30} - 6.3 \times 10^{-4} X_{37} + 1.16 \times 10^{-3} X_{38} + 2.8 \times 10^{-4} X_{39} - 4.28 \times 10^{-3} X_{36}$

TABLE 12
STATISTICAL PROPERTIES OF DISCRIMINANT FUNCTIONS

CASE	SAMPLE MEAN: TRANSIT TRIPS $\overline{Z}_1$	SAMPLE MEAN: AUTO TRIPS $\overline{Z}_2$	MAHALANOBIS DIST., D_2	SIGNIFICANCE OF VARIANCE RATIO: DEG. OF FREEDOM	VARIANCE RATIO, F	PROB., P
1	0.00875	—0.00956	0.879	4 and 45	2.57	$0.2 > P > 0.1$
2	0.00992	—0.01246	1.074	6 and 43	2.00	$0.2 > P > 0.1$
3	0.00066	—0.00159	1.051	6 and 463	20.37	$0.001 > P$
4	0.00137	—0.00211	1.629	6 and 463	31.55	$0.001 > P$
5	0.00314	—0.00100	1.935	11 and 458	20.23	$0.001 > P$
6	0.00360	0.00005	1.661	5 and 464	38.70	$0.001 > P$
7	—0.00312	—0.00746	2.032	15 and 454	15.44	$0.001 > P$
8	0.00815	0.00289	1.882	8 and 351	20.76	$0.001 > P$
9	0.00107	—0.00238	1.617	9 and 460	20.75	$0.001 > P$
10	0.00198	—0.00161	1.681	10 and 459	19.38	$0.001 > P$
11	—0.00179	—0.00559	1.782	10 and 459	20.54	$0.001 > P$
12	—0.00105	—0.00501	1.857	10 and 459	21.40	$0.001 > P$
13	—0.02391	—0.03316	4.050	15 and 424	25.14	$0.001 > P$
14	—0.01259	—0.02185	4.057	15 and 424	25.18	$0.001 > P$

TABLE 13

COMPARATIVE PERFORMANCE OF DISCRIMINATE FUNCTIONS

		MEAN, Z^*, OF $\overline{Z}_1$ AND $\overline{Z}_2$ AS BOUNDARY POINT					MINIMUM ERROR TOTAL OVER ALL POSSIBLE BOUNDARY POINTS	
			ERRORS OF MODE CLASSIFICATION					
CASE	TOTAL NO. OF TRIPS	BOUNDARY POINT $(\overline{Z}_1 + \overline{Z}_2)/2$	TRANSIT TRIPS	AUTO TRIPS	TOTAL	%	TOTAL	%
1	50	—0.00405	6	9	15	30.0	14	28.0
2	50	—0.00127	7	8	15	30.0	13	26.0
3	470	—0.000465	65	80	145	30.9	136	28.9
4	470	—0.00037	44	68	112	23.8	108	23.0
5	470	0.00107	43	60	103	21.9	102	21.7
6	470	0.001825	35	76	111	32.6	105	22.3
7	470	—0.00529	42	63	105	22.3	103	21.9
8	360	0.00552	44	45	89	24.7	87	24.2
9	470	—0.000655	54	68	122	30.0	120	25.5
10	470	0.000185	58	64	122	30.0	117	24.9
11	470	—0.00369	46	67	113	24.0	108	23.0
12	470	—0.00303	45	67	112	23.8	105	22.3
13	440	—0.02854	25	38	63	14.3	60	13.6
14	440	—0.01722	27	38	65	14.8	62	14.1

CHAPTER SEVEN

COMPARISON OF REPORTED TRAVEL TIMES IN THE CHICAGO AREA WITH TIMES COMPUTED FROM NETWORK MODELS

TIME AS A FACTOR INFLUENCING TRAVEL DECISIONS

The time taken to complete a journey from one place to another is a central fact of travel. Time minimization appears to be a key objective in a large proportion of travel decisions. The importance of this factor in the weighing of travel alternatives is brought out in various bodies of survey data both by the correlation between time advantage of travel facilities and greater frequency of use, and by direct testimony of travelers. The data from the transportation use study of the Cook County Highway Department, treated in Chapters Five and Six, are evidence in point. Furthermore, time as a physical variable can be measured on a standard scale. To obtain detailed and quantitative information on time as a factor in choices among travel alternatives, and to relate experience of users to data on the transportation network that is available to them, were then desirable objectives from the point of view of the present project.

A fundamental question concerns the degree of correspondence between minimum-path time calculations, carried out in terms of network models, and observed or reported values for elapsed times of trips through the actual transportation networks. To throw light on this question, an analysis of reported and computed times between selected pairs of zones in the Chicago metropolitan area was undertaken.

NETWORK MODELS

In this investigation representations of the 1956 Chicago public transportation (transit) and private automobile (arterial) networks, developed by the Chicago Area Transportation Study, constitute the network models.

It should be emphasized that the purposes to which the network data are put here differ from the original purposes. The aim herein is to relate travel times reported by users of the system to the path values computed from the link descriptions, treating these path values as estimates of actual travel times. In this way an attempt can be made to establish comparability of time estimates for different transportation modes, to obtain reasonably reliable time estimates where direct empirical data are absent, and to strengthen the basis for measuring the influence of differences in travel time on mode choice. On the other hand, the primary aim of CATS in developing link and path values has been to achieve realistic volumes of travel through the network. Reasons why considerable differences between reported and computed times are to be expected are discussed in the last section of this chapter.

COMPUTATION OF MINIMUM-TIME PATHS

By means of a sequence of computer programs prepared for this purpose, the information describing the 1956 Chicago transit and arterial networks was converted from the original format used by CATS to the format used by the Bureau of Public Roads. The BPR tree-building program could then be utilized to compute minimum-time paths through the transit and arterial networks for comparison with reported trips. The origin and destination nodes of each trip are identified with centroids of zones; hence, the computed times are for interzonal travel. Times were computed in minutes.

TRIP DATA

The sources of trip information for this investigation are home interviews conducted separately in 1956 by CATS and by the Cook County Highway Department.

In both the CATS and the CCHD home-interview data the elapsed time is among the items of information describing each trip. Elapsed times of CATS trips are arrival times minus departure times (the elapsed times were not asked for directly). Elapsed times of CCHD trips were reported as such (departure and arrival times were also reported as separate items of information). Travel time in the CATS home-interview data is coded in 6-min units (tenths of hours). Travel time in the CCHD home-interview data is coded in 10-min units (difference in travel time between actual and alternative trips is coded in 3-min units). In the analyses that follow, the midpoints of the coded time intervals are taken as the reported values. The elapsed time reported for a trip can be compared with the elapsed time along the minimum-time path connecting the corresponding pair of nodes as computed in the process of tree construction. To achieve the correspondence in practice, origins and destinations within zones are mapped into the zone centroids.

The CATS file of first work trips to the Central Area of Chicago (Districts 01 and 11), which is a subset of the complete 1956 trip file, was transcribed from cards to magnetic tape. The trips were then sorted by zone of destination within zone of origin. Information on all trips satisfying the following three conditions was printed out: (1) The zone of destination was in the Central Business District—i.e., the Loop (district 01, equivalent to ring 0, made up of zones 01001 through 01004); (2) The zone of origin was in ring 6 or 7, these being the two outermost rings within the CATS cordon line; (3) Nine or more other trips were recorded having the same zone of origin and the same zone of destination as the given trip. Trip mode was disregarded in making the selection. As a whole, this is designated trip sample 1.

There are 22 pairs of zones with trips satisfying the stated conditions. Among these, there are 16 different origin zones in various locations within rings 6 and 7, while three of the four Loop zones (01001, 01002, and 01004) appear as destinations. The Loop zones are each approximately 0.25 sq mi in area. Of the 16 outer zones represented, two are approximately 1 sq mi and 14 are approximately 4 sq mi in area. The average geographical distance from the Loop is 16 mi for ring 6 and 24 mi for ring 7. The trips by automobile, by railroad, and by rapid transit (elevated-subway) in trip sample 1 were segregated for the purpose of comparison with computed paths; the three subsamples are designated trip samples 1a, 1b, and 1c, respectively.

A subset of trips from the CCHD trip file was selected as follows. Zones of origin and destination of work trips in the CCHD file were determined from the street-address codes. These trips were then sorted by zone of destination within zone of origin and the information on the trips was printed out. For each of the five home-interview cluster samples, that zone was identified which contains the largest portion (as it turned out, all or nearly all) of the sample dwellings. The five zones are 41096, 43125, 46152, 52205, and 76561. The first four zones are within the City of Chicago, in rings 4 and 5, and each has an area of 4 sq mi. Zone 76561 is in ring 7 and has an area of 4 sq mi. All trips satisfying the following conditions were selected for analysis: (1) The origin was in one of the five cluster-sample zones; (2) The destination was not in the zone of origin or in a zone immediately adjacent to it. As a whole, this is designated trip file 2. Trip sample 2a consists of automobile trips from this file, sample 2b consists of railroad trips, sample 2c consists of elevated-subway trips, and sample 2d consists of bus trips.

COMPARISON OF REPORTED AND COMPUTED TRAVEL TIMES USING VARIOUS TRIP SAMPLES

Comparisons were made between reported and computed travel times using the seven trip samples described in the foregoing. The results of the comparisons are summarized in Table 14.

Automobile Trips

The average computed time was somewhat less than the average reported time for both samples of automobile trips. The average difference between reported and computed times for 40 trips from the CATS file (sample 1a) was 4.9 ± 2.1 min, whereas the average difference for 95 trips from the CCHD file (sample 2a) was 6.1 ± 0.8 min.

Railroad Trips

The average computed time was considerably greater than the average reported time for both samples of railroad trips. The average difference between computed and reported times for 215 trips from the CATS file (sample 1b) was 20.9 ± 1.1 min, whereas the average difference for 19 trips from the CCHD file (sample 2b) was 37.1 ± 3.8 min.

Elevated-Subway Trips

The average computed time was again considerably larger than the average reported time for both trip samples. The average differences between computed and reported times for 18 trips from the CATS file (sample 1c) was 20.2 ± 2.8 min, whereas the average difference for 15 trips from the CCHD file (sample 2c) was 9.8 ± 2.2 min.

TABLE 14

COMPARISONS BETWEEN REPORTED AND COMPUTED TRAVEL TIMES BY AUTOMOBILE AND BY PUBLIC TRANSPORTATION [a]

COMPARISON	NO. OF TRIPS	REPORTED TIME (MIN) TRIP SAMPLE	REPORTED TIME (MIN) MEAN	COMPUTED TIME (MIN) NETWORK	COMPUTED TIME (MIN) MEAN	REPORTED MINUS COMPUTED TIME (MIN) MEAN ± STD. ERROR	REPORTED MINUS COMPUTED TIME (MIN) STD. DEV.
1	40	(1a) CATS, auto	64.5	CATS Arterial	59.6	4.9 ± 2.1	13.2
2	215	(1b) CATS, railroad	62.2	CATS Transit	83.1	−20.9 ± 1.1	16.1
3	18	(1c) CATS, el-subway	54.7	CATS Transit	74.9	−20.2 ± 2.8	12.1
4	95	(2a) CCHD, auto	29.4	CATS Arterial	23.3	6.1 ± 0.8	8.1
5	19	(2b) CCHD, railroad	68.7	CATS Transit	105.8	−37.1 ± 3.8	16.5
6	15	(2c) CCHD, el–subway	38.3	CATS Transit	48.1	− 9.8 ± 2.2	8.7
7	33	(2d) CCHD, bus	41.4	CATS Transit	42.1	− 0.7 ± 2.1	12.1

[a] 1956 data from Chicago Area Transportation Study and Cook County Highway Department.

Bus Trips

A sample of bus trips was present in file 2 (but not in file 1 because of the distance between rings 6 and 7 and the central area). The average computed time was slightly larger than the average reported time for 33 bus trips from the CCHD file (sample 2d). The average difference between computed and reported times was 0.7 ± 2.1 min, not statistically significant.

EXTENDED COMPARISON OF REPORTED AND COMPUTED TRAVEL TIMES FOR TRIPS BY PUBLIC TRANSPORTATION

The comparisons with interview data summarized in the preceding section indicated that the computed times for the transit network were in many instances considerably greater than the average travel times reported by the commuters traveling the routes. The agreement between reported and computed travel times by automobile, on the other hand, was relatively good. A further study, the results of which are reported here, was undertaken to examine in more detail the relationships between reported and computed times by public transportation.

The trip data consist of an enlarged sample from the 1956 CATS file of first work trips to the Central Area of Chicago. All pairs of zones were included in this study which have ten or more trips between them by all modes of transportation. There is a sufficient number of these trips to provide reliable measures of variability as well as average travel times. All three modes of public transportation are well represented.

The data were first screened by examination of individual trip records. The purpose of the screening was to eliminate questionable data (for example, the respondent who took 9 hr to travel 2 mi). Error correction was not possible, because the original interview forms were not available. Of the 5,309 public-transportation trips examined, 19 (0.36 percent) were excluded as obviously erroneous. Next, the trips were classified by zone pair, principal mode, and reported travel time. The zone numbers serve to identify also the larger area units—districts, sectors, and rings. The corresponding travel times computed from the CATS 1956 transit network model were then entered. A separate analysis of variance, and corresponding mean travel times, were computed for each ring-mode combination. The sources of variation identified in each analysis of variance were (1) individual trips within zone pairs, (2) zone pairs within sectors, and (3) sectors.

The results, in terms of mean travel times, are presented in Table 15. The variances among trips of the same mode and having both a common origin zone and a common destination zone are given in Table 16. On the whole, the earlier findings are confirmed and extended. The computed travel times are consistently greater than the average reported times. Only once in 16 ring-mode analyses of variance did the mean computed travel time fall within the 95 percent confidence limits for the mean reported time, and in this instance there were only 14 trips (from ring 5 to the Central Area by bus). In all other instances the mean computed time was significantly greater than the mean reported time. The magnitudes of the differences between reported and computed times are, however, far from uniform. Railroad computed and reported times differ by the largest amount; elevated-subway times differ by less; while bus times are in closest agreement. Furthermore, the differences for railroad and bus times are relatively constant from ring to ring, but the differences for elevated-subway times appear to increase with increasing distance from the Central Area.

DISCUSSION

On the whole, the computed and reported times for automobile and bus trips are quite close. There are greater differences in the times for rail trips.

Some of the reasons why a close agreement between times computed from the network models and reported times would not be expected have been brought out in discussions and correspondence with E. Wilson Campbell of the Chicago Area Transportation Study, as follows: (1) In the network models all the trips from a zone are generated at one point (the load node), generally near

TABLE 15

MEAN REPORTED AND COMPUTED TRAVEL TIMES BY PUBLIC TRANSPORTATION FOR WORK TRIPS TO CENTRAL AREA OF CHICAGO (DISTRICTS 01 AND 11)[a]

RING OF TRIP ORIGIN	RAILROAD			ELEVATED-SUBWAY			BUS		
	NO. OF TRIPS	MEAN TRAVEL TIME (MIN)		NO. OF TRIPS	MEAN TRAVEL TIME (MIN)		NO. OF TRIPS	MEAN TRAVEL TIME (MIN)	
		REPORTED	COMPUTED		REPORTED	COMPUTED		REPORTED	COMPUTED
1	—	—	—	44	24.4	28.3	468	22.2	23.4
2	—	—	—	354	33.8	38.1	807	32.0	33.8
3	141	29.9	45.5	761	36.7	44.3	606	39.6	41.6
4	338	40.7	53.5	1008	44.4	52.7	298	47.7	51.5
5	142	43.9	58.4	52	50.0	58.8	14	57.4	58.7
6	144	55.0	70.2	19	53.4	68.1	—	—	—
7	92	70.8	88.9	—	—	—	—	—	—

[a] Based on 1956 trip and network data of Chicago Area Transportation Study.

the center of the zone, and likewise are terminated at single points within the destination zones. The points chosen may not coincide with the centers of trip-end populations. Furthermore, if the trip sample is small, as it generally will be, the average reported times may vary rather widely around the true mean. (2) Travel times in the 1956 network models are considered representative of average times in a 24-hr day. Actual trips will have occurred at specific times during the day. (3) Close agreement between reported and computed times for railroad trips is especially unlikely because of the extreme variation of times in scheduled railroad runs. CATS calculated all railroad link values on the basis of an average speed of 30 mph. A specific reported trip time may be considerably different from the computed time. (4) Terminal friction times are included in the transit network. These terminal times represent average walk and wait times during a 24-hr day. The terminal times also serve to prevent short and unrealistic trips by rail. By most standards, a 15-min friction time at the beginning of a railroad trip and a 10-min friction time at the beginning of an elevated-subway trip would be considered high. However, in the "fine tuning" of the transit assignment procedure the best comparison with known transit travel patterns was obtained by using these values.

TABLE 16

VARIANCE OF REPORTED TRAVEL TIMES FOR TRIPS HAVING BOTH A COMMON ORIGIN ZONE AND A COMMON DESTINATION ZONE; WORK TRIPS TO CENTRAL AREA BY PUBLIC TRANSPORTATION[a]

MODE	DEG. OF FREEDOM	VARIANCE	STD. DEV. (MIN)
Railroad	715	134.424	11.59
El.-subway	1903	96.804	9.84
Bus	1820	127.368	11.29

[a] 1956 data of Chicago Area Transportation Study.

CHAPTER EIGHT

INVESTIGATION OF ACCESSIBILITY RATIOS IN RELATION TO MODAL SPLIT, DATA FROM CATS

The accessibility ratio, as defined by Schofer and Voorhees (*9*) or in modified form, has recently been used or proposed as a predictor of modal split for several urban areas. Associated with each zone is a measure of the accessibility to all other zones by means of, first, the private automobile and, second, the mass transit networks. The proportion of the total trips originating in each zone which will be transit trips is then estimated as a function of the ratio of transit accessibility to automobile accessibility. The relationship between accessibility ratios and modal split was investigated in the present project using data from the Chicago area.

METHOD

A measure of accessibility, A_{ik}, of zone i to a set of other zones, indexed by j, when using travel mode k, is defined as follows:

$$A_{ik} = \Sigma_j (e_j / t_{ijk}^2) \qquad (10)$$

in which e_j is the total number of trips ending in zone j, regardless of mode, and t_{ijk} is the minimum travel time from zone i to zone j using mode k. If there are two alternative modes of travel (i.e., $k = 1$ or $k = 2$), it is reasonable to suppose that the value of the accessibility ratio for zone i, A_{i1}/A_{i2}, will be related to the proportion of trips from zone i that use mode 1 rather than mode 2. Presumably, the higher this ratio, the more attractive the transit network should appear to the traveler as an alternative to the automobile network.

APPLICATION

Accessibility ratios so defined, with mode 1 identified as public transportation and mode 2 identified as automobile transportation, were computed for the traffic zones into which the Chicago area has been divided (CATS analysis zones). First, the zone-to-zone travel times for all pairs of zones were computed both by way of the arterial network and by way of the transit network; the basic link travel times underlying these calculations were taken from the CATS 1956 network descriptions. The minimum-path trees were constructed by use of BPR program PR-1. In order to obtain travel-time estimates with the desired accuracy (to the nearest minute or better) it was necessary to write a new computer program to skim and format trees. The computer program ACCESS was written and used to compute accessibility measures, A_{ik}, for all zones and both modes. The ratio of transit accessibility to automobile accessibility, A_{i1}/A_{i2}, was then formed for each zone i. Also found for each zone from the 1956 CATS survey data (CATS Table 71, "Internal Trip Zone of Destination Summary with Factored Trips Spread by Priority Mode") was the percentage of the total person trips by public or private vehicles that involved use of public vehicles; i.e., transit person trips as a percentage of all vehicular person trips.

RESULTS

A plot of the percentage of person trips by transit vs the accessibility ratio as defined in the foregoing is shown in Figure 10 for 568 Chicago-area traffic zones having computable accessibility ratios (some of the X's represent more than one zone). It had been anticipated that there might be a relatively strong positive correlation between the two variables; if so, the accessibility ratio might prove valuable as a predictor of modal choice. The scattered distribution of the observations as plotted in Figure 10 indicates, however, that in the data at hand there is no clear evidence of a relationship between accessibility ratio and actual modal choice that might be useful for predictive purposes. The coefficient of correlation between the two variables is −0.294 which, for 568 cases, is a significantly negative value rather than the anticipated positive value. The proportion of transit trips averaged over the 568 zones was 15.5 percent.

A similar analysis was made excluding all zones for which the reported proportion of transit trip ends was zero. The correlation between percentage of trips by transit and the accessibility ratio was −0.258 for the 521 zones meeting the criterion. Again, the correlation is small but significantly negative. The proportion of transit trips averaged over these zones was 16.9 percent.

Separate plots of the type shown in Figure 10 were also made for all zones falling within rings 3, 4, 5, 6, and 7, which are at successively greater distances from the central business district of Chicago. There is no indication of a useful functional relationship between the accessibility ratio and the proportion of trips by transit in any of these plots.

Other measures of accessibility than the one applied in this investigation have been, or might be, proposed. The absence of even modest positive correlations between the accessibility ratio and degree of transit use in the present study did not encourage attempts at further refinement along these lines.

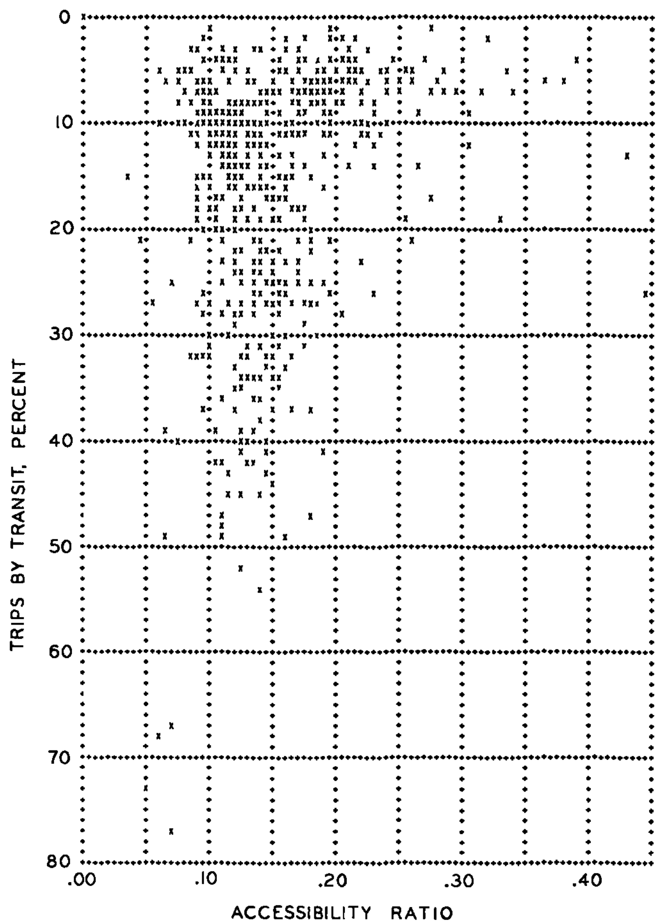

Figure 10. Plot of percentage of vehicular trips in which public transportation was used vs the accessibility ratio (transit accessibility/arterial accessibility) for 568 Chicago zones. Based on 1956 person-trip and network data from the Chicago Area Transportation Study.

CHAPTER NINE

IITRI WORK-TRIP SURVEY

BACKGROUND AND MOTIVATION

A survey of travel between place of residence and place of work was carried out with the cooperation of staff members of IIT Research Institute for the purpose of gaining additional knowledge and insight concerning factors affecting choices among transportation alternatives in an urban environment. The survey was specifically designed to throw light on questions of importance from the point of view of the present project. The information obtained in this way either was not available elsewhere or was required for testing relationships found in other bodies of data.

The decision to proceed with the survey was reached only after completion of the first stage of the project, in which a number of other sources of data were investigated, and after carefully weighing the advantages and disadvantages.

The physical location of the main research facilities and offices of IITRI is well suited to an urban transportation study of the type undertaken. The group of buildings, including a new 20-story research tower occupied in 1965, is situated at the northwest corner of the intersection of State and 35th Streets on the near south side of Chicago. The location is at the southern end of IIT Center, a 27-block area devoted to education and research, which is also the site of Illinois Institute of Technology, The Institute of Gas Technology, The Association of American Railroads Research Center, and The John Crerar Library. IIT Center extends from 30th Street on the north to 35th Street on the south and from Michigan Avenue on the east to the Dan Ryan Expressway on the west. The origin of the street numbering system for Chicago, the intersection of State and Madison Streets in the heart of the Chicago central business district or Loop, is 3.5 mi due east. The population of the city of Chicago, which occupies 224 sq mi, is approximately 3.5 million; the population of the Chicago Standard Metropolitan Statistical Area, with an area of 3,714 sq mi, is approximately 6.2 million (1960 census data).

An extensive network of road and rail transportation facilities serves the Chicago area. Locations of expressways and tollways are shown in Figure 11. Locations of rail lines—elevated-subway and commuter railroad—are shown in Figure 12. There are access points to major facilities for travel by either public or private vehicles in IITRI's immediate vicinity. Entrance and exit ramps for both northbound and southbound automobile travel on the Dan Ryan Expressway connect with 35th Street about 0.2 mi west of State Street. Other expressways serving the Chicago area—Calumet, Stevenson, Eisenhower, Kennedy, etc.—can be reached via the Dan Ryan. Lake Shore Drive can be entered or exited at 31st Street (0.5 mi north of 35th Street) at a point 1 mi east of State Street. The system of local and arterial streets can be utilized for automobile travel either exclusively or in combination with expressway segments. Free parking for IITRI employees is available in the block extending from State Street east to Wabash and from 35th Street north to 34th.

The 35th Street station on the north-south rapid-transit (elevated-subway) rail line is about half a block (0.08 mi) west of State Street on 35th Street. All trains stop at this station, which was recently rebuilt with installation of an escalator connecting the elevated platform with the ground level. The elevated tracks actually bisect the IITRI parking lot.

Bus routes run both north and south along State Street (No. 36A and Express, the latter using the Dan Ryan Expressway in part) and east and west along 35th Street (No. 35). The entire network of rapid transit and bus lines operated within Chicago by the Chicago Transit Authority is accessible on a uniform fare basis. With some exceptions, the fare is $0.25 without transfers and $0.30 if one or more transfers are made.

Commuter railroad lines (Chicago and North Western, Milwaukee, Burlington, Rock Island, Illinois Central) radiate outward from stations located in and around the Chicago central business district. Access to these railroads from IITRI requires use of other modes of travel, usually rapid transit in combination with bus or walking. Commuter railroad fares vary with distance and with other factors reflected in the fare structures of the different companies.

In evaluating the desirability of carrying out a travel survey, it was considered essential to relate any new data on actual travel behavior to properties of the transportation system as well as to characteristics of the travelers and the spatial distribution of activities. An important point in favor of a survey of the type under consideration was the availability of information on the Chicago transportation networks, as developed by the Chicago Area Transportation Study. Network data as of 1956 had already been obtained from CATS for the purposes of the present project, and travel paths had been constructed which could be compared with reported paths. Also, an updated description of the Chicago arterial or automobile network, as of 1965, was in course of preparation by CATS. Correspondence could thus be established between travel opportunities and actual travel over a wide area in and around Chicago.

In summary, the location of IIT Research Institute, near the center of one of the largest metropolitan areas of the country, served by all the major modes of urban transportation, gave rise to the possibility of an informative study of factual aspects of travel to and from work by staff mem-

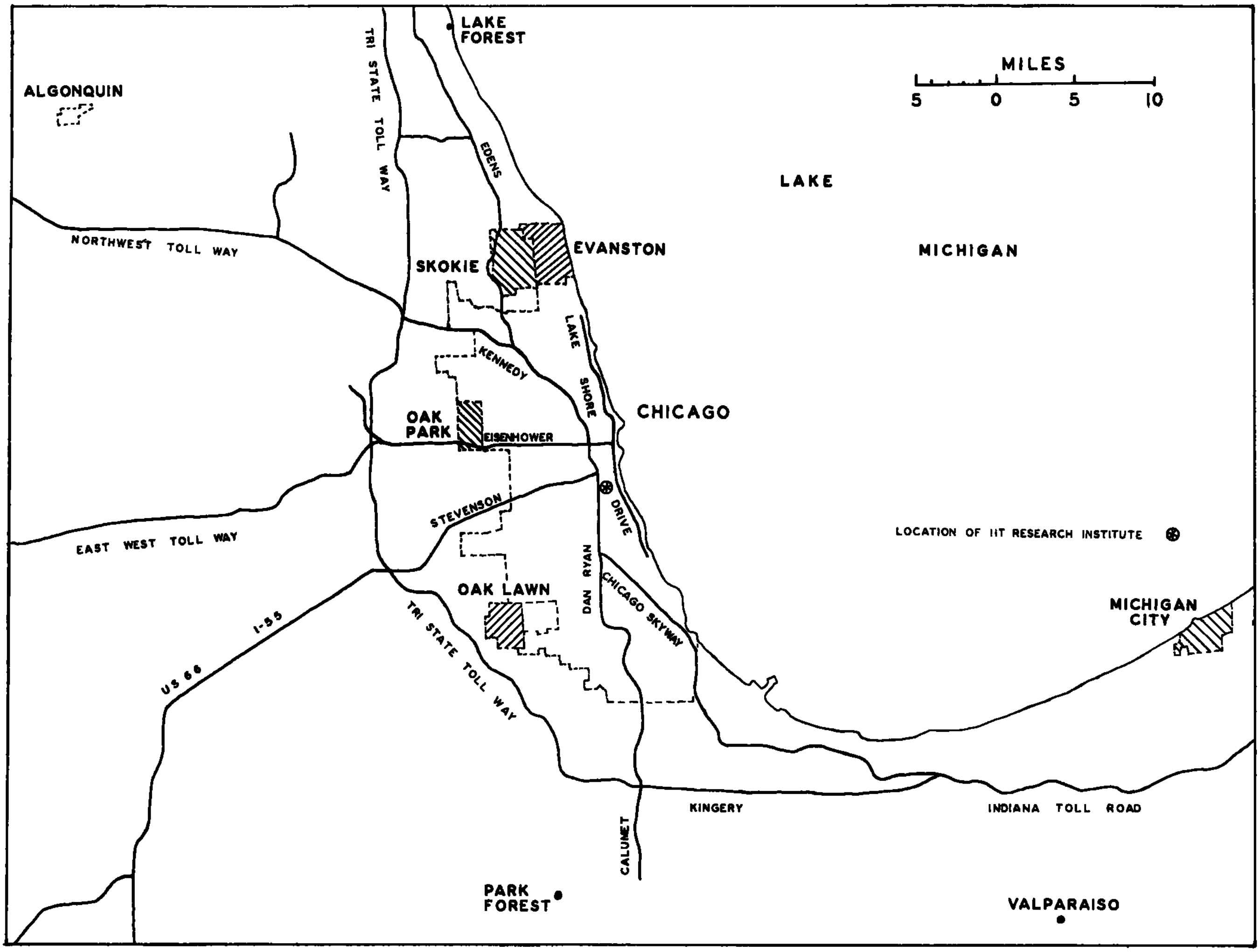

Figure 11. Expressways and tollways in the Chicago area, 1965.

bers, and of the factors influencing their travel decisions, in the light of the travel opportunities open to them.

It was recognized that in some important respects the resulting information would be limited. The sample size would be relatively small, the sample would not be randomly selected from the urban community as a whole, and the survey would be restricted to one category of trips; i.e., work trips. In spite of these limitations, it was considered that the results could be well worth the effort. Alternative modes and routes of travel between home and work, with various advantages and disadvantages that make them truly competitive, are available to a large proportion of staff members. Because of the largely scientific and technical orientation of the staff, it was confidently expected that relatively accurate information would be provided. The repetitive nature of work trips, and the fact that they usually require a significant expenditure of time and energy in the course of a busy day, is cause for serious reflection by each individual on the range of possibilities that are open to him. It was the intent in proposing a survey at IITRI to draw on the knowledge, experience, and judgment of the staff as a basis for an analysis in some depth of factors that are important in the choices actually made by a group of users of a complex of urban transportation facilities.

Permission to conduct the survey by means of a questionnaire to be distributed to individual staff members was obtained from the IITRI administration prior to detailed planning. It was made clear that the data so obtained would be used only for the purposes of this project and that there would be no identification of individuals contributing information. Response would be on a purely voluntary basis.

QUESTIONNAIRE DESIGN

The set of questions to be asked, and the method of presentation, were objects of discussion and experimentation over a period of several months. To aid in designing a questionnaire that would elicit a maximum of cogent data without placing excessive demands on the time of IITRI staff members, a review was made of kinds of information

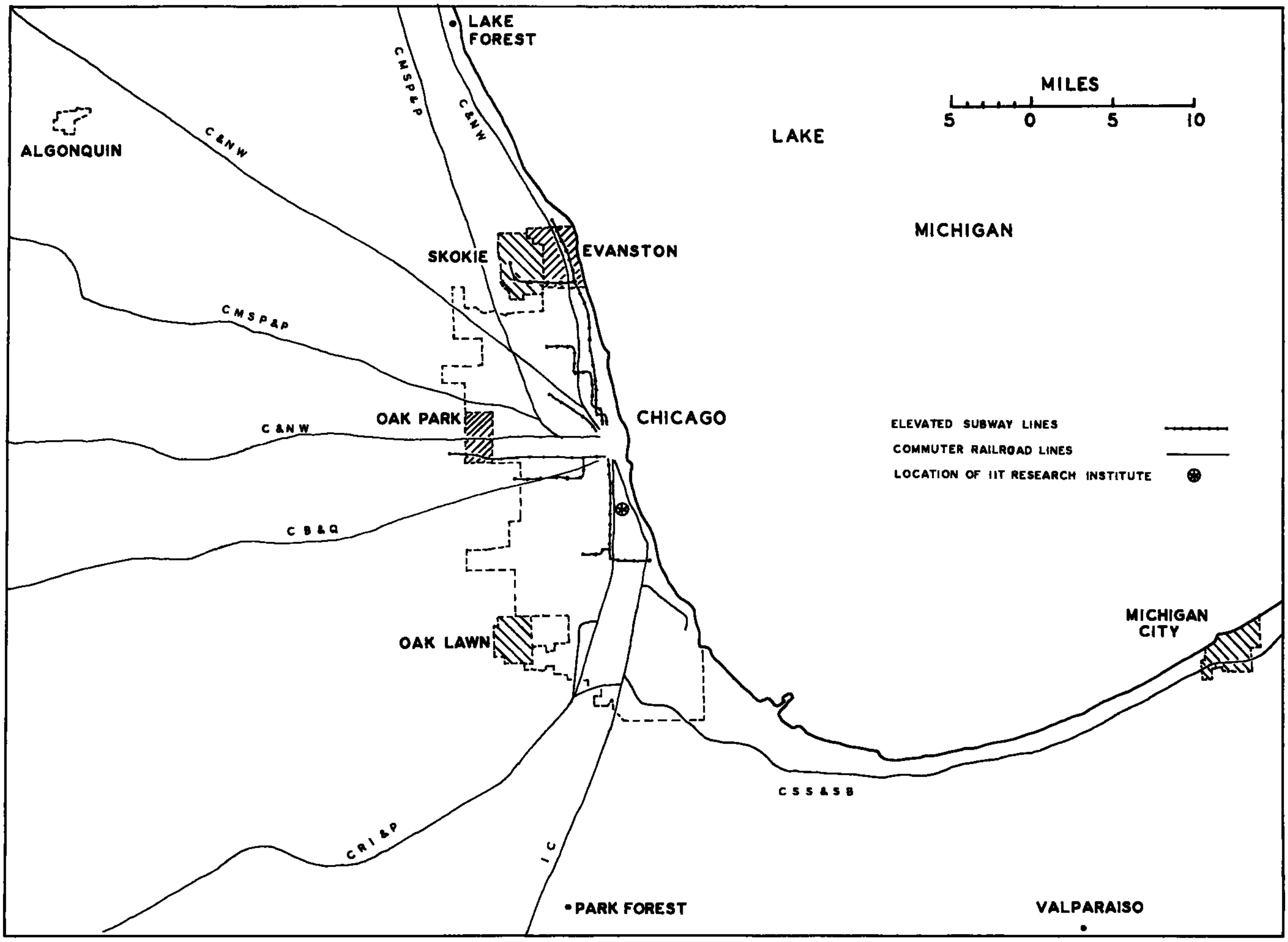

Figure 12. Elevated subway and commuter railroad lines in the Chicago area, 1965

collected and formats employed in a number of prior surveys. Organizations which had conducted surveys include Chicago Area Transportation Study (1956), Cook County Highway Department (1956), Southeastern Wisconsin Regional Planning Commission (1963), Penn-Jersey Transportation Study (1960), Stanford Research Institute (1963), University of Pennsylvania (1964, NCHRP Project 8-3), University of Michigan Survey Research Center (1963), and U.S. Bureau of the Census (1960, Census of Population and Housing; 1961, Nationwide Automobile Use Survey; 1963, Census of Transportation). Factors considered by various authors to be important in the choice of travel mode were reviewed, as were the results of earlier work on the present project.

Three successive preliminary versions of the questionnaire were tested by submission to selected groups of staff members with a request for comments. The final version of the questionnaire is reproduced in Appendix B.

In the initial design and the subsequent refinement of the questionnaire, some basic decisions were required. A strong constraint for any survey is that the number of items of information requested cannot be expanded indefinitely without encountering reductions in the quality and quantity of the returns that, beyond a certain point, will result in diminished total worth. For this reason several proposed questions were rejected. For example, it was decided, largely on these grounds, not to ask for a detailed breakdown of costs of automobile travel; the information ultimately requested, for all types of trips, was simply "cost of one-way trip (if you know or can readily estimate this)".

Numerous revisions were made in the wording and format of questions in an attempt to achieve clarity and conciseness. These are aims which can never be completely realized in practice, yet are as important to the success of a survey as properly defining the scope. In retrospect, it is apparent that not all ambiguity was avoided. For example, that part of question 6 which asks for the number of persons in the household under 16 was not in all cases interpreted as including very young children. Likewise, in question 10, "How far is it, in blocks or miles, from your residence to the nearest stop or station where you could or do take public transportation to work?", several respondents noted both a nearer access point which they do not generally use and a farther access point which they do.

A certain amount of redundancy in the information requested turned out to be highly useful in the process of coding the results, when each questionnaire was examined as an entire document. A number of instances of inconsistent or incomplete data were discovered and/or resolved by reference to all information bearing on a particular point. For example, the segment-by-segment description of a route given in reply to question 12 was expected to agree with the travel modes checked in question 11. Inconsistencies could usually be resolved without difficulty. In certain cases where doubt remained after examining all the written information, the person was called for clarification.

So far as possible, hypothetical questions were avoided in designing the survey. It was judged of greater value to focus on actual travel through an existing set of facilities than to elicit reactions to postulated situations. The expectation was that the ranges of variation of the influential factors in real travel choices would be sufficiently great to provide useful information concerning the functional relationships.

While it was thus decided to confine the survey to the realities of present-day travel, it was also decided to include, along with the more strictly objective and factual questions, certain questions concerning factors explicitly considered by the trip makers to be important in comparisons and choices among travel alternatives. Comment is made first on the more narrowly factual questions.

The first page of the questionnaire asks for relevant information concerning the person, the household, and various travel-related characteristics. The following items are covered: (1) name; (2) home address (street, city, zip code); (3) work building; (4) travel distance between home and work; (5) length of time at present home address; (6) number of persons in the household (a) 16 or older and (b) younger than 16; (7) whether the person is licensed to drive or not, and the number of drivers in the household; (8) the number of passenger cars owned by members of the household; (9) whether the person is a member of a car pool, and, if so, the total membership; (10) the travel distance between home and the nearest stop or station where public transportation could be taken to work, and the kind of public transportation (bus, elevated-subway, or railroad) available there.

Detailed information was sought concerning the various types of trips made by each respondent, including both their relative frequencies and their individual characteristics. These questions appear on the middle foldout sheet and final page of the questionnaire. A trip type was defined, for the purposes of this survey, by the mode or combination of modes of travel used during the trip. Six modes of travel—walking, car driver, car passenger, bus, elevated-subway, railroad—were listed explicitly on the survey form, and a seventh could be entered. Any combination of modes, indicated by checks in the appropriate row and columns, then specified a single trip type; a set of from one to four trip types was reported by each person.

The relative frequencies of each of the trip types over a period of a year were specified by the respondents, totaling 100 percent for trips from home to work and also 100 percent for trips from work to home.

The normal door-to-door travel time from home to work, the one-way cost (if this were known or could readily be estimated), and the one-way total of blocks walked are items of information applying to every type of trip. In addition, the following facts were requested for every type of trip involving use of public transportation: the number of transfers from one public vehicle to another, the total time spent waiting for vehicles, and the percent chance of having a seat, the latter broken down by bus, elevated-subway, and railroad.

A segment-by-segment description of the route most often taken in traveling from home to work completed the set of basic facts concerning the person's work trips.

The following comments concern the relatively subjective information; that is, factors stated by the respondents to be important in their evaluation of, and selection among, travel alternatives. The questionnaire is so organized that this kind of information falls under four headings: (1) reasons why a particular type of trip may be necessary; (2) desirable features of a particular type of trip; (3) undesirable features; and (4) main reason or reasons for switching to or from use of public transportation for most trips between home and work (if in fact such a switch had been made during the time the person had maintained his present places of employment and residence). Possible responses under these four headings were deliberately left open in the design of the questionnaire because it was not considered feasible to categorize all the possible factors in a satisfactory manner prior to the actual execution of the survey. However, by way of example, and as a reminder of the wide range of possible responses, some factors frequently mentioned on the literature as important aspects of travel were listed on the questionnaire adjacent to the boxes headed "Reasons why that type of trip may be necessary," "Desirable features of that type of trip." and "Undesirable features of that type of trip." Under all four headings it was required that the respondent actually write out his replies, if any.

EXECUTION OF THE SURVEY

Advance notice of the survey was given in *Dispatch*—a periodic newsletter that goes to all IITRI staff members—two days prior to the distribution of the questionnaires. The questionnaires themselves were distributed on October 29, 1965, to IITRI staff members working in Chicago. This was a day on which all employees, both full- and part-time, were paid. Arrangements were made with the Payroll Department for distribution of survey forms with pay checks. A note of appreciation to those cooperating in the survey, and a reminder to those who had not yet replied, was placed in the November 11 issue of *Dispatch*.

The number of Chicago-based IITRI employees on November 1, 1965, was 1,455 (from Personnel records). The number of filled-out questionnaires returned to the project staff was 711. Thus information was obtained relating to travel to and from work for 49 percent of all IITRI employees working in Chicago. This result is considered excellent in view of the amount and variety of information called for in the questionnaire and the fact that participation was purely voluntary.

DATA PREPARATION, AUXILIARY DATA

Coding of Questionnaire Data

As completed questionnaires were received, case numbers were assigned. Lists of factors named under the four headings discussed in the foregoing were compiled. The factors were eventually organized into a single, combined list with a set of reference codes.

After the code key for the factors had been developed, the information in the completed questionnaires was transcribed to code sheets by project personnel preparatory to key punching. The coding was done casewise; i.e., all the information pertaining to one person was treated simultaneously. In this way ambiguities or inconsistencies were brought to light and resolved in terms of the evidence provided by an entire questionnaire. A check list of expressways and tollways in the Chicago area was consulted in the partial coding of the data given in reply to question 12, which asked for a segment-by-segment description of the route most often taken in traveling from home to work. Employee identification numbers, inserted during coding of the survey data, made possible the subsequent matching of survey data with data from personnel records.

One person card and one card for each reported trip type (maximum of four) resulted for each case.

Geographic Reference System and Coding of Home Locations

Information obtained from respondents in the work-trip survey included residential street address, city or town, and postal zip code. X and Y geographical grid coordinates and geographical zones were found for these places of residence by reference to maps covering Chicago and surrounding areas. The grid coordinate system adopted is that used by the Chicago Area Transportation Study in coding data from their large-scale 1956 survey. The intersection of State and Madison Streets in downtown Chicago is assigned the coordinate values $X = 500$ and $Y = 500$. The units are tenths of miles. The origin of the coordinate system is at a point 50 miles west and 50 miles south of the intersection of State and Madison; hence values of X increase from west to east and values of Y increase from south to north.

All Chicago addresses and most suburban addresses were pinpointed on maps showing streets and house numbers as well as the X, Y coordinate system. In these cases home locations were coded to the nearest 0.1 mi in each direction. Where suburban street addresses could not be exactly located on available maps, coordinates of a point near the center of the town were assigned. For Chicago and adjacent suburban areas a detailed street map published by a major oil company was used with an overlay on which coordinate lines were drawn. For outlying suburban areas, a set of coordinatized atlas sheets prepared by the Chicago Area Transportation Study in 1955-56 was used in conjunction with a more recent set of maps published by Sidwell Studios. After X and Y coordinates had been found for all places of residence, the ring, sector, and zone numbers of the CATS geographic reference system were obtained from an additional map. The various maps required for the geographic coding were made available through the courtesy of the Chicago Area Transportation Study.

Use of the CATS geographic reference system made it possible to relate data from the IITRI work-trip survey to data from previous surveys and to data on the Chicago transportation network.

As a further aid in analysis of the data, code numbers were assigned to all cities and towns in which one or more respondents resided. Ninety-four communities other than Chicago were represented. However, the majority of respondents (56 percent) lived in Chicago proper.

A separate set of punched cards was prepared containing case number, X and Y coordinates of place of residence, the ring, sector, and zone numbers, and the city code number.

Data From Personnel Records

Certain items of collateral information were obtained from records made available in the form of listings and punched cards by the Personnel Department of IITRI. These items are: employee identification number, sex, year and month of birth, level of education, work experience, year and month of hiring, full- or part-time employment, job code, and division code. The job code numbers permitted a subsequent rough assignment of salary level.

Collation and Transcription of Data

Items of information from three separate sources were finally available: (1) data from the survey questionnaires; (2) location data obtained from maps; and (3) data from personnel records. The various items of information, collated by case, were transcribed onto a single magnetic tape.

Checks on Distances, Times, Costs, Etc.

Computer programs were written to list all items of data in easily readable form and to perform numerous checks for reasonableness, consistency, and completeness.

From values of X and Y coordinates of home locations and the work location the straight-line distance and also the rectangular-distance (sum of distances in the X and Y directions) were computed for every case. The ratios of the reported travel distance to the rectangular distance, and of the reported travel distance to the straight-line distance were also computed. The average speed (reported travel distance divided by reported door-to-door travel time) and the cost per mile (reported cost of one-way trip divided by reported travel distance) were computed for every trip report. Examination of the resulting distributions indicated that for the most part there was reasonably good agreement between the reported and computed values. In a few cases round-trip instead of one-way values had been reported. In one case it was discovered that the person was working at an IITRI facility in Gary rather than in Chicago. In several cases, mostly persons living less than 1 mi from work, the reported travel distance was less than the straight-line distance. Corrections were made where clearly indicated.

SURVEY DATA DISTRIBUTIONS

Characteristics of Respondents

The group of persons participating in the work-trip survey is characterized by the following distributions:

1. Sex. Roughly one-fifth of the respondents (146 out of 698) were female.

2. The average age of all respondents was 34.7 years. The age distribution of 698 respondents by decades is as follows:

Decade	10-	20-	30-	40-	50-	60-
Persons	17	231	265	134	44	7

3. Education. The distribution of 671 respondents by educational level is: no degree, 282; bachelor's degree, 173; master's degree, 148; doctor's degree, 68. Thus, about 58 percent of the participating staff members have at least a bachelor's degree.

4. Salary. A rough mapping of job codes into salary levels resulted in the following distribution of 698 respondents: low, 360; low medium, 97; high medium, 209; high, 32.

5. Residence time. The average length of time persons had maintained their present residence was 5.7 years.

6. Driving status. Approximately 92 percent of respondents (645 out of 702) were licensed to drive a car.

7. Car-pool membership. Approximately 20 percent of respondents (139 out of 702) were members of car pools for travel between home and work. The average membership per car pool report was 3.1.

Characteristics of Households

The households to which respondents belong are characterized by the following distributions:

1. Persons younger than 16. The average reported number of persons younger than 16 per household was 1.3.

2. Persons 16 or older. The average number of persons 16 or older per household was 2.3. Thus, the average number of persons of all ages per household was 3.6.

3. Drivers. The average number of persons licensed to drive per household was 1.8. The frequency distribution of 702 households by number of drivers is as follows:

Drivers	0	1	2	3	4	5	8
Households:	22	185	411	59	18	6	1

There are one or more drivers in 97 percent of the households.

4. Cars. The average number of passenger cars owned per household was 1.2. The frequency distribution of 701 households by number of cars owned is as follows:

Cars:	0	1	2	3
Households:	58	435	187	21

There were one or more cars at 92 percent of the households and two or three cars at 30 percent of the households.

Residential Locations

The geographical distribution of the homes of persons participating in the survey is shown in Figure 13, a basic plot of residential locations generated by computer from the *X* and *Y* coordinate numbers. The locations of IIT Research Institute, and of the intersection of State and Madison Streets in the Chicago Loop, are also marked. The area in which staff members live extends from the town of Algonquin on the west to Michigan City on the east, and from Valparaiso on the south to Lake Forest on the north. Aside from the blank area to the east that is coincident with Lake Michigan, there is a scattering of residences in all directions from the place of work.

Distribution of Travel Distances

The mean reported travel distance between home and work is $\bar{x} = 14.21$ mi, with individual distances ranging from 0.2 to 70.0 mi. The standard deviation of reported travel distances is $s = 9.56$ mi. These figures are based on 702 replies in the work-trip survey.

A gamma distribution function was fitted to the data in accordance with the finding by Voorhees et al. (*33*) that functions of this type provide a concise and relatively accurate representation of trip-length distributions encountered in many situations.

The frequency distribution of reported travel distances is represented by the histogram in Figure 14 (bars are of approximately equal area); the cumulative distribution of reported travel distances is shown in Figure 15. The curves of Figures 14 and 15 are, respectively, a gamma frequency function and its integral.

The gamma frequency function has the form

$$f(x) = \frac{\beta^{a}}{\Gamma(a)} (x - M)^{a-1} e^{-\beta(x-M)} \qquad (11)$$

in which x is the variate (in the present instance travel distance in miles), M is the location parameter (the lower limit for values of x, in the present instance 0), a is the shape parameter, β is the scale parameter, $e = 2.71828$ (the base of natural logarithms), and Γ denotes the ordinary gamma function. The shape and scale parameters were estimated from the empirical mean and standard deviation (the method of moments) as follows:

$$a^{*} = \bar{x}^{2}/s^{2} = 2.2082 \qquad (12)$$

$$\beta^{*} = \bar{x}/s^{2} = 0.1554 \qquad (13)$$

in which a^{*} and β^{*} are estimates of a and β, respectively. The equation of the gamma frequency function of Figure 14 is then

$$f(x) = \left(\frac{0.1554^{2.2082}}{1.1067}\right)(x^{1.2082})(2.71828^{-0.1554x}) \qquad (14)$$

The representation of the empirical data on travel distance by the gamma statistical distribution function is reasonably good over most of the range. The fit is poorest for short distances. The excess of very short trips in the survey data is attributed to the substantial number of respondents who occupy apartments on the IIT campus itself.

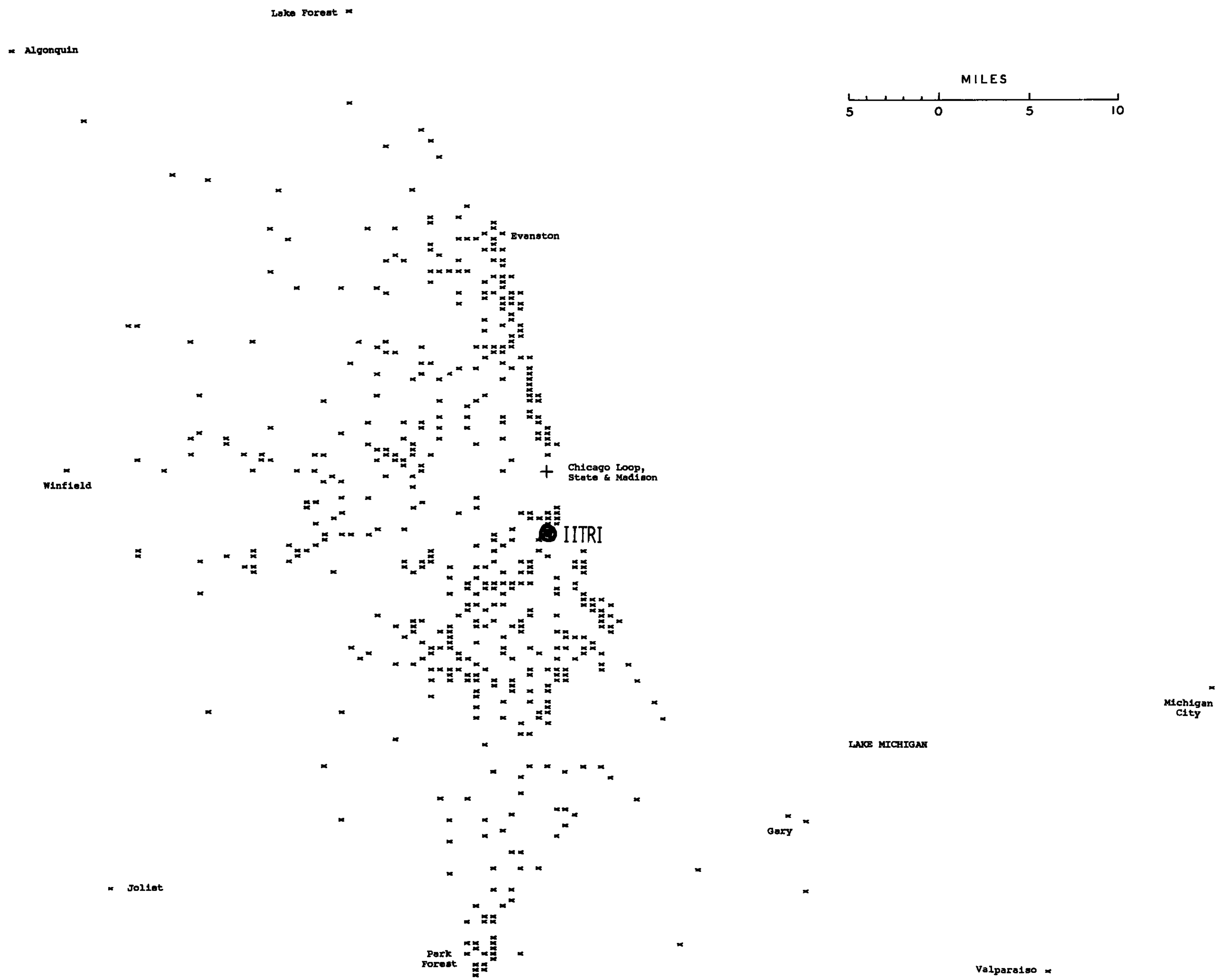

Figure 13. Places of residence of persons working at IIT Research Institute and responding in the work-trip survey.

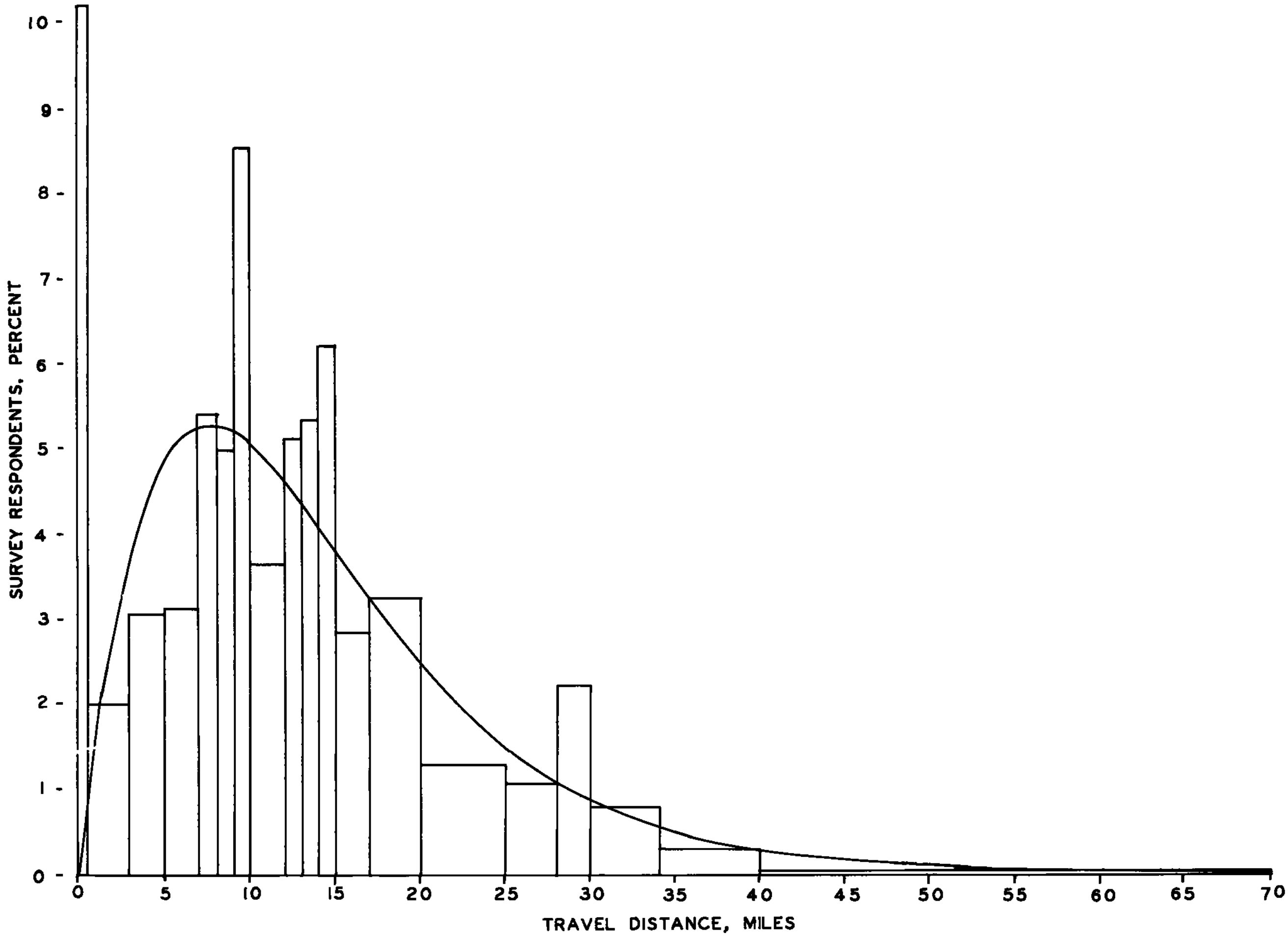

Figure 14. Frequency distribution of respondents in IITRI work-trip survey, by reported travel distance. The histogram represents empirical values; the fitted curve is a gamma frequency function.

DISTANCE FROM HOME TO PUBLIC TRANSPORTATION

Access to public transportation from the place of residence varied greatly, the distance ranging from a fraction of a block to several miles. The average reported distance from home to the nearest station or stop where public transportation could be taken to work was 5.5 blocks. However, about one-half of the respondents lived within 2 blocks of an access point.

Classification of Trip Types

Altogether, 1,368 trip reports were given by 702 persons in the survey, an average of slightly less than 2 per person, with a range of 1 to 4. A trip type is defined by the combination of travel modes used during the trip. Out of a logically possible set of $2^7 = 128$ different trip types, 41 were actually reported by 1 or more persons. These 41 basic types were grouped into 10 trip classes for purposes of analysis and comparison (Table 17). The 10 trip classes are defined as follows:

1. Walk only.
2. Drive car.
3. Ride in car.
4. Use bus.
5. Use elevated-subway.
6. Use elevated-subway and bus.
7. Drive or ride in car and also use elevated-subway and/or bus.
8. Use railroad in combination with elevated-subway and/or bus.
9. Drive or ride in car and also use railroad in combination with elevated-subway and/or bus.
10. Use "other" mode of travel.

Trip Properties

Values applying to the 10 classes of trips specified in the foregoing are presented in Table 18, which gives (a) the number and percentage of trip reports in each class, (b) the weighted frequency of occurrence of trips in each class, and (c) the unweighted average values, calculated from the data of the trip reports within each class, for one-way travel distance, travel time, door-to-door average speed, trip cost, cost per unit of travel distance, distance walked in the course of a trip, number of transfers from one public vehicle to another, and the time spent waiting for public vehicles. The following comments relate to the information presented in Table 18.

TRIP FREQUENCIES

The weighted frequency of occurrence of trips of a given class was computed by using as weights the percentages reported in the questionnaire for trips of that class both to work and from work. There are some definite shifts in the relative frequencies of trips of the various classes in going from the count of trip reports to the weighted frequency of occurrence of the trips themselves. Trips as car driver (class 2) account for 38.9 percent of the trip reports, but an actual majority—50.1 percent—of the trips on a weighted basis. Walking trips (class 1) and elevated-subway trips (class 5) are also a higher proportion of the total on a weighted than on an unweighted basis. The reverse is true of the remaining trip classes.

Trips of classes 7 and 9 are of mixed mode in the sense that both a private automobile and mass transit are used during a trip. These two trip classes account for 8.9 percent of the trip reports and 6.5 percent of the trips.

SPEED

The values for average speed in Table 18 are ratios of average travel distance in miles to average door-to-door travel time in hours.

COST

A cost figure was given for 75 percent of car-driver and car-passenger trips, but for better than 96 percent of the

TABLE 17

KINDS OF TRIPS REPORTED, IITRI WORK-TRIP SURVEY

		MODES REPORTED USED IN TRIP							
TRIP TYPE	TRIP CLASS	WALK	DRIVE	RIDE, CAR	BUS	EL-SUBWAY	RAIL-ROAD	OTHER	NO. OF TRIP REPORTS
1	10							X	8
2	5					X			45
3	10					X		X	3
4	8					X	X		15
5	4				X				60
6	10				X			X	1
7	8				X		X		1
8	6				X	X			107
9	8				X	X	X		10
10	3			X					192
11	10			X			X	X	1
12	7			X		X			22
13	9			X		X	X		18
14	7			X	X				5
15	7			X	X	X			2
16	9			X	X	X	X		8
17	2		X						521
18	7		X			X			15
19	10		X			X		X	2
20	9		X			X	X		9
21	7		X		X	X			5
22	9		X		X	X	X		5
23	3		X	X					1
24	1	X							48
25	10	X						X	1
26	5	X				X			58
27	8	X				X	X		31
28	4	X			X				14
29	8	X			X		X		2
30	6	X			X	X			89
31	8	X			X	X	X		17
32	3	X		X					9
33	7	X		X		X			1
34	9	X		X		X	X		11
35	7	X		X	X				1
36	9	X		X	X	X	X		4
37	2	X	X						11
38	7	X	X			X			1
39	9	X	X			X	X		8
40	7	X	X		X	X			2
41	9	X	X		X	X	X		4
All									1368

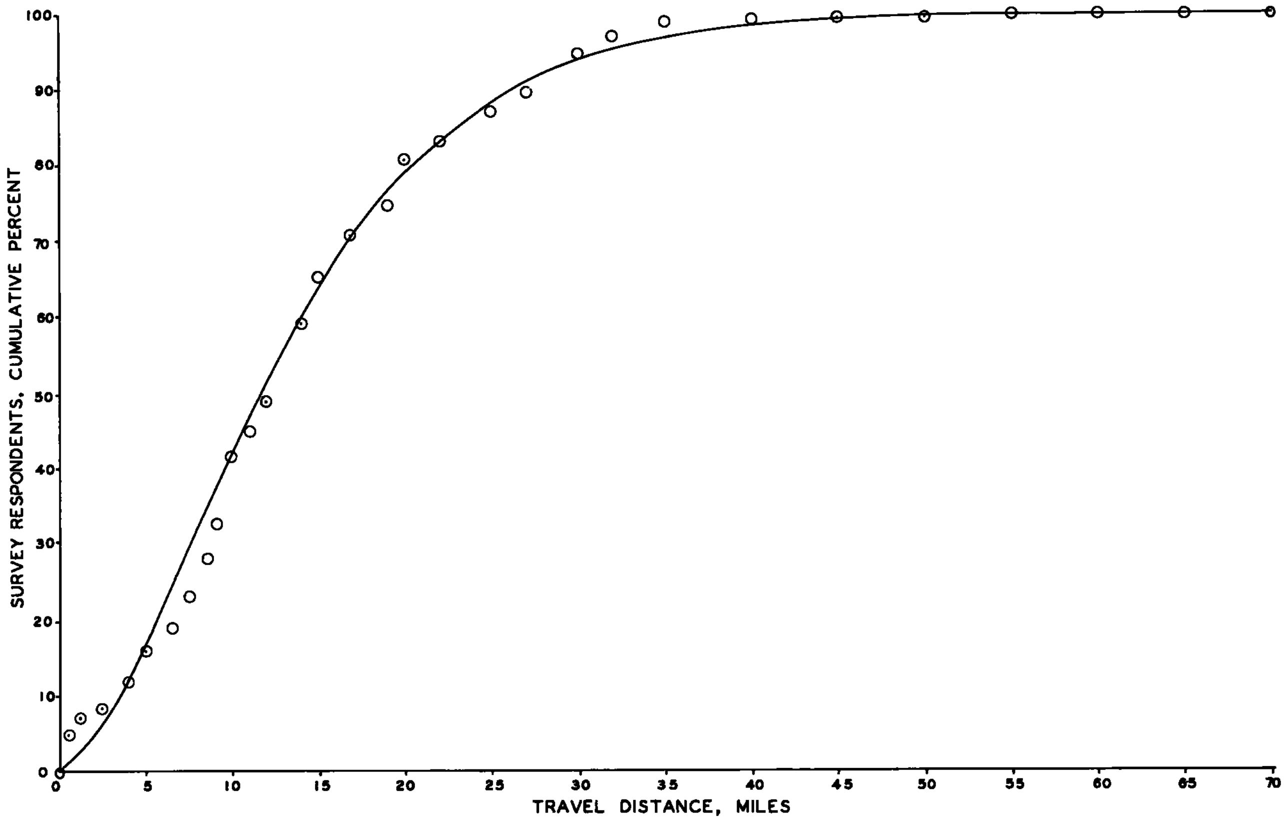

Figure 15. Cumulative distribution of respondents in IITRI work-trip survey, by reported travel distance. The points represent empirical values; the fitted curve is a gamma cumulative distribution function.

TABLE 18

AVERAGE VALUES CHARACTERIZING TEN DIFFERENT WAYS OF TRAVELING BETWEEN HOME AND WORK, IITRI WORK-TRIP SURVEY

TRIP CLASS	REPORTS (NO.)	REPORTS (%)	WEIGHTED FREQUENCY OF OCCURRENCE (%)	ONE-WAY TRAVEL DIST. (MI)	TRAVEL TIME (MIN)	TRAVEL SPEED (MPH)	COST ($)	COST PER MILE ($)	DISTANCE WALKED (BLOCKS)	NO. OF TRANS-FERS	WAITING TIME (MIN)
(1) Walk	48	3.5	5.5	0.5	13	2.5	0.00	0.000	5.7	—	—
(2) Drive car	532	38.9	50.1	15.2	38	24.3	0.84	0.056	0.5	—	—
(3) Ride in car	202	14.8	13.3	15.8	37	25.5	0.17	0.011	0.6	—	—
(4) Bus	74	5.4	2.4	6.7	50	8.0	0.30	0.045	2.8	1.1	14
(5) El-subway	103	7.5	10.1	12.4	45	16.6	0.30	0.024	4.6	0.4	6
(6) Bus + el	196	14.3	9.6	12.3	59	12.4	0.38	0.031	3.0	1.5	12
(7) Car + bus and/or el	54	4.0	2.3	17.3	61	17.1	0.50	0.029	1.2	1.0	7
(8) RR + bus and/or el	76	5.5	1.9	23.9	79	18.1	1.21	0.050	6.3	1.6	12
(9) RR + car + bus and/or el	67	4.9	4.2	26.9	76	21.2	1.18	0.044	3.2	1.5	11
(10) Other: bicycle, taxi, etc.	16	1.2	0.6	—	—	—	—	—	—	—	—
All	1368	100.0	100.0								

other eight classes of trips as a whole. The variation among those cost estimates that were provided for car-driver and passenger trips was high. The standard deviation of estimated cost per trip was \$0.80 for driving trips (compared with a mean of \$0.84) and \$0.38 for car-passenger trips (compared with a mean of \$0.17). The costs per mile are ratios of average trip cost to average travel distance.

"OTHER" MODES OF TRAVEL

It may be noted from Table 18 that there were 16 trip reports in which "other" modes of travel were specified. Use of a taxicab was reported five times, apartment-house courtesy car and jitney once each. The Skokie Swift (operated by the Chicago Transit Authority over the previous North Shore Railroad tracks from Dempster Street in Skokie to the Howard Street elevated station in Evanston) was twice indicated as an "other" mode of transportation. Seven men reported use of a bicycle, in one case as a means of getting to and from a rapid transit station. The average travel distance for the six reports of pure bicycle trips is 7.0 mi and the average speed 12.7 mph.

SEAT PROBABILITIES

Survey data on seat probabilities for trips by public transportation, not covered in Table 18, are summarized as follows. The average reported seat probability on buses was 69 percent, on elevated-subway cars 70 percent, and on railroad cars 87 percent. These probabilities are based on all bus, elevated-subway, and railroad trip segments respectively, regardless of the particular trip type or class.

EXPRESSWAY USE

Expressway use for trips by car, also not covered in Table 18, is summarized as follows. A segment-by-segment description of the route was given in 74 percent of the 734 reports of automobile trips (trip classes 2 and 3). One or more expressways were named as route segments in 89 percent of these trip descriptions, and two, three, or four different expressways were named in 43 percent of the trip descriptions.

Distribution of Travel Times

The mean reported travel time from home to work, based on 1,334 reports for all types of trips, is $\bar{x} = 46.21$ min. The standard deviation of travel times is $s = 22.77$ min. A gamma statistical distribution function was fitted to the travel-time data by the same method employed in fitting the travel-distance data (see prior section on "Distribution of Travel Distances"). As in fitting the distance data, the location parameter, M, is here assigned a value of 0 in accordance with the non-negativity of the variates travel distance and travel time. Estimates of the shape parameter, α, and the scale parameter, β, are, from the present data,

$$\alpha^* = \bar{x}^2/s^2 = 4.1173 \qquad (15)$$

and

$$\beta^* = \bar{x}/s^2 = 0.08909 \qquad (16)$$

Hence, the equation of the gamma frequency function is

$$f(x) = \left(\frac{0.08909^{4.1173}}{6.9661}\right)(x^{3.1173})(2.71828^{-0.08909x}) \qquad (17)$$

The cumulative distribution of reported trip times is shown in Figure 16, in which the curve is the fitted gamma cumulative distribution function. As in the fitting of the travel-distance data, values of the cumulative distribution function were derived from the frequency function by straightforward numerical integration.

The empirical data on travel times are approximated reasonably well by the gamma statistical distribution function. The agreement is poorest in the range of travel times from about 30 min to just under 1 hr; over this range the empirical cumulative frequencies fall below the curve. A partial explanation is that there was an apparent tendency in reporting travel times to round times in the vicinity of an hour to the even hour.

A gamma statistical distribution function was fitted to the same set of travel-time data by a maximum-likelihood method (*33*). The estimates for α and β are $\alpha^* = 3.5276$ and $\beta^* = 0.07634$. The resulting equation for the frequency distribution function is then (with $M = 0$)

$$f(x) = \left(\frac{0.07634^{3.5276}}{3.4266}\right)(x^{2.5276})(2.71828^{-0.07634x}) \qquad (18)$$

There was no apparent improvement in the fit by use of the maximum-likelihood method.

Distribution of Proportionate Use of Public Transportation

The respondents in the work-trip survey gave the proportion of all their trips during a year that were of each trip type, separately for trips to work and trips from work. This information is used here in an investigation of the proportion of trips that involve use of public transportation. Specifically, the interest is in the statistical distribution of proportionate use of public transportation over the survey population.

DATA

By combining trips to work and trips from work, the proportion of each person's trips in which the mode of at least one segment of the trip was public transportation (i.e., bus, elevated-subway, or commuter railroad) was determined. In other words, the trips falling within trip classes 4 through 9 were combined and expressed as a proportion of all the person's trips.

Based on 696 individual cases, the mean proportion of trips in which public transportation was used is $\bar{x} = 0.3108 = 31.08$ percent. The standard deviation of the proportion of trips in which public transportation was used is $s = 0.4111 = 41.11$ percent.

BETA DISTRIBUTION FUNCTION

The gamma distribution function, used earlier to represent distributions of travel distances and times, is appropriate in many applications in which there is a lower bound on the values which the variate may assume. The beta distribution function is similarly appropriate in many applications in which there are both upper and lower bounds on

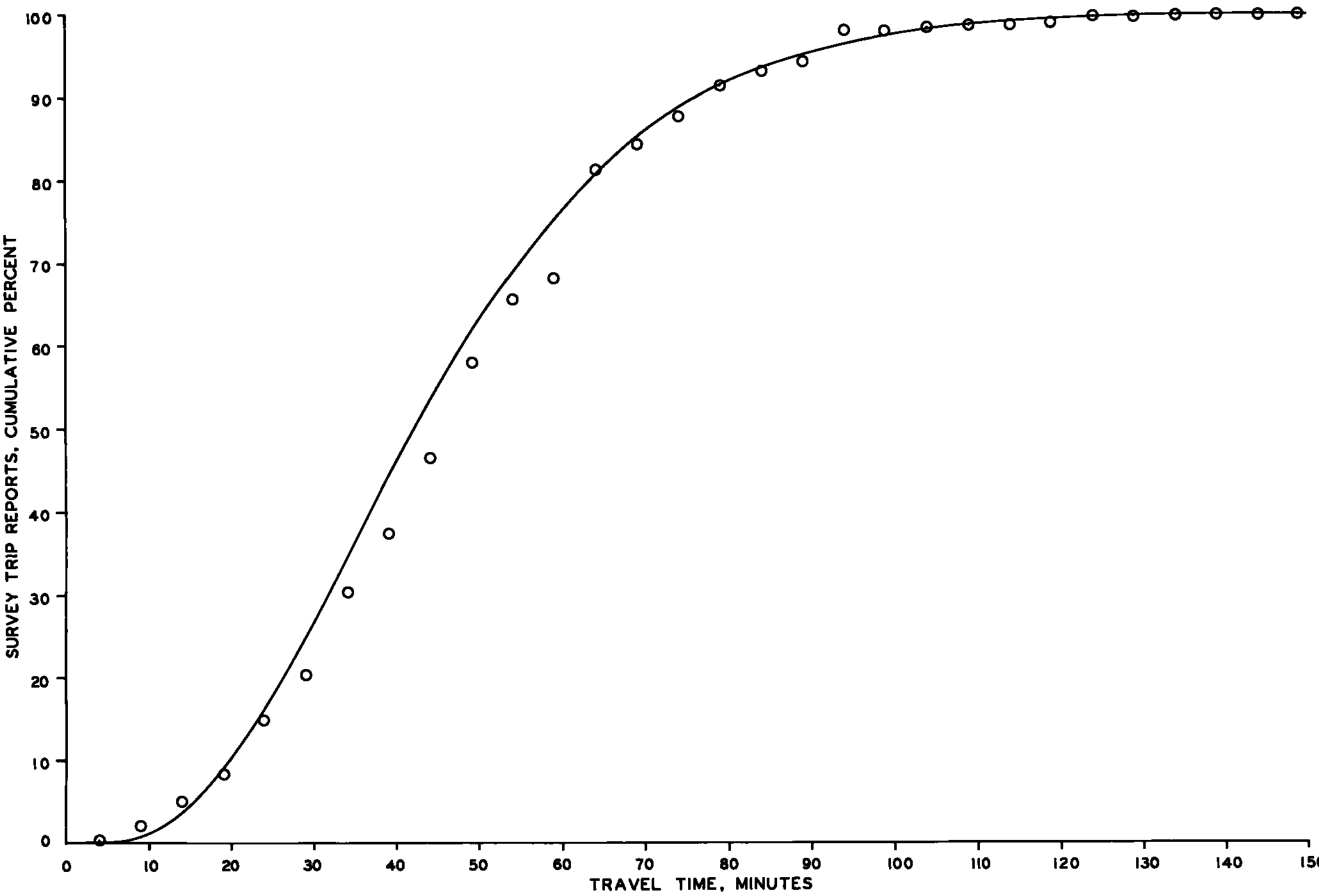

Figure 16. Cumulative distribution of respondents in IITRI work-trip survey, by reported trip times. The points represent empirical values; the fitted curve is a gamma cumulative distribution function.

the values of the variate. The present variate, proportion of a person's trips by public transportation, is necessarily restricted to the range $0 \leq x \leq 1$. Furthermore, there is extreme accumulation of observations at both ends of the range, resulting in a roughly U-shaped empirical distribution. This is apparent in Figure 17, in which the empirical frequencies are represented by the histogram.

The beta frequency function has the form

$$f(x) = \frac{\Gamma(n)}{\Gamma(r)\Gamma(n\text{-}r)} x^{r-1} (1\text{-}x)^{n-r-1} \qquad 0 \leq x \leq 1, n > r > 0 \qquad (19)$$

in which r and n are parameters which jointly determine the shape of the frequency curve and Γ again denotes the ordinary gamma function (*34*). The parameters n and r can be estimated as functions of the empirical mean and standard deviation (method of moments), as follows:

$$n^* = \frac{\bar{x}(1-x)}{s^2} - 1 = 0.2674 \qquad (20)$$

$$r^* = \frac{\bar{x}^2(1-x)}{s^2} - x = 0.0831 \qquad (21)$$

Using n^* and r^* as estimates of n and r, respectively, the equation for the beta frequency function in the present application is then

$$f(x) = \left(\frac{3.377}{(11.533)(5.005)}\right)(x^{-0.9169})((1-x)^{-0.8157}) \qquad (22)$$

The frequency distribution curve (dotted line) of Figure 17 represents the solution points of the equation.

A method for integrating the beta frequency function to obtain the corresponding cumulative distribution function (incomplete beta function) was developed and programmed. A transformation is employed which enables the integration to be carried out with sufficient accuracy even when the frequency function is extremely U-shaped, as in the present example.

The empirical cumulative distribution of proportion of trips by public transportation is shown in Figure 18, in which the curve is the corresponding beta cumulative distribution function. Considering that only two parameters are computed from the data, the beta function fits the distribution of reported proportion of trips by public transportation (modal split within individuals) reasonably well.

The appropriateness of gamma and beta distribution functions as mathematical representations of kinds of variation inherent in modal assignment problems is apparent

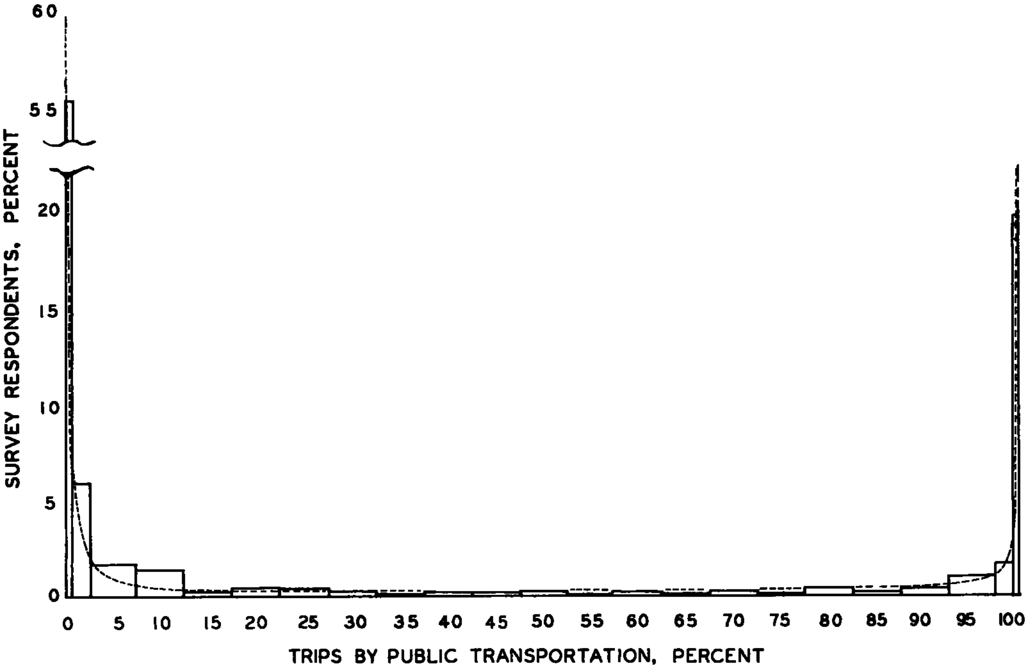

Figure 17. Frequency distribution of respondents in IITRI work-trip survey, by reported proportion of trips in which public transportation is used. The histogram represents empirical values; the fitted curve is a beta frequency function.

from the analyses of data from the IITRI work-trip survey that have been presented. The utility of such models lies in providing efficient ways of describing travel characteristics and, beyond this, in providing conceptual tools for the analysis of the factors determining variation.

RELATIONSHIPS AMONG REPORTED AND COMPUTED TRAVEL TIMES AND DISTANCES

Each questionnaire of the work-trip survey reports the travel distance between home and work, and the normal door-to-door travel time for each trip report. These reported distances and times are compared with each other and with distances and times computed from data external to the survey.

Distance Comparisons

From the X and Y coordinates of place of residence and place of work two distances were computed for each case: (1) the straight-line distance between the two trip ends and (2) rectangular distance (sum of distances in directions parallel to the X and Y axes). The correlation between reported travel distance and computed straight-line distance is 0.968. The correlation between reported travel distance and computed rectangular distance is 0.962. Both correlations are derived from survey data on 696 individual cases. Reported travel distance is plotted against computed rectangular distance in Figure 19. In these 696 cases the mean reported travel distance is 14.2 mi, the mean computed straight-line distance is 10.8 mi, and the mean computed rectangular distance is 13.4 mi.

Travel Times Computed from Network Models

Three sets of automobile travel times and one set of public-transportation travel times, computed from models of the transportation facilities of the Chicago area, were compared with the corresponding travel times reported in the work-trip survey. The network models, developed by the Chicago Area Transportation Study, are as follows:

1. 1956 Arterial network. Path values (travel times) between all pairs of zones were computed under the present project. These are the travel times used in the investigations reported in Chapters Seven and Eight.

2. 1965 Unloaded arterial network. The description of the network of automobile travel facilities in the Chicago area was updated as of 1965 by the Chicago Area Transportation Study. With the zone in which IIT Research Institute is located (zone 45) as one end of every path, two sets of path values were computed by CATS. The first set of path values, here referred to under the model designation "1965 unloaded arterial network," was computed from the basic link values, as updated, with no adjustment for congestion effects.

3. 1965 Loaded arterial network. The second set of path values, here referred to under the model designation "1965 loaded arterial network," was computed by CATS with link values adjusted for congestion effects. This was accomplished by CATS in the course of a complete assignment of zonal interchange volumes (using the intervening opportunities method) by making the final step the assignment of trips originating in zone 45. Thus, this second set of computed 1965 path values reflects the effects of maxi-

mum network loading. It should be emphasized that these path values are treated here as correlates of actual travel times, whereas their use by CATS is primarily to achieve relatistic volumes of travel through the network; the interpretation as trip times here permits integration with other decision-related data.

4. 1965 Transit network. As with the 1956 arterial network, path values, interpreted as estimates of travel times, were computed under the present project and used in the prior investigations reported in Chapters Seven and Eight.

Aggregation of Survey Data by Zone of Residence

To enable comparison with values derived from the network models, which are on a zone-to-zone basis, survey data on travel times and distances were aggregated by zone. The work end of each survey trip is in zone 45, hence aggregation is by zone of residence. The travel distances reported by respondents residing in each zone were averaged, as were the reported travel times by automobile and by public transportation.

Variation of Travel Times by Automobile and by Public Transportation for Fixed Zone of Residence

The standard deviation of reported travel times by automobile for work trips from the same zone of residence is 7.11 min (based on 473 degrees of freedom). The standard deviation of reported travel times by public transportation for work trips from the same zone of residence is 13.12 min (based on 330 degrees of freedom). The latter figure may be compared with the standard deviation of 10.74 min obtained by pooling 1956 data of the Chicago Area Transportation Study on bus, elevated-subway, and railroad work trips to the central area (data of Table 16).

Comparisons of Reported and Computed Travel Times

Correlations between mean reported travel times and travel times (path values) computed from the network models are given in Table 19. The highest of the four correlations, based on data for 196 zones of residence, is 0.86 between mean reported travel times by car and the times derived from the 1965 loaded arterial network. The reported times are plotted against the computed times in Figure 20, to-

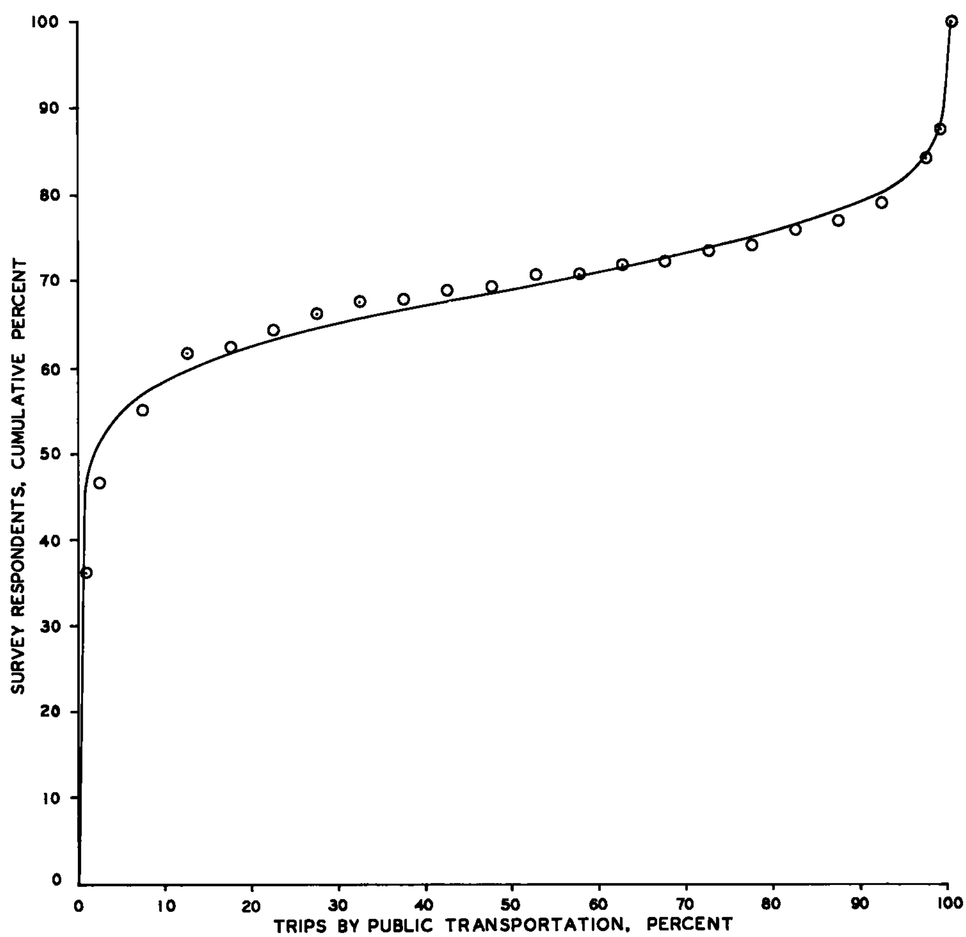

Figure 18. Cumulative distribution of respondents in IITRI work-trip survey, by reported proportion of trips in which public transportation is used. The points represent empirical values; the fitted curve is a beta cumulative distribution function.

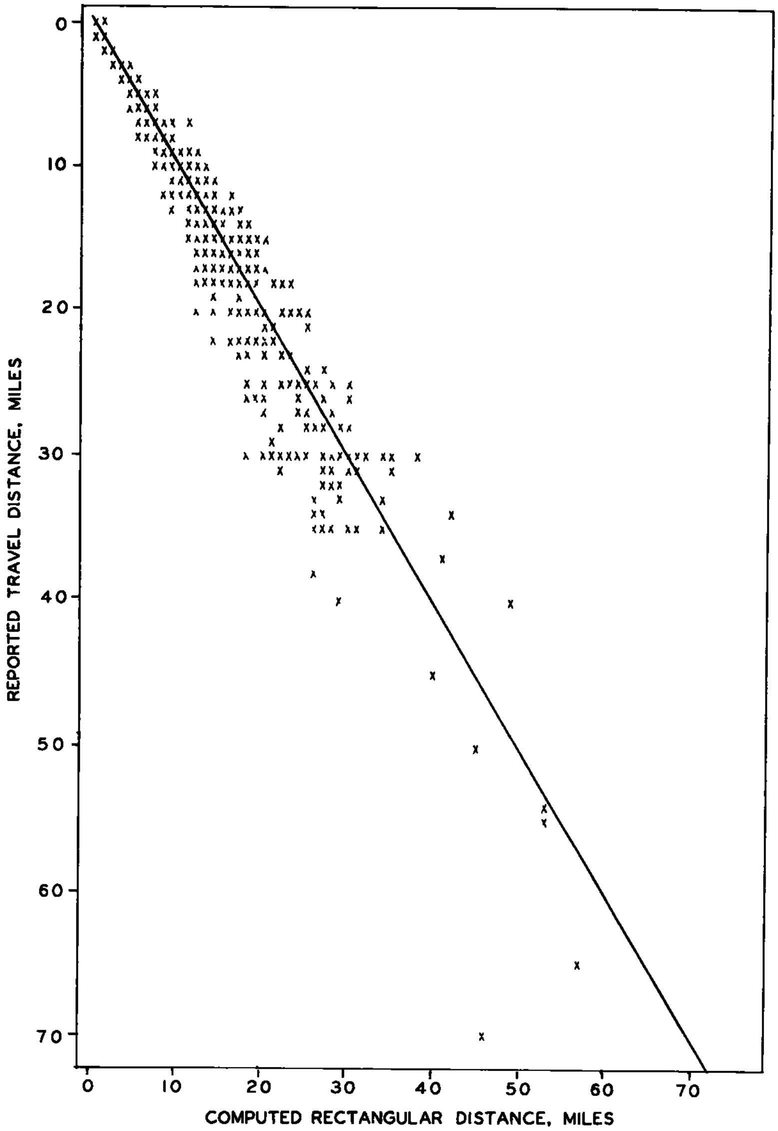

Figure 19. Plot of reported travel distance vs rectangular distance (sum of north-south and east-west distances computed from X and Y coordinates of trip ends) for IITRI work-trip survey. Curve is line of equal values.

TABLE 19

ZONE-BASED COMPARISONS AMONG TRAVEL TIMES: (1) REPORTED IN IITRI WORK-TRIP SURVEY AND (2) COMPUTED FROM CATS NETWORK DATA

COMPARISON	SOURCES OF TIME ESTIMATES y	x	NO. OF ZONES	PRODUCT-MOMENT CORRELATION, r, BETWEEN y AND x	LINEAR REGRESSION OF y ON x, $y^* = \bar{y} + b\,(x - \bar{x})$
1	Reported times by car (zone means), IITRI survey	Computed times by car, CATS 1956 arterial network	246	0.8083	$y^* = 39.25 + 0.81\,(x - 38.32)$ $= 8.05 + 0.81\,x$
2	Reported times by car (zone means), IITRI survey	Computed times by car, CATS 1965 unloaded arterial network	245	0.7501	$y^* = 39.38 + 1.19\,(x - 21.46)$ $= 13.86 + 1.19\,x$
3	Reported times by car (zone means), IITRI survey	Computed times by car, CATS 1965 loaded arterial network	196	0.8576	$y^* = 35.71 + 0.62\,(x - 45.42)$ $= 7.77 + 0.62\,x$
4	Reported times by public transportation (zone means), IITRI survey	Computed times by public transportation, CATS 1956 transit network	215	0.7838	$y^* = 60.30 + 0.63\,(x - 70.78)$ $= 15.92 + 0.63\,x$

gether with the least-squares line of regression of reported on computed times. The corresponding equation is given in Table 19. The mean reported time is 35.7 min; the mean computed time, 45.4 min, is considerably longer.

The correlation between mean reported automobile times and times derived from the unloaded 1965 arterial network, 0.75, is the lowest of those presented in Table 19, and is in fact somewhat lower than the correlation, 0.81, found between the reported times and times derived from the 1956 arterial network model. The linear regression equations are given in Table 19. As would be expected, the mean time, 39.4 min, reported in the survey is considerably longer than the mean time, 21.5 min, computed from the unloaded 1965 arterial network. The mean reported time, 39.2 min, and the mean computed time, 38.3 min, are quite close in comparison 1 of Table 19, which relates to the 1956 arterial network. This is in accordance with the understanding that the 1956 link values were chosen by CATS to represent traffic conditions intermediate between an essentially empty network and peak congestion. The correlation between reported times by car and times derived from the loaded 1965 arterial network is based on fewer zones than the other two correlations concerned with automobile travel times because there were 50 zones in which one or more survey respondents lived but for which the calculated interchange volume with zone 45 (in the intervening-opportunities assignment) was negligible.

The correlation between reported times by public transportation in the work-trip survey and the times computed from the 1956 CATS transit network is 0.78 based on 215 zones (Fig. 21). The regression equation is given in Table 19. The mean reported time is 60.3 min, the mean computed time 70.8 min. The computed times by public transportation are thus appreciably longer than the 1965 reported times, in agreement with the findings concerning 1956 reported times presented in Chapter Seven. No updated version of the CATS model of the Chicago transit network was available at the time the comparisons with survey data were made.

In the comparison of reported times and computed times by transit, using data from the work-trip survey, it should be recognized that the location of IIT Research Institute is particularly favorable with respect to elevated-subway travel. The average walking time to the rapid-transit station plus the waiting time during the rush period is about 5 min. The computed time includes a 10-min terminal

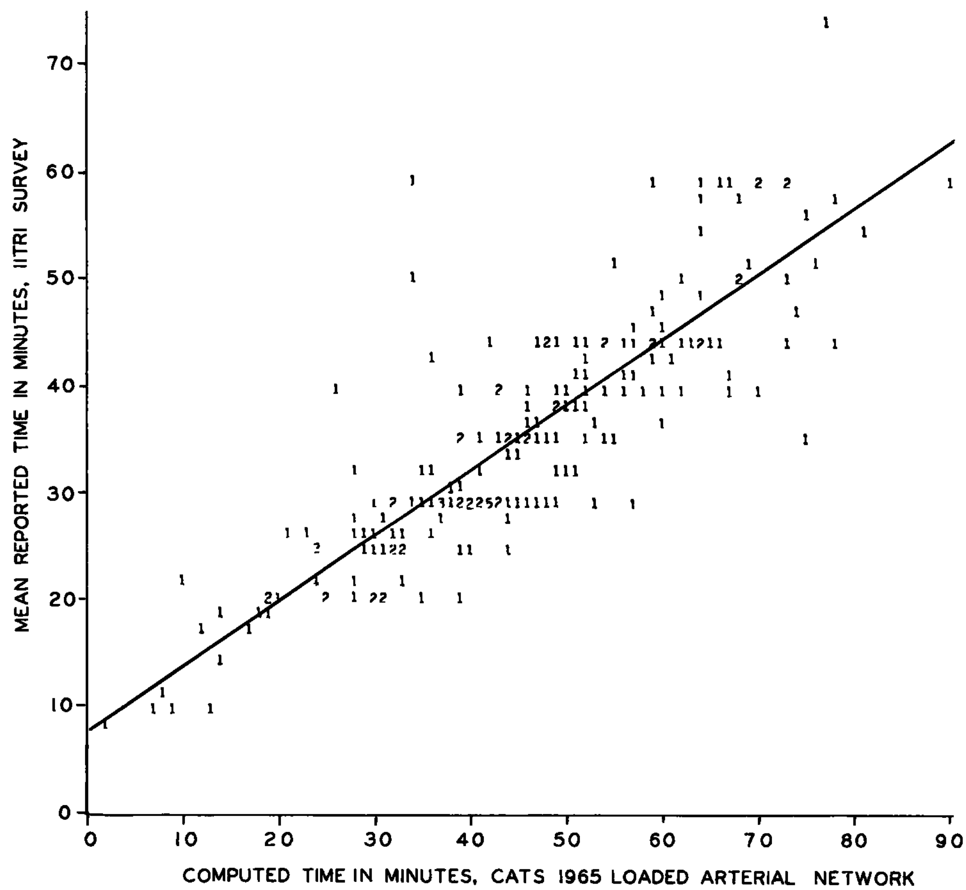

Figure 20. Reported travel time by car (mean value from IITRI work-trip survey) vs computed time (path value from loaded 1965 CATS arterial network). Frequency plot of paired values for 196 zones of residence. Curve is least-squares line of regression of reported on computed time.

time. To the extent of the difference, reported times would be expected to be shorter than the computed times. In view of this situation, the mean difference between transit computed and reported times, 10.5 min, is not excessive.

Further Correlations Among Travel Times and Distances

Correlations between additional pairs of variables, on a zone basis, are given in Table 20. All values, both reported and computed, refer to travel between zone 45 and other zones in the Chicago area. Noteworthy is the relatively strong correlation, 0.83, between reported travel time by car and reported travel distance. The comparable correlation between reported travel time by public transportation and reported travel distance is 0.71. The direct correlation between reported travel times by car and by public transportation is 0.64.

The correlations between reported distances and computed times, and between pairs of computed times (variable pairs 4 through 9 of Table 20), are in general higher than the correlations involving reported times.

MULTIVARIATE STATISTICAL MODELS OF MODAL CHOICE APPLIED TO SURVEY DATA

Purpose

The purpose of the analyses reported here is to assess effects on modal choice due to a number of variables acting jointly. In particular, characteristics of persons and households are treated in conjunction with properties of the transportation facilities available to them in order to clarify the complex of causes impinging on modal choice in a representative urban situation. The variables investigated include, so far as practicable, those which seem likely, either *a priori* or on the basis of substantial evidence from previous studies, to have a considerable impact on modal choice. Thus, the research phase covered here is in a sense the culmination of stage 2 of the project, because it constitutes a test, carried out with new data, of a collection of factors indicated, on grounds of inherent reasonableness or prior evidence, to be potentially useful predictors of modal choice.

Method

The method used here is that of multivariate linear regression analysis. Several particular models are formulated, each with a single dependent variable and multiple independent variables. The general model is of the form

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \epsilon \qquad (23)$$

in which y is the dependent variable, $x_1, \ldots, x_n$ are the independent variables, $\beta_0, \beta_1, \ldots, \beta_n$ are the unknown coefficients of the model, and ϵ represents the net effect of contributions to the value of y other than those specified by the first $n + 1$ terms on the right-hand side. Empirical

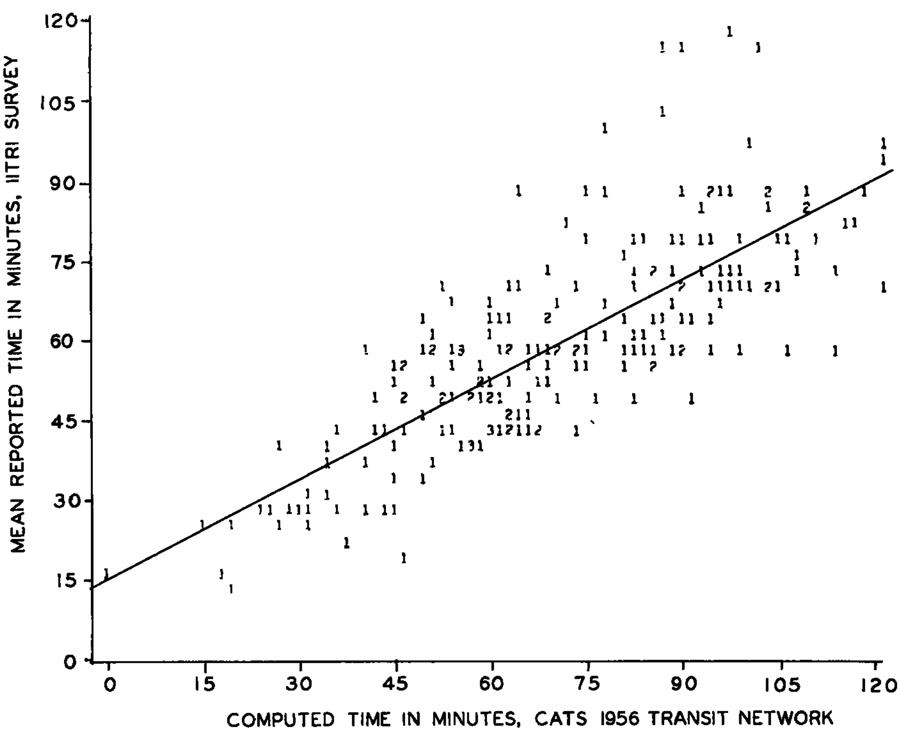

Figure 21. Reported travel time by public transportation (mean value from IITRI work-trip survey) vs computed time (path value from CATS 1965 transit network). Frequency plot of paired values for 215 zones of residence. Curve is least-squares line of regression of reported on computed time.

regression coefficients, $b_0, b_1, \ldots, b_n$, are computed as estimates of $\beta_0, \beta_1, \ldots, \beta_n$, respectively, from a set of m observations, each observation consisting of simultaneous values of $y, x_1, \ldots, x_n$, using the least-squares criterion; i.e., minimizing $\sum_{i=1}^{m} e_i^2$ in which

$$e_i = y_i - (b_0 + b_1x_{1i} + \ldots + b_nx_{ni}) \qquad (24)$$

The actual calculations were performed using an IBM type 7094 computer and a stepwise regression program (program BMD02R) written at the University of California, Los Angeles (*32*). At each step one independent variable is added to the regression equation. The variable added is the one which reduces the residual sum of squared deviations by the largest amount. Variance ratios (F values) are computed for all independent variables at each stage in the development of the regression equation, indicating the relative effect on the residual variance of removing a variable currently in the equation or introducing a variable currently not in the equation.

Variables and Data

The coefficients of the regression models were evaluated from data relating to 696 individual cases in the IITRI work-trip survey.

The complete set of variables, both dependent and independent, from which multiple-regression models were constructed is defined in Table 21. The empirical values of the variables consist of data from the IITRI work-trip survey except as otherwise noted in the following. The definitions of most of the variables given in Table 21 are self-explanatory; additional comments follow.

DEPENDENT VARIABLES

Eight different dependent variables, $y_1, \ldots, y_8$, are defined in Table 21. Each was included in one or more regression models. Dependent variables with odd-numbered subscripts (i.e., y_1, y_3, y_5, and y_7) designate the proportion (percentage) of the person's trips that belong to a specified trip category. Three categories of trips are recognized: (1) trips in which the person walks the entire distance (i.e., trip class 1 as defined earlier); (2) trips in which the person drives, or rides in, a car without using public transportation (i.e., trip classes 2 and 3 combined); (3) trips in which the person uses one or more forms of public transportation (bus, elevated-subway, railroad) (i.e., trip classes 4 through 9 combined). Trips to work and trips from work in each category were pooled prior to calculating the percentage occurrence. The dependent variables y_1, y_3, and y_5 designate, respectively, walking trips, car trips, and transit trips, each expressed as a percentage of all the person's trips. The dependent variable y_7 designates transit trips as a percentage of all trips by car or transit; i.e., eliminating walking trips from the total.

TABLE 20

CORRELATIONS AMONG REPORTED AND COMPUTED TRAVEL TIMES AND DISTANCES IN THE CHICAGO AREA ON A ZONE BASIS[a, b]

VARIABLE PAIR	VARIABLES: x_1	VARIABLES: x_2	NO. OF ZONES	PRODUCT-MOMENT CORRELATION, r, BETWEEN x_1 AND x_2
(1)	Reported times by car (zone means), IITRI survey	Reported travel distances (zone means), IITRI survey	246	0.83
(2)	Reported times by public transportation (zone means), IITRI survey	Reported travel distances (zone means), IITRI survey	215	0.71
(3)	Reported times by public transportation (zone means), IITRI survey	Reported times by car (zone means), IITRI survey	197	0.64
(4)	Computed times by car, CATS 1956 arterial network	Reported travel distances (zone means), IITRI survey	262	0.91
(5)	Computed times by public transportation, CATS 1956 transit network	Reported travel distances (zone means), IITRI survey	262	0.91
(6)	Computed times by public transportation, CATS 1956 transit network	Computed times by car, CATS 1956 arterial network	583	0.95
(7)	Computed times by car, CATS 1965 unloaded arterial network	Computed times by car, CATS 1956 arterial network	641	0.92
(8)	Computed times by car, CATS 1965 loaded arterial network	Computed times by car, CATS 1956 arterial network	373	0.90
(9)	Computed times by car, CATS 1965 loaded arterial network	Computed times by car, CATS 1965 unloaded arterial network	373	0.91

[a] All times and distances relative to zone 45. [b] Data from IITRI work-trip survey and CATS network descriptions.

TABLE 21

VARIABLES TESTED FOR INCLUSION IN MULTIPLE-REGRESSION MODELS OF FACTORS INFLUENCING CHOICE OF TRAVEL MODE, IITRI WORK-TRIP SURVEY

VARIABLE	DEFINITION
	(a) DEPENDENT VARIABLES
y_1	Walking trips, percent. Trips to or from work in which the person walks the entire distance, as percent of all trips.
y_2	Walking trips, normal deviate. Inverse probability function (deviate of the cumulative normal distribution with mean = 0 and standard deviation = 1) corresponding to y_1. Extreme values 0.0% and 100.0% are transformed into —3.00 and +3.00, respectively.
y_3	Automobile trips, percent. Trips to or from work in which the person drives or rides in a private automobile without using public transportation, expressed as percent of all trips.
y_4	Automobile trips, normal deviate. Inverse probability function (cf. y_2) of y_3.
y_5	Transit trips, percent. Trips to or from work in which the person uses public transportation (bus, elevated-subway, railroad) at least part of the way, expressed as percent of all trips.
y_6	Transit trips, normal deviate. Inverse probability function (cf. y_2) of y_5.
y_7	Transit vs automobile trips, percent. $y_7 = y_5/(y_3 + y_5)$.
y_8	Transit vs automobile trips, normal deviate. Inverse probability function (cf. y_2) of y_7.
	(b) INDEPENDENT VARIABLES, GROUP A
x_1	Sex. 1, male; 2, female.
x_2	Age. Years.
x_3	Age, quadratic. $x_3 = x_2^2$.
x_4	Salary level. 1, low; 2, low medium; 3, high medium; 4, high.
x_5	Salary level, quadratic. $x_5 = x_4^2$.
x_6	Residence time. Years at present residence.
x_7	Younger persons. No. of persons in household younger than 16.
x_8	Older persons. No. of persons in household 16 or older.
x_9	Drivers. No. of persons in household licensed to drive.
x_{10}	Cars. No. of cars owned by members of the household.
x_{11}	Cars, quadratic. $x_{11} = x_{10}^2$.
x_{12}	Cars-to-drivers ratio. $x_{12} = x_{10}/x_9$. $x_{12} = 0$ if $x_9 = 0$.
x_{13}	Drivership. 1, the person is licensed to drive; 2, not licensed to drive.
x_{14}	Transit proximity. Distance from home to station or stop where public transportation can be taken, in blocks.
x_{15}	Travel distance. Reported travel distance between home and work, in miles.
x_{16}	Travel distance, logarithmic. $x_{16} = \ln(10x_{15})$.
x_{17}	Straight-line distance. Euclidean distance between home and work computed from geographical coordinates, in miles.
x_{18}	Straight-line distance, logarithmic. $x_{18} = \ln x_{17}$.
x_{19}	Rectangular distance. Sum of north-south and east-west distances between home and work computed from geographical coordinates, in miles.
x_{20}	Rectangular distance, logarithmic. $x_{20} = \ln(10x_{19})$.
x_{21}	Walking travel time (for entire distance from home to work), in minutes.
x_{22}	Car travel time, in minutes.
x_{23}	Transit travel time, in minutes.
x_{24}	Time difference. $x_{24} = x_{23} - x_{22}$.
x_{25}	Time ratio, logarithmic. $x_{25} = \ln(x_{23}/x_{22})$.
x_{26}	Cost by car. Reported cost of trip by car, in dollars.
x_{27}	Cost by transit. Reported cost of trip by public transportation, in dollars.
x_{28}	Cost difference, first definition. $x_{28} = x_{27} - x_{26}$.
x_{29}	Cost difference, second definition. $x_{29} = x_{28} - 0.0436x_{15}$. Average reported travel cost by car is $0.0436 per mile.
x_{30}	Expressway use. No. of expressways and tollways used in car trip.
x_{31}	Distance walked. Total number of blocks walked in transit trip.
x_{32}	Transfers. Number of transfers in transit trip.
x_{33}	Waiting time. Time spent waiting for vehicles in transit trip, in minutes.
x_{34}	Seat probability. Percent probability of having a seat in transit trip.
	(c) INDEPENDENT VARIABLES, GROUP B: CROSS PRODUCTS
x_{35}	Sex times logarithm of time ratio. $x_{35} = x_1 x_{25}$.
x_{36}	Sex times expressway use. $x_{36} = x_1 x_{30}$.
x_{37}	Sex times distance walked. $x_{37} = x_1 x_{31}$.
x_{38}	Age times logarithm of time ratio. $x_{38} = x_2 x_{25}$.
x_{39}	Salary level times logarithm of time ratio. $x_{39} = x_4 x_{25}$.
x_{40}	Salary level times cost difference (first definition). $x_{40} = x_4 x_{28}$.
x_{41}	Salary level times cost difference (second definition). $x_{41} = x_4 x_{29}$.
x_{42}	Drivership times logarithm of time ratio. $x_{42} = x_{13} x_{25}$.
x_{43}	Drivership times cost difference (second definition). $x_{43} = x_{13} x_{29}$.
x_{44}	Cars times time difference. $x_{44} = x_{10} x_{24}$.
x_{45}	Cars-to-drivers ratio times logarithm of time ratio. $x_{45} = x_{12} x_{25}$.

Dependent variables with even-numbered subscripts are inverse-probability transforms of the preceding percentage variables (*35*). In other words, each percentage is transformed into the corresponding deviate of a cumulative normal distribution with zero mean and unit variance. The extreme percentages 0 and 100 are transformed into −3 and +3, respectively. These values correspond roughly with the limits of resolution of the work-trip data, inasmuch as there are at most 250 or so working days in a year, with possible trips in both directions; a normal deviate of −3 is equivalent to about 0.1 percent on the cumulative distribution curve and +3 is equivalent to about 99.9 percent.

INDEPENDENT VARIABLES

The independent variables are divided into two groups, A and B, in Table 21. The group B variables are cross-products of selected group A variables and were formed to represent possible interactions between them. The comments that follow apply to a subset of the group A variables requiring, in some cases, assignment of values by indirect methods. Respondents in the survey were asked for information concerning only those types of trips actually taken. For the present purpose, however, it is desired to specify travel opportunities not utilized, as well as those utilized, by each person. Just three trip categories are distinguished here, but information is needed describing these for every case.

Of first priority is information provided by, or known to apply to, a particular person. For example, if the person reported a type of trip involving public transportation, then in his case the values of variables x_{23} (transit travel time), x_{27} (cost by transit), etc., would be taken from the data of his questionnaire.

Second in priority is information provided by other persons participating in the survey who have the same zone of residence as the person with missing information. To make this second-priority information available, cases were aggregated by zone of residence and average values of the following variables were computed by zone from all applicable data: travel time and number of expressways used in trips by automobile; travel time, cost, distance walked, number of transfers, waiting time, and seat probability in trips by public transportation.

Of third priority in estimating travel time is the use of regression equations relating reported times to times computed from CATS network models, as discussed in the earlier section on "Relationships Among Reported and Computed Travel Times and Distances." Of lowest priority in estimating other trip properties is use of overall average values from the work-trip survey, or overall average values per unit of travel distance multiplied by reported travel distance.

The procedures followed in assigning alternative values to individual variables of Table 21 are as follows:

1. x_{21}, walking travel time. First alternative: travel distance divided by the overall average speed (2.5 mph) derived from trips of class 1.

2. x_{22}, car travel time. First alternative: zone average, from survey data. Second alternative: use of the equation from comparison 3 of Table 19 with interzonal time computed from CATS 1965 loaded arterial network. Third alternative: use of the equation from comparison 1 of Table 19 with interzonal time computed from CATS 1956 arterial network.

3. x_{23}, transit travel time. First alternative: zone average from survey data. Second alternative: use of the equation from comparison 4 of Table 19 with interzonal time computed from CATS 1956 transit network.

4. x_{26}, cost by car. First alternative: travel distance multiplied by the weighted average cost per mile ($0.0436) for travel by car for trip classes 2 and 3.

5. x_{27}, cost by transit. First alternative: zone average. Second alternative: if zone of residence is in the city of Chicago, $0.30; otherwise, travel distance multiplied by weighted average cost per mile ($0.0422) for trip classes 7, 8, and 9.

6. x_{30}, expressway use. First alternative: zone average. Second alternative: overall average number (1.4) of expressways reported in class 2 and 3 trips.

7. x_{31}, distance walked in transit trip. First alternative: zone average. Second alternative: overall average (3.6) of number of blocks walked in trips of classes 4 through 9.

8. x_{32}, transfers in transit trip. First alternative: zone average. Second alternative: overall average (1.2) of number of transfers in trips of classes 4 through 9.

9. x_{33}, waiting time in transit trip. First alternative: zone average. Second alternative: overall average waiting time (10.6 min) in trips of classes 4 through 9.

10. x_{34}, seat probability in transit trip. First alternative: zone average. Second alternative: weighted average of seat probabilities (72 percent) for bus, elevated-subway, and railroad trip segments.

Results

The final form of two of the multiple-regression models investigated is specified in Table 22. These are the models considered of greatest interest. The dependent variables are y_7, trips by public transportation as a percentage of trips by either car or public transportation, and y_8, the inverse probability transformation of y_7. The values of the regression coefficients corresponding to the listed independent variables are given, together with the standard errors of the regression coefficients and the variance ratios (*F* values), in Table 22.

The independent variables listed in Table 22 are a subset of those listed in Table 21. Actually, all 45 independent variables defined in Table 21 were candidates for inclusion in the two regression equations of Table 22. The variables not included in the equations had uniformly smaller *F* values than those included, in fact sufficiently small that their introduction would result in little further decrease in the residual variance.

The residual variance (mean square error) of y_7 is 983.28 with 683 degrees of freedom. The regression mean square is 42,246.22 with 12 degrees of freedom. The multiple correlation coefficient, R, is 0.6559; R^2 is 0.430. Thus, 43.0 percent of the total sum of squared deviations of the dependent variable, y_7, from its mean is accounted for by the effects of the independent variables.

TABLE 22

MULTIPLE REGRESSION MODELS OF MAJOR FACTORS INFLUENCING USE OF PUBLIC TRANSPORTATION (PT) VS PRIVATE AUTOMOBILES. DATA FROM IITRI WORK-TRIP SURVEY. RESULTS OF ANALYSIS OF TWO DIFFERENT DEPENDENT VARIABLES (y_7 *AND* y_8) AND 45 INDEPENDENT VARIABLES ($x_1, \ldots, x_{45}$)

	DEPENDENT VARIABLE					
	y_7: TRIPS INVOLVING PT AS % OF ALL TRIPS BY CAR OR PT			y_8: INVERSE PROBABILITY FUNCTION OF y_7		
INDEPENDENT VARIABLE	REGR. COEFF.	STD. ERROR	*F* RATIO	REGR. COEFF.	STD. ERROR	*F* RATIO
Constant term	151.6050	—	—	4.7414	—	—
x_2 Age	—2.8201	0.8258	11.66	—0.1830	0.0459	15.90
x_3 Age, square	0.04180	0.01091	14.67	0.00261	0.00060	19.09
x_5 Salary level, square	—	—	—	0.03215	0.01711	3.53
x_{10} Cars	—31.3240	7.7127	16.49	—1.6710	0.4081	16.76
x_{11} Cars, square	6.4255	2.2574	8.10	0.3433	0.1193	8.28
x_{12} Cars-to-drivers ratio	—14.6124	5.1290	8.12	—0.8668	0.2696	10.33
x_{13} Licensed to drive or not	21.6464	4.9071	19.46	1.3806	0.2577	28.70
x_{16} Travel distance, log	—20.5208	6.3451	10.46	—0.7814	0.3329	5.51
x_{18} Straight-line distance, log	30.9592	6.8952	20.16	1.4154	0.3620	15.29
x_{23} PT travel time	—0.2221	0.1056	4.43	—0.01481	0.00554	7.14
x_{25} PT-car time ratio, log	—12.1888	4.8859	6.22	—0.5174	0.2568	4.06
x_{29} PT-car cost difference	—38.9156	5.2817	54.29	—1.9036	0.2780	46.90
x_{33} PT waiting time	—1.4370	0.2534	32.17	—0.0612	0.0134	20.83

Similarly, the residual mean square of y_8 is 2.707 with 682 degrees of freedom and the regression mean square is 108.611 with 13 degrees of freedom. $R = 0.6583$ and $R^2 = 0.433$. Thus, 43.3 percent of the y_7 sum of squares is accounted for by the independent variables of the regression equation.

Interpretation

A number of substantive findings emerge from the multivariate statistical analyses that have been described.

First, there is structure in the data, in the sense that there is overwhelming evidence for the existence of functional relationships between the dependent and independent variables. The ratio of regression to residual mean squares, *F*, is 43 for the equation estimating y_7 and 40 for the equation estimating y_8. The expected value of *F* is one under the assumption that the independent variables have no systematic effects on the dependent variable.

The independent variables exerting major influence on the dependent variables, as measured by the individual *F* values, are relatively few in number. There are 12 independent variables in the first regression equation of Table 22 and 13 in the second. There were 45 candidate independent variables for each equation.

A smaller number of basic variables underlie the explicit set of independent variables in both equations, where by basic variables, as distinguished from transformed variables, are meant those closest to the original data. For example, there are both linear and quadratic terms in the single basic variable, age. The basic variables in the estimating expression for y_7 are 11 in number—age, cars, drivers, drivership, travel distance, straight-line distance, travel time by public transportation, travel time by car, cost by public transportation, cost by car, and waiting time in trips by public transportation. There is one additional basic variable—salary level—in the expression for y_8.

Examination of the independent variables not included in the regression equations of Table 22 is of equal interest with the examination of those included. There are 33 independent variables outside the equation for y_7 and 32 outside the equation for y_8. The following basic variables are not represented in either equation in any form: sex, length of time the person has lived at his present residence, number of persons in the household 16 years or older, number of persons younger than 16, proximity to public transportation, rectangular distance between home and work, walking time for the entire travel distance, number of expressways used in trips by car, distance walked in trip by public transportation, number of transfers, and seat probability. In addition, salary level is not represented in the first equation. Exclusion from the regression equations does not mean that the variables are totally without effect, but it does mean that the effects of the included variables are dominant.

It is striking that none of the cross-product variables, x_{35} through x_{45} (i.e., the group B independent variables of Table 21), appear in either regression equation. The interactions between the component variables of these cross-products are evidently slight, though several have significant main effects. This result supports the conclusion that relatively simple modal assignment models can capture nearly all the predictive power inherent in a given set of independent variables. There are apparently limits beyond which mathematical elaboration in model construction is pointless.

The regression equations for the two different dependent variables, y_7 and y_8, are similar to a large extent. One additional independent variable, x_5 (salary level squared), is in the second equation; however, the F value, 3.53, associated with the coefficient of this variable is the smallest of those listed in Table 22. Otherwise, the two sets of independent variables are identical.

FACTORS CITED AS IMPORTANT IN EVALUATION AND SELECTION OF MODES OF TRAVEL

Basic Data

Responses to the four open-ended questions included in the survey are presented in Table 23. The single set of factors and factor codes was set up after an initial listing of all the various answers given to these four questions. The factors are arranged in 20 groups for convenience of coding and reference.

The frequency of citation of each factor is given, broken down simultaneously by citation aspect and by trip class or switch direction. The frequencies of the replies written in under the following three headings in the questionnaire are given according to aspect and the class of trip referred to: (1) "reasons why that type of trip may be necessary", (2) "desirable features of that type of trip", and (3) "undesirable features of that type of trip." The three aspects—(1) "determinative", (2) "favorable", and (3) "unfavorable"—applied to the factors as listed in Table 23 correspond, respectively, to the three questionnaire headings.

The fourth open-ended question was answerable only if the person had switched to or from predominant use of public transportation for his work trips while maintaining his present places of employment and residence. The questionnaire heading under which replies were written in read "main reason or reasons for the switch." The frequencies of the cited factors are given in Table 23 according to the direction of the switch and under the single aspect "determinative."

Frequency and Aspect of Citation of Some General Travel Factors in Relation to Trip Mode

The basic data of Table 23 could be considered from many points of view. The approach taken here is to compare various kinds of trips with respect to the frequency of citation of some of the general factors or qualities most often invoked in assessing relative merit of travel alternatives. The factors are: (1) general preference or absence of real alternatives, (2) cost, (3) travel time, (4) variability of travel time, (5) convenience, (6) comfort, (7) effort and strain of travel, (8) danger or safety, and (9) effects of weather. Tables 24 through 32 present information on these factors, derived from Table 23. In each of the eight tables citation frequencies are given separately for trip classes 1 through 9. The data are also summarized by combining trip classes: trips by car (classes 2 and 3), trips by public transportation (classes 4, 5, 6, and 8), mixed-mode trips (classes 7 and 9), and all trips (classes 1 through 9, excluding "other" trips).

The number of factor citations for each trip class or combination is divided by the number of trip reports of that class to give the relative frequency of citation (expressed as a percentage). With the exception of Table 24, which is concerned solely with determinative factors (general preference or lack of real alternatives), each table classifies the frequency of citation of the subject factor by aspect: determinative with respect to selection of trip type, or favorable or unfavorable. If a factor is determinative of choice of a particular type of trip, it may also be said to favor it; so citations under the aspects of determinative and favorable can reasonably be combined when emphasizing the contrast between favorable and unfavorable assessments.

An index of the overall assessment of a specified kind of trip relative to a specified factor is defined here as a function of the numbers of determinative, favorable, and unfavorable citations and the number of trip reports. Let A be the assessment index, D be the number of citations of the factor under the aspect of determinative, F be the number of favorable and U the number of unfavorable citations, and N be the number of trip reports. Then,

$$A_{ij} = 100(D_{ij} + F_{ij} - U_{ij})/N_i \qquad (25)$$

in which i denotes the kind of trip and j the factor in question. The assessment index can be either positive or negative, depending on the balance between favorable and unfavorable citations. The factor of 100 in the above equation means that A is measured on a percentage scale.

The citation frequency for each of the general factors was found by pooling data from individual factor code groups in Table 23. The footnotes to Tables 24-32 state which code groups were pooled.

GENERAL PREFERENCE AND LACK OF REAL ALTERNATIVES

The number of citations of the factor "general preference and lack of real alternatives" (Table 24) was roughly proportional to the number of trip reports in the various trip classes. The lack of contrast in relative frequency of citation is particularly evident in the results for combined trip classes; the citation percentages are 15.0, 13.6, and 14.9 for automobile, transit, and mixed-mode trips, respectively. This factor was considered as determinative of choice of travel mode rather than as favorable or unfavorable.

TRAVEL COST

The travel cost factor (Table 25) was stated to be determinative of choice in 1.4 percent of all trip reports. Walking trips, car-passenger trips, and elevated-subway trips have the highest assessment indices ($A = 35$, 34, and 38, respectively), followed by trips with both elevated-subway and bus links ($A = 18$) or these in combination with automobile links ($A = 22$). High values of A in the present context indicate that the trip type is considered economical, low values of A indicate that it is considered expensive. Driving trips ($A = 9$), bus trips ($A = 11$), and trips with railroad and automobile links ($A = 8$) have relatively poor cost ratings, whereas railroad trips without automobile links have the lowest assessment index of all ($A = -13$).

TABLE 23

FREQUENCY OF CITATION OF FACTORS INFLUENCING MODAL CHOICE, IITRI WORK-TRIP SURVEY. FACTORS CITED UNDER ASPECT OF (1) DETERMINATIVE, (2) FAVORABLE, OR (3) UNFAVORABLE WITH RESPECT TO TYPE OF TRIP TAKEN, OR AS DETERMINATIVE WITH RESPECT TO A PREVIOUS SWITCH TO OR FROM PREDOMINATE USE OF PUBLIC TRANSPORTATION

FACTOR CODE	DEFINITION	ASPECT[a]	TRIP CLASS CITATIONS (NO.) WALK 1	DRIVE, CAR 2	RIDE, CAR 3	BUS 4	EL 5	BUS + EL 6	EL/BUS + CAR 7	RR 8	RR + CAR 9	OTHER 10	SWITCH DIRECTION TO PT	FROM PT
00	(No entry)	D	14	147	56	5	16	15	9	5	10	2		4
		F	9	54	28	21	10	34	6	14	3	3		
		U	17	107	78	5	18	12	11	8	5	2		
01	("None" or equivalent entered)	D	1	4	2		1	1	1			1		
		F	2	14	4	16	2	29	4	7	7			
		U	6	33	27		7	3	4		1	1		
09	Factor other than those listed below	D	1	1		1	1		3	1	1	1	3	2
		F	1		1				1	1		2		
		U		4	2				1					
	General reasons for choice:													
A1	Preferred, best	D	9	26	7		8	6	2		7			1
A2	Poor alternative(s)	D		14	3					1	1			
A3	No alternative	D	1	10	5	8	2	10		3	3	1		
A4	Normal, routine, usual, regular	D	2	36	9		10	11	2	2	3			
A5	Pleasant, enjoyable	D		1										
		F		3	3				1		1			
A6	Health	D												1
		F	1											
		U					1							
A7	Change, variety	D						1		1				2
		F		2	1									
A8	Reasonable alternative	D			1			1	1					
		F		1				2		2				
	Travel time:													
B1	Time, speed	D	1	34	9		1	2					2	37
		F	7	259	83	2	18	11	8	2	7	4		
		U	1	4	2	13	10	46	16	25	33	2		
B2	Time, except in rush periods	D		1										
		F		6										
B3	Uncertainty of arrival time	D											1	
		U		38	16	22	3	21	2	6	1			
B4	Certainty of arrival time	D		1										
		F		1			2	4	2	2	1			
B5	Reliability, dependability	D		1										
		F		1	1		4	1			1			
B6	Waste of time, boring	D											1	
		U		5		1		1						
B7	Delays	U		6	2		1	1		1				
	Cost:													
C1	Cost, expense	D		1									2	3
		F		1	1	1						1		
		U		31	2		1	2	3	13	11	3		
C2	Economy	D		5	7		1	2		1			6	5
		F	17	82	63	6	34	32	15	2	14	4		
C3	Wear on car	U		8										
C4	Save wear on car	D					1	1					1	
		F				1	4	1			2			
C5	Insurance rate	F						1						
		U		2										
	Danger, safety, accidents:													
D1	Danger	D											1	
		U	1	25	8	2	1	4		2		2		
D2	Danger at night	D		1										
		U							1		1	1		
D3	Safety	D			1						1		2	
		F	6	10	6	5	26	30	4	27	20	1		
D4	Safety at night	D		1										
		F		2										
D5	Possible accidents	U		19										
D6	Possible car failure	U		2	1									

TABLE 23 (*continued*)

FACTOR CODE	DEFINITION	ASPECT [a]	Trip class citations (no.): WALK 1	DRIVE, CAR 2	RIDE, CAR 3	BUS 4	EL 5	BUS + EL 6	EL/BUS + CAR 7	RR 8	RR + CAR 9	OTHER 10	Switch direction: TO PT	FROM PT
	Effort, strain, tension:													
E1	Driving strain	D					2				1		8	
		U		170	4				1					
E2	Less driving strain	D											1	
E3	No driving strain	D											1	
		F			3	2	6	7	2	2	5			
E4	Passenger strain	D											1	
		U			12									
E5	Relaxation, rest	D											4	
		F			3	2	5	5	3	11	4			
E6	Effort	U	1	31						1	1	1		
E7	Less effort	D		1										
		F	1	2	1			1						
E8	Fatigue	U	1	3				2		1				
E9	Tension, constant attention	U		5	1									
	Convenience, etc.:													
F1	Convenience	D	3	41	11	1	4	1	1		1	1	7	18
		F	15	295	102	11	40	33	10	7	7	7		
F2	Inconvenience	D												2
		U			1	1		4	1	4	6			
F4	Flexibility, mobility	D		4										
		F		20	1									
F5	Independence, no schedule	D		5										
		F		22	1									
F6	Easiest, simplest, practical	D	3	7	2		1							
		F		1	1		1	1						
F7	Lack of flexibility, mobility, or independence	U		4	8	2				1	1			
	Comfort, amenities within vehicles:													
G1	Comfort	D		1	1					1			3	7
		F	1	153	65	1	13	7	11	14	17	4		
G2	Discomfort	D												1
		U				1	4	8	2	6	1			
G3	Standing	D												2
		U				8	15	34	2	8	7			
G4	Standing during rush period	D												1
		U					1		2					
G5	Seat available	D				1								
		F		2	1	1		1	1		1			
G6	Crowding, congestion in vehicles	D		2										5
		U		1	1	11	21	51	3	5	9			
H1	Privacy	D		1										
		F		5	1									
H2	Lack of privacy	U		1	1		1	1						
H3	Can read, study, work	D											6	
		F			9	4	49	58	27	27	40	3		
H4	Can't read, etc.	U		11	4									
H5	Can converse	D			2									
		F		3	7	1			1					
H7	Listen to radio	F		7	1									
H8	Smoke	F		2	1									
		U				1	1	1	1		1			
H9	Sleep	F			2		3	2	2	2	7			
I1	Air	F								1	1			
		U		1										
I2	Air conditioning	D											1	
		F						1			1			
I3	Dirt, fumes, odors	D											1	
		U		1			2	7						
I4	Cleanliness	F		1										
I5	Temperature	U						1	1	1				
I6	Noise, vibration	U					3	1	2					
I7	Disagreeable passengers	U				2		2						
I8	Bus drivers	U						1	1					

TABLE 23 (*continued*)

FACTOR CODE	DEFINITION	ASPECT [a]	TRIP CLASS CITATIONS (NO.) WALK 1	DRIVE, CAR 2	RIDE, CAR 3	BUS 4	EL 5	BUS + EL 6	EL/BUS + CAR 7	RR 8	RR + CAR 9	OTHER 10	SWITCH DIRECTION TO PT	FROM PT
	Weather:													
J1	Weather	D				1		1	1			1		1
		F		1			1							
		U		4		1	3	3	1	1		1		
J2	Exposure to weather	D												2
		U	18			42	35	82	6	24	16	4		
J3	Less or no exposure to weather	F		2	1			2	1		1			
J4	Bad weather	D	1	16	6	14	16	52	9	31	16	2		
		U	3	5	1		1	1			1			
J5	Good weather	D	2	2						1		1		
		F								1				
J6	Bad weather driving	D	1				3	3					1	
		U		20	2									
J7	Cold in winter	U	1						1	1				
J8	Better in bad weather	D		1				3		2				
		F	1	4	1	2	5	4	1	3				
	Environment:													
K1	Beauty, scenery	F	2	1				1				2		
K3	Pleasant neighborhood	F									1			
K4	Unpleasant neighborhood	D												2
		U	2	1			1	4			1			
K5	Poor lighting	U					1							
K6	People watching	F						3						
	Walking, bicycling:													
L1	Walking	D		1			1							1
		F	1					1		1	2			
		U			1	8	13	26	1	15	5			
L2	Less or no walking	D		1									1	
		F		1	1			3	1					
		U		1				1	1					
L3	Like to walk	D	1											
		F	3				2			4	1			
L4	Exercise, fresh air	D					1			1		2		
		F	8				6			3	1	1		
L5	Better than walking	D		1										
		F		1		2		1						
L6	No bike rack, bike parking	U										1		
	Driving task:													
M1	Like to drive, don't mind	D		1										
		F		51	1									
M2	Dislike driving	D						4		1	1		2	
		F					1	1			1			
		U		5										
M3	Tired of driving	D						1		1			1	
		F					1							
M4	Can't or don't drive	D					2	1	1		1	1		
M5	Physical disability for driving	D						1			1		1	
	Car availability:													
N1	Car not available, not operable	D	5		33	47	27	95	15	33	17	5	2	
N2	Don't have car	D	3			1	10	2						
N3	Car available or needed at home, by wife, etc.	D	1		8	3	8	15	9	7	11	1	1	
		F			3						1			
N4	Car not available at home	U		11										
N5	Acquired car or additional car	D											17	
		U		1										
N6	Disposed of car	D										2		
N7	Car available, became (more) available	D		4	1								4	

TABLE 23 (*continued*)

FACTOR CODE	DEFINITION	ASPECT [a]	TRIP CLASS CITATIONS (NO.): WALK 1	DRIVE, CAR 2	RIDE, CAR 3	BUS 4	EL 5	BUS + EL 6	EL/BUS + CAR 7	RR 8	RR + CAR 9	OTHER 10	SWITCH DIRECTION: TO PT	FROM PT
	Car need, uses:													
P1	Car needed or better for errands, etc.	D		108	3									
		F		4										
P2	Car needed for work	D		65										
		F		1										
P3	Work non-standard hours, go to school	D		31	1		1	3		3	1			3
		F		3										
P4	Carry packages	D		5										
		F		1										
		U				1		1						
P5	Purchase gasoline	D		7	1									
		F		1										
P6	Go home or out for lunch	D		2										
P7	Better for late or off hours	D		5						1	1			
		F		3										
	Car pool and riding arrangements:													
Q1	Car pool member	D		29	30									3
Q2	Car pool started, joined car pool	D												2
Q3	Car pool disbanded, left car pool	D											4	
Q4	Uncertainty or difficulty of arrangement	D											1	
		U		1	13									
Q5	Miss car pool	D								2	1			
Q6	Pick up or discharge others	D		1										
		U		3	2									
Q7	Wait for others	U		5	14				1					
Q8	Inconvenience others	U		1	6				6					
R1	Take passenger(s)	D		2										1
R2	Ride available	D			17				1		1			1
R3	Ride not available	D		2		3	1	13	2	2	2	1	1	
R4	Driver not available	D		1		2	1	5			1			
R5	Miss ride	D							1	1				
	Road network, congestion:													
S1	Congestion	D						3		1	1		7	
		U		202	26	1		3		1				
S2	Congestion in rush periods	D					1		1				1	
		U		10										
S3	Road repairs	U		4										
S4	Trucks on road	U		1										
S5	Dan Ryan Expressway opened	D												1
S6	Stevenson (SW) Expressway opened	D												7
	Parking:													
T1	Parking	F				1								
		U		13										
T2	Parking, walking in lot	D	1											
		F				1								
		U		4	1									
T3	No parking problems	F	1					2						
	Public transportation, general reactions:													
U1	Poor PT	D		17	5									8
		U						1						
U2	Dislike PT	D		3										2
		F		1										
		U						2						
U3	Dislike buses	D												1
		U				1								
U5	Poor equipment	U				1	2	2						
U6	New or better equipment	D											1	

TABLE 23 (*continued*)

FACTOR CODE	DEFINITION	ASPECT [a]	TRIP CLASS CITATIONS (NO.): WALK 1	DRIVE, CAR 2	RIDE, CAR 3	BUS 4	EL 5	BUS + EL 6	EL/BUS + CAR 7	RR 8	RR + CAR 9	OTHER 10	SWITCH DIRECTION: TO PT	FROM PT
V1	Use for errands or meetings in Loop	D					1	1		2	1			
V2	Car left at home	D	1					1		1				
		F	1				1	1						
V3	Always available	D											1	
		F	1			1		1		2				
	Public transportation access, stops, stations:													
W1	Too far to PT, distance	D		1										
		U							1					
W2	Difficult to get to station	D												1
		U							1					
W3	Poor stations	U						1		1	1			
W4	Stairs at station	U					1							
W5	Miss bus or train	D		5	1		1	1	1					
W6	Buses pass by	U				3								
W7	Too many stops	U						1	1		1			
W8	Uncertainty of getting vehicle	D	1					1						1
		U						1						
	Public transportation schedules and routes:													
X1	Poor schedules, routes	D		1										1
		U						1		4	1			1
X2	Irregular schedules, service	D		1						1				1
		U						3						
X3	Fixed, rigid schedules	U						2		8	3			
X4	Good schedule	D						1					1	
		F					1	1	1					
X5	Poor late or off-hours service	D		4										2
		F		1										
		U					3	3	1	1	2			
X6	Poor connections between RR and elevated-subway	U								2	2			
X7	North Shore line closed	D												2
X8	Skokie Swift line opened	D											2	
	Public transportation waiting, transferring:													
Y1	Waiting	U	1			45	10	89	6	20	14	1		
Y2	No or less waiting	D							1					
		F		10	1		2							
Y3	Transferring	D		1										3
		U				18	4	67	4	24	23			
Y4	No or less transferring	D		2	1									
		F		6			1							
Y5	Transferring in bad weather	U						3						
Y7	Transferring in loop	D	2											1
		U						1		3	1			

[a] D = determinative; F = favorable; U = unfavorable.

TRAVEL TIME

The travel time factor (Table 26) was cited as determinative in 3.6 percent of all trip reports and in 6.0 percent of automobile trip reports. There are marked differences between the trip classes with respect to this factor. The assessment index has the high value $A = 53$ for trips by car (classes 2 and 3 combined). Walking trips ($A = 15$) and elevated-subway trips ($A = 9$) are the only other trip classes for which A is positive. Bus trips ($A = -15$), trips with both bus and elevated-subway links ($A = -17$), and mixed-mode trips without railroad links ($A = -15$) are assessed considerably lower. Railroad trips (classes 8 and

9 combined) have the lowest assessment ($A = -34$) with respect to travel time.

VARIABILITY OF TRAVEL TIME

The variability of travel time (Table 27) may be considered separately from average travel time in terms of survey response categories. The number of citations (142) is quite small, and in only two instances (both driving trips) was this factor recorded as determinative. The assessment index is non-negative only for walking trips ($A = 0$), elevated-subway trips ($A = 2$), trips by elevated-subway and/or bus in combination with car ($A = 0$), and trips by railroad in combination with car ($A = 2$). Car driving and passenger trips ($A = -8$), trips with elevated-subway and bus links ($A = -9$), and railroad trips without car links (A = −7) are clustered at a somewhat lower level on the assessment scale. Pure bus trips rate considerably lower with respect to variability of travel time ($A = -30$).

CONVENIENCE

Convenience (Table 28) is the general travel factor most often cited in the survey. In terms of the component code groups combined under the general names, there are 686 references to convenience and 601 references to travel time in the data of Tables 28 and 26, respectively. These are considerably larger than the totals for any other general factors.

Convenience was stated to be determinative in 6.3 percent of the trip reports, with concentration in walking, car driver and passenger, and elevated-subway trips. Car driver trips have the highest assessment index ($A = 73$) followed by car passenger trips ($A = 54$). Walking trips ($A = 44$) and elevated-subway trips ($A = 45$) are next in level of convenience as measured by their index values. Trips by bus or involving combinations of car, bus, and elevated-subway links are judged lower in convenience ($A = 12$, 16, and 18 for trips of classes 4, 6, and 7, respectively). Assessed lowest in convenience are railroad trips with or without use of a car ($A = 2$).

TABLE 24

GENERAL PREFERENCE AND LACK OF REAL ALTERNATIVES AS FACTORS STATED TO BE DETERMINATIVE OF MODAL CHOICE, IITRI WORK-TRIP SURVEY. FREQUENCY OF CITATION OF THESE FACTORS[a] CLASSIFIED BY TYPE OF TRIP

TRIP CLASS	NO. OF TRIP REPORTS	CITATIONS (NO.)	CITATIONS (%)
(1) Walk	48	12	25.0
(2) Drive, car	532	86	16.2
(3) Ride, car	202	24	11.9
(4) Bus	74	8	10.8
(5) El	103	20	19.4
(6) Bus + el	196	27	13.8
(7) El/bus + car	54	4	7.4
(8) RR	76	6	7.9
(9) RR + car	67	14	20.9
Combined:			
(2), (3) Car	734	110	15.0
(4)–(6), (8) PT	449	61	13.6
(7), (9) Mixed	121	18	14.9
(1)–(9) All	1352	201	14.9

[a] Numbers of citations are pooled counts from these factor code groups: A1, preferred, best; A2, poor alternative(s); A3, no alternative, A4, normal, routine, usual, regular.

TABLE 25

TRAVEL COST AS A STATED FACTOR IN MODAL CHOICE, IITRI WORK-TRIP SURVEY. FREQUENCY OF CITATION OF THIS FACTOR[a] CLASSIFIED JOINTLY BY TYPE OF TRIP AND BY ASPECT

TRIP CLASS	NO. OF TRIP REPORTS	CITATION ASPECT: DETERMINATIVE (NO.)	DETERMINATIVE (%)	FAVORABLE (NO.)	FAVORABLE (%)	UNFAVORABLE (NO.)	UNFAVORABLE (%)
(1) Walk	48	0	0.0	17	35.4	0	0.0
(2) Drive, car	532	6	1.1	83	15.6	41	7.7
(3) Ride, car	202	7	3.5	64	31.7	2	1.0
(4) Bus	74	0	0.0	8	10.8	0	0.0
(5) El	103	2	1.9	38	36.9	1	1.0
(6) Bus + el	196	3	1.5	34	17.3	2	1.0
(7) El/bus + car	54	0	0.0	15	27.8	3	5.6
(8) RR	76	1	1.3	2	2.6	13	17.1
(9) RR + car	67	0	0.0	16	23.9	11	16.4
Combined:							
(2), (3) Car	734	13	1.8	147	20.0	43	5.8
(4)–(6), (8) PT	449	6	1.3	82	18.3	16	3.6
(7), (9) Mixed	121	0	0.0	31	25.6	14	11.6
(1)–(9) All	1352	19	1.4	277	20.5	73	5.4

[a] Numbers of citations are pooled counts from these factor code groups: C1, cost, expense, C2, economy; C3, wear on car; C4, save wear on car; C5, insurance rate

COMFORT

Comfort (Table 29) was declared to be determinative of choice in only 0.2 percent of trip reports. The highest assessment indices are associated with car driver trips ($A = 29$), car passenger trips ($A = 33$), and railroad-auto trips ($A = 24$). Intermediate index values are associated with trips having car and elevated-subway or bus links ($A = 17$), trips with railroad but not car links ($A = 12$), and elevated-subway trips ($A = 9$). Walking trips ($A = 2$), bus trips ($A = 0$), and trips with both bus and elevated-subway links ($A = 0$) have the lowest assessment indices.

EFFORT AND STRAIN OF TRAVEL

The physical and mental effort and strain of travel are

TABLE 26

DOOR-TO-DOOR TRAVEL TIME OR SPEED AS A STATED FACTOR IN MODAL CHOICE, IITRI WORK-TRIP SURVEY. FREQUENCY OF CITATION OF THIS FACTOR[a] CLASSIFIED JOINTLY BY TYPE OF TRIP AND BY ASPECT

TRIP CLASS	NO. OF TRIP REPORTS	CITATION ASPECT: DETERMINATIVE (NO.)	DETERMINATIVE (%)	FAVORABLE (NO.)	FAVORABLE (%)	UNFAVORABLE (NO.)	UNFAVORABLE (%)
(1) Walk	48	1	2.1	7	14.6	1	2.1
(2) Drive, car	532	35	6.6	265	49.8	4	0.8
(3) Ride, car	202	9	4.4	83	41.1	2	1.0
(4) Bus	74	0	0.0	2	2.7	13	17.6
(5) El	103	1	1.0	18	17.5	10	9.7
(6) Bus + el	196	2	1.0	11	5.6	46	23.5
(7) El/bus + car	54	0	0.0	8	14.8	16	29.6
(8) RR	76	0	0.0	2	2.6	25	32.9
(9) RR + car	67	0	0.0	7	10.4	33	49.2
Combined:							
(2), (3) Car	734	44	6.0	348	47.4	6	0.8
(4)-(6), (8) PT	449	3	0.7	33	7.3	94	20.9
(7), (9) Mixed	121	0	0.0	15	12.3	49	40.5
(1)-(9) All	1352	48	3.6	403	29.8	150	11.1

[a] Numbers of citations are pooled counts from these factor code groups: B1, time, speed; B2, time, except in rush periods.

TABLE 27

VARIABILITY IN TRAVEL TIME AS A STATED FACTOR IN MODAL CHOICE, IITRI WORK-TRIP SURVEY. FREQUENCY OF CITATION OF THIS FACTOR[a] CLASSIFIED JOINTLY BY TYPE OF TRIP AND BY ASPECT

TRIP CLASS	NO. OF TRIP REPORTS	CITATION ASPECT: DETERMINATIVE (NO.)	DETERMINATIVE (%)	FAVORABLE (NO.)	FAVORABLE (%)	UNFAVORABLE (NO.)	UNFAVORABLE (%)
(1) Walk	48	0	0.0	0	0.0	0	0.0
(2) Drive, car	532	2	0.4	2	0.4	44	8.3
(3) Ride, car	202	0	0.0	1	0.5	18	8.9
(4) Bus	74	0	0.0	0	0.0	22	29.7
(5) El	103	0	0.0	6	5.8	4	3.9
(6) Bus + el	196	0	0.0	5	2.6	22	11.2
(7) El/bus + car	54	0	0.0	2	3.7	2	3.7
(8) RR	76	0	0.0	2	2.6	7	9.2
(9) RR + car	67	0	0.0	2	3.0	1	1.5
Combined:							
(2), (3) Car	734	2	0.3	3	0.4	62	8.4
(4)-(6), (8) PT	449	0	0.0	13	2.9	55	12.2
(7), (9) Mixed	121	0	0.0	4	3.3	3	3.3
(1)-(9) All	1352	2	0.1	20	1.5	120	8.9

[a] Numbers of citations are pooled counts from these factor code groups: B3, uncertainty of arrival time; B4, certainty of arrival time; B5, reliability, dependability; B7, delays.

TABLE 28

CONVENIENCE AS A STATED FACTOR IN MODAL CHOICE, IITRI WORK-TRIP SURVEY. FREQUENCY OF CITATION OF THIS FACTOR[a] CLASSIFIED JOINTLY BY TYPE OF TRIP AND BY ASPECT

TRIP CLASS	NO. OF TRIP REPORTS	CITATION ASPECT: DETERMINATIVE (NO.)	DETERMINATIVE (%)	FAVORABLE (NO.)	FAVORABLE (%)	UNFAVORABLE (NO.)	UNFAVORABLE (%)
(1) Walk	48	6	12.5	15	31.2	0	0.0
(2) Drive, car	532	57	10.7	338	63.5	4	0.8
(3) Ride, car	202	13	6.4	105	52.0	9	4.4
(4) Bus	74	1	1.4	11	14.9	3	4.0
(5) El	103	5	4.8	41	39.8	0	0.0
(6) Bus + el	196	1	0.5	34	17.3	4	2.0
(7) El/bus + car	54	1	1.8	10	18.5	1	1.8
(8) RR	76	0	0.0	7	9.2	5	6.6
(9) RR + car	67	1	1.5	7	10.4	7	10.4
Combined:							
(2), (3) Car	734	70	9.5	443	60.4	13	1.8
(4)–(6), (8) PT	449	7	1.6	93	20.7	12	2.7
(7), (9) Mixed	121	2	1.6	17	14.0	8	6.6
(1)–(9) All	1352	85	6.3	568	42.0	33	2.4

[a] Numbers of citations are pooled counts from these factor code groups. F1, convenience; F2, inconvenience; F4, flexibility, mobility; F5, independence, no schedule; F6, easiest, simplest, practical; F7, lack of flexibility, mobility, or independence.

covered by this general factor (Table 30). Very few of the respondents (0.2 percent) listed this factor as determining choice of travel mode. There is a sharp contrast between driving and other classes of trips with respect to this factor. The assessment index for driving trips ($A = -39$) is much lower than the next lowest values for car passenger trips ($A = -5$) and walking trips ($A = -2$). All other classes of trips have positive indices. Trips by bus ($A = 5$), by a combination of bus and elevated-subway ($A = 6$), and by car together with elevated-subway and/or bus ($A = 7$) have similar index values. The highest indices are associated with elevated-subway trips ($A = 13$) and railroad trips as a whole ($A = 14$).

DANGER OR SAFETY

Again, danger or safety (Table 31) was rarely named as

TABLE 29

COMFORT AS A STATED FACTOR IN MODAL CHOICE, IITRI WORK-TRIP SURVEY. FREQUENCY OF CITATION OF THIS FACTOR[a] CLASSIFIED JOINTLY BY TYPE OF TRIP AND BY ASPECT

TRIP CLASS	NO. OF TRIP REPORTS	CITATION ASPECT: DETERMINATIVE (NO.)	DETERMINATIVE (%)	FAVORABLE (NO.)	FAVORABLE (%)	UNFAVORABLE (NO.)	UNFAVORABLE (%)
(1) Walk	48	0	0.0	1	2.1	0	0.0
(2) Drive, car	532	1	0.2	153	28.8	0	0.0
(3) Ride, car	202	1	0.5	65	32.2	0	0.0
(4) Bus	74	0	0.0	1	1.4	1	1.4
(5) El	103	0	0.0	13	12.6	4	3.9
(6) Bus + el	196	0	0.0	7	3.6	8	4.1
(7) El/bus + car	54	0	0.0	11	20.4	2	3.7
(8) RR	76	1	1.3	14	18.4	6	7.9
(9) RR + car	67	0	0.0	17	25.4	1	1.5
Combined:							
(2), (3) Car	734	2	0.3	218	29.7	0	0.0
(4)–(6), (8) PT	449	1	0.2	35	7.8	19	4.2
(7), (9) Mixed	121	0	0.0	28	23.1	3	2.5
(1)–(9) All	1352	3	0.2	282	20.8	22	1.6

[a] Numbers of citations are pooled counts from these factor code groups: G1, comfort, G2, discomfort.

TABLE 30

EFFORT AND STRAIN OF TRAVEL AS A STATED FACTOR IN MODAL CHOICE, IITRI WORK-TRIP SURVEY. FREQUENCY OF CITATION OF THIS FACTOR[a] CLASSIFIED JOINTLY BY TYPE OF TRIP AND BY ASPECT

TRIP CLASS	NO. OF TRIP REPORTS	CITATION ASPECT: DETERMINATIVE (NO.)	DETERMINATIVE (%)	FAVORABLE (NO.)	FAVORABLE (%)	UNFAVORABLE (NO.)	UNFAVORABLE (%)
(1) Walk	48	0	0.0	1	2.1	2	4.2
(2) Drive, car	532	1	0.2	2	0.4	209	39.3
(3) Ride, car	202	0	0.0	7	3.5	17	8.4
(4) Bus	74	0	0.0	4	5.4	0	0.0
(5) El	103	2	1.9	11	10.7	0	0.0
(6) Bus + el	196	0	0.0	13	6.6	2	1.0
(7) El/bus + car	54	0	0.0	5	9.2	1	1.8
(8) RR	76	0	0.0	13	17.1	2	2.6
(9) RR + car	67	1	1.5	9	13.4	1	1.5
Combined:							
(2), (3) Car	734	1	4.6	9	1.2	226	30.8
(4)–(6), (8) PT	449	2	0.4	41	9.1	4	0.9
(7), (9) Mixed	121	1	0.8	14	11.6	2	1.6
(1)–(9) All	1352	3	0.2	65	4.8	234	17.3

[a] Numbers of citations are pooled counts from these factor code groups: E1, driving strain; E3, no driving strain; E4, passenger strain; E5, relaxation, rest; E6, effort; E7, less effort; E8, fatigue; E9, tension, constant attention.

determinative of choice (0.3 percent of trip reports). The highest assessment indices indicating relative safety are for railroad trips as a whole ($A = 31$) and elevated-subway trips ($A = 24$). Next are trips with both elevated-subway and bus links ($A = 13$) and walking trips ($A = 10$). Pure bus trips ($A = 4$) and mixed-mode automobile-rapid transit-bus trips ($A = 6$) have the lowest assessment indices of any of the classes of trips involving public transportation. The lowest indices are for car-passenger trips ($A = -1$) and car-driver trips ($A = -6$).

WEATHER

Vulnerability to weather is, to a greater or lesser extent, and in various ways, a characteristic of all types of trips.

TABLE 31

DANGER OR SAFETY AS A STATED FACTOR IN MODAL CHOICE, IITRI WORK-TRIP SURVEY. FREQUENCY OF CITATION OF THIS FACTOR[a] CLASSIFIED JOINTLY BY TYPE OF TRIP AND BY ASPECT

TRIP CLASS	NO. OF TRIP REPORTS	CITATION ASPECT: DETERMINATIVE (NO.)	DETERMINATIVE (%)	FAVORABLE (NO.)	FAVORABLE (%)	UNFAVORABLE (NO.)	UNFAVORABLE (%)
(1) Walk	48	0	0.0	6	12.5	1	2.1
(2) Drive, car	532	2	0.4	12	2.2	46	8.6
(3) Ride, car	202	1	0.5	6	3.0	9	4.4
(4) Bus	74	0	0.0	5	6.8	2	2.7
(5) El	103	0	0.0	26	25.2	1	1.0
(6) Bus + el	196	0	0.0	30	15.3	4	2.0
(7) El/bus + car	54	0	0.0	4	7.4	1	1.8
(8) RR	76	0	0.0	27	35.5	2	2.6
(9) RR + car	67	1	1.5	20	30.0	1	1.5
Combined:							
(2), (3) Car	734	3	0.4	18	2.4	55	7.5
(4)–(6), (8) PT	449	0	0.0	88	19.6	9	2.0
(7), (9) Mixed	121	1	0.8	24	19.8	2	1.6
(1)–(9) All	1352	4	0.3	136	10.0	67	5.0

[a] Numbers of citations are pooled counts from these factor code groups: D1, danger; D2, danger at night; D3, safety; D4, safety at night; D5, possible accidents; D6, possible car failure.

Personal exposure to weather is a particular drawback for some kinds of trips, hazardous driving for others. A large proportion (13.1 percent) of the citations of this factor were under the aspect of constraining or determining choice (Table 32). This was especially so for the public-transportation trips, where the proportion of determinative citations ranges from 18 to 43 percent. Walking trips ($A = -40$) and bus trips ($A = -35$) have the lowest assessment indices with respect to weather effects. Next lowest are elevated-subway trips ($A = -14$) and trips combining bus and elevated-subway ($A = -11$). Car-driver trips ($A = -1$), car-passenger trips ($A = 2$), trips with car and railroad links ($A = 0$), and trips with car plus elevated-subway and/or bus links ($A = 7$) have higher indices. Finally, the trip class with the highest assessment index relative to weather is railroad ($A = 13$).

Some Additional Specific Factors Related to Modal Choice

Table 23 contains detailed data on a large number of specific factors that survey respondents considered important with respect to modal choice. These specific factors are in addition to the more general factors treated in the preceding section. Those specific factors cited most frequently in connection with the various classes of trips are pointed out here. Again, there are three aspects under which factors can be ascribed to trips—determinative, favorable, and unfavorable.

DETERMINATIVE FACTORS

Car unavailability, on the one hand, and car necessity, on the other, comprise the most frequently cited specific factors determining non-driving and driving trips, respectively. The specific factors (with their codes, see Table 23) under car unavailability are "car not available or not operable" (N1), "don't have car" (N2), and "car needed at home" (N3). The specific factors under car necessity are "car needed or better for errands" (P1), "car needed for work" (P2), and "work nonstandard hours" (P3).

FAVORABLE FACTORS

"Exercise, fresh air" (L4) was stated to be a desirable property of walking trips by eight persons out of 48 reporting this type of trip. "Like to drive, don't mind driving" (M1) was a factor cited in 10 percent of the reports of driving trips. The factor "can read, study, work" (H3) was with consistently high frequency stated to be a favorable aspect of trips by rail. The trip classes with the proportion of reports in which this factor was favorably cited are: elevated-subway, 48 percent; bus + elevated-subway, 30 percent; car + elevated-subway and/or bus, 50 percent; car + railroad, 36 percent; railroad, 60 percent.

UNFAVORABLE FACTORS

The specific factor most often cited as unfavorable to car trips is "congestion" (S1). This was noted on 38 percent of car-driver reports and on 13 percent of car-passenger reports.

The unfavorable factors most frequently noted on reports of trips involving public transportation are: "waiting" (Y1), 185 citations; "transferring" (Y3), 140 citations; "crowding and congestion in vehicles" (G6), 100 citations; "standing" (G3), 74 citations; and "walking" (L1), 68 citations.

TABLE 32

WEATHER AS A STATED FACTOR IN MODAL CHOICE, IITRI WORK-TRIP SURVEY. FREQUENCY OF CITATION OF THIS FACTOR[a] CLASSIFIED JOINTLY BY TYPE OF TRIP AND BY ASPECT

		CITATION ASPECT					
	NO. OF	DETERMINATIVE		FAVORABLE		UNFAVORABLE	
TRIP CLASS	TRIP REPORTS	(NO.)	(%)	(NO.)	(%)	(NO.)	(%)
(1) Walk	48	2	4.2	1	2.1	22	45.8
(2) Drive, car	532	17	3.2	7	1.3	29	5.4
(3) Ride, car	202	6	3.0	2	1.0	3	1.5
(4) Bus	74	15	20.3	2	2.7	43	58.1
(5) El	103	19	18.4	6	5.8	39	37.9
(6) Bus + el	196	59	30.1	6	3.1	86	43.9
(7) El/bus + car	54	10	18.5	2	3.7	8	14.8
(8) RR	76	33	43.4	3	3.9	26	34.2
(9) RR + car	67	16	23.9	1	1.5	17	25.4
Combined:							
(2), (3) Car	734	23	3.1	9	1.2	32	4.4
(4)–(6), (8) PT	449	126	28.1	17	3.8	194	43.2
(7), (9) Mixed	121	26	21.5	3	2.5	25	20.7
(1)–(9) All	1352	177	13.1	30	2.2	273	20.2

[a] Numbers of citations are pooled counts from these factor code groups; J1, weather; J2 exposure to weather; J3, less or no exposure to weather; J4, bad weather, J6, bad weather driving; J7, cold in winter; J8, better in bad weather.

Factors Motivating Switches Between Major Modes of Travel

There were 150 instances in which the person responded affirmatively to the question on switching major mode of travel while working at IITRI and residing at his or her present address. In one-third (51) of these cases the switch was to greater use of public transportation facilities; in the remaining two-thirds (99) of the cases the switch was in the opposite direction.

The reasons given for having made the switch to or from use of public transportation for most work trips are presented in Table 33. The specific factors as originally listed in Table 23 are indexed by the factor codes in Table 33. These specific factors are grouped into ten classes of reasons. The frequencies of citation of reasons in each class are given separately for mode changes in the two directions. Frequencies are expressed as numbers of citations of factors in each class and also as a percentage of the number of switches.

The effort and strain involved in driving, and highway congestion, were cited most often (27 citations or 53 percent of the number of switches) as factors motivating the change to greater use of public transportation. Factors related to the availability of means of transportation (14 citations), cost (9 citations), and convenience (9 citations) were next in frequency of occurrence.

Those moving to greater use of cars most frequently mentioned travel time and availability of means of transportation as motivating factors (37 citations each or 37 percent of the number of switches). Convenience (24 citations), comfort (16 citations), and general preference (14 citations) were the factors next in frequency of occurrence.

The factors exhibiting the sharpest contrast between the two opposite switch directions are (1) ease of travel (less effort, strain, road congestion), (2) travel time, (3) general preference, and (4) cost. The first and fourth factors tend to favor use of public transportation, the second and third factors tend to favor use of cars.

TABLE 33

STATED REASONS FOR HAVING SWITCHED TO OR FROM PREDOMINANT USE OF PUBLIC TRANSPORTATION, IITRI WORK-TRIP SURVEY. NUMBER OF CITATIONS OF FACTORS IN EACH CLASS OF REASONS AND PERCENT FREQUENCY RELATIVE TO NUMBER OF PERSONS REPORTING EACH TYPE OF SWITCH (51 TO AND 99 FROM PT)

CLASS OF REASONS FOR SWITCHING	FACTOR CODES [a]	SWITCH DIRECTION: TO PT (NO.)	TO PT (%)	FROM PT (NO.)	FROM PT (%)
(1) Availability of means of transportation	M5, N1, N3, N5, N6, N7, Q1, Q2, Q3, R2, R3, S5, S6, V3, X7, X8	14	27.4	37	37.4
(2) General preference	A1, A7, U1, U2, U3	0	0.0	14	14.1
(3) Cost	C1, C2, C4	9	17.6	8	8.1
(4) Time	B1, B3, B6	4	7.8	37	37.4
(5) Convenience	F1, F2, Q4, X1, X2, X4, X5	9	17.6	24	24.2
(6) Comfort	G1, G2, G3, G4, G6, I2, I3, U6	6	11.8	16	16.2
(7) Ease (less effort, strain, road congestion)	E1, E2, E3, E4, E5, L1, L2, M2, M3, S1, S2, W2, W8, Y3, Y8	27	52.9	7	7.1
(8) Safety, health	A6, D1, D3	3	5.9	1	1.0
(9) Environment, weather	J1, J2, J6, K4	1	2.0	5	5.0
(10) Auxiliary activities	H3, P3, R1	6	11.8	4	4.0

[a] See Table 23 for definition of codes.

CHAPTER TEN

CONSTRUCTION AND TESTING OF A COMPOSITE CHICAGO NETWORK

A composite Chicago network was formed by combining portions of the 1956 transit and arterial networks developed by the Chicago Area Transportation Study. The composite network covers approximately 65 percent of the CATS study area geographically—all but the southernmost portion. It includes most of the suburban-railroad and rapid-transit lines. The reduction in size was dictated by the capacity of existing computer programs, which were written for networks with a maximum of 4,000 nodes. The composite network contains 378 of the original 679 zones of the study area; it consists of approximately 3,600 nodes, 6,300 two-way links, and about 100 one-way links.

As initial steps in the construction of the composite network, computer programs were written to make the following changes in the original transit and arterial network descriptions:

1. Delete all nodes in specified zones.
2. Renumber remaining nodes.
3. Delete artificial links in the transit network.
4. Add approach links from arterial loading nodes to transit centroids.
5. Rewrite all link descriptions in the card format used by the U. S. Bureau of Public Roads.

To the merged output of these programs were added approximately 90 one-way transfer links from the arterial network to selected rail and rapid-transit terminals. (Transfers in this direction allow mixed-mode home-to-work trips.)

A tree-building program (TREES) was written and used to test the performance of the composite network. Ten trees were built. The most conspicuous result was the almost exclusive preponderance of automobile trips. This was due not to a defect in the method of constructing the composite network, but to the differential times assigned to the links of the component arterial and transit subnetworks, which consistently favored automobile travel.

For application of BPR programs, one further step was required—the addition of dummy nodes to limit the number of outbound links from each node to four. An additional processor was written to accomplish this. The resulting network description was used with the BPR programs PR-6 (Build Network Description), PR-12 (Print Link Data), PR-1 (Build Selected Trees), and PR-11 (Format Selected Trees).

Arterial travel times between selected zones as computed by the program TREES were compared to the corresponding times computed by the BPR tree-building program. There were small discrepancies, but in both sign and magnitude they appeared to be due to the different methods of scaling and rounding used in the two tree-building programs.

A second version of the composite network was constructed, in which the arterial-to-transit links were reversed, allowing mixed-mode work-to-home trips. This change was made using the "update" option of BPR program PR-6. In the second version, the link between the auto network and the centroid of the zone in which IIT Research Institute is located (zone 45, the "work" zone of the work-trip survey) was assigned an artificially large travel time. This time penalty caused all paths in the minimum-time tree from zone 45 to begin on public transportation. Leading from the centroid of zone 45 to the transit subnetwork were two terminal bus links, each with a friction time of 5 min, and one terminal rapid-transit link with a friction time of 10 min. The time on the two bus links was reduced to 2 min; the time on the rapid-transit link was reduced to 3 min. The computed paths and their associated travel times and link modes were obtained from the resulting tree using a new "trace" program and these path descriptions were compared to those trips reported in the IITRI survey in which public transportation was used (trips of classes 4 through 9). The correlation between reported and computed times for 130 zones was 0.866. The mean reported time was 54.1 min, the mean computed time 57.1 min. The computed paths involve the use of a car for part of the trip about twice as often as the reported trips. This is, in part, probably due to neglecting car availability as a factor in the computed paths, but it also suggests that the cost and inconvenience of parking, especially near elevated-subway stations, were underestimated.

Experience in constructing and testing a composite network demonstrates that this approach to modeling a multimodal transportation system is feasible and has potential advantages with respect to realism and flexibility in the simulation of system properties. It would appear desirable in further work with such models to explicitly incorporate factors other than travel time alone where the data permit. For example, measures of monetary cost, safety or risk of accident, and waiting time could be associated directly with links and paths of the network in accordance with the concept of vector-cost assignment (Chapter Three).

CHAPTER ELEVEN

DISCUSSION AND CONCLUSIONS

The subject matter of the present research project, factors influencing utilization of the various modes of transportation in trip making within urban areas, is highly relevant to basic decisions concerning the character of future metropolitan travel facilities. The importance of making sound decisions in the shaping of metropolitan transportation networks is now generally recognized in view of the continuing growth of population and its increasing concentration in the urban areas of the country. Transportation technology has provided a variety of feasible means and modes of urban travel. However, intelligent evaluation of alternative possibilities in transportation planning requires that many factors other than purely technical ones be taken into account. The way a complex of transportation facilities of various modes will be used depends as much on characteristics of the population and the geographical distribution of activities as on the characteristics of the network itself. The interplay of the diverse factors that affect modal travel patterns requires for its elucidation both penetrating methods and adequate data.

Sufficient understanding of how a complex of urban transportation facilities functions, or ought to function, requires the point of view that it is in a fundamental sense a single system, its component parts operating in concert to achieve desired human objectives. The measures of effectiveness relate to how well and how efficiently the system serves the travel needs of the population of users. Freedom of choice between alternative ways of traveling complicates the problems of valuation and prediction; at the same time it makes it possible to investigate empirically the factors that are important to travelers in the making of travel decisions. Research on the present project has utilized appropriate conceptual models in conjunction with data on travel through multi-modal urban transportation systems in order to identify the main factors influencing modal choice and to quantify the effects of these factors operating jointly.

Some basic decisions were required in establishing the particular lines of investigation to be followed in pursuit of the overall objectives. Emphasis in the project was given to securing and analyzing information concerning individuals rather than confining the study to aggregate data. It has seemed particularly important that the description of travel opportunities accord with the way those opportunities are viewed by trip makers. The person is the locus of decision, and it is at this level that the factors influencing decision can be studied in greatest detail. Travel patterns in the large are, after all, the result of a multitude of personal choices. The best approach, one which permits both depth of causal analysis and breadth of population coverage, is the statistical treatment of detailed information on a large number of individual cases. This is the course that has been followed to the extent possible.

The unit of assignment in most of the work reported here is the trip between specified end points. Origins and destinations have been treated as given, the concern being with the way in which travel is accomplished. Characteristics of alternative types of trips as wholes are brought into the analysis, as distinguished from assignment on the basis of characteristics of the zones of origin or destination only. In this way, more kinds of information, and more accurate information, describing the particular alternatives open to travelers can be studied in relation to known choices. The one detailed investigation aimed at splitting trips on the basis of trip-end characteristics—the investigation of zonal accessibility ratios—had a negative outcome.

Only work trips have been studied in this project. Reasons for this restriction are: (1) greater availability of data (e.g., 1960 census data on the journey to work); (2) presumed greater accuracy of the data due to the repetitive nature of work trips; (3) wider use of public transportation for work trips than for trips with other purposes; (4) the predominance of work trips during peak periods of travel when the transportation system as a whole is performing at or near capacity.

The following conclusions either reiterate and extend points made in the preceding chapters of the report or are based on the results considered as a whole.

Figures 22 through 28 show functional relationships between use of mass transit (transit trips expressed as a percentage of all trips by either automobile or transit) and seven factors: (1) age of the trip maker, (2) number of drivers in the household, (3) number of cars owned by members of the household, (4) trip time by car, (5) trip time by transit, (6) waiting time during transit trip, and (7) cost of transit trip. The curves were derived from the first equation of Table 22 by setting each of the basic independent variables of the equation, except the one named, equal to its mean value, and then varying the latter. The vertical line through each curve marks the mean value of the named variable itself; the corresponding estimate of transit use is approximately 28.5 percent. The coefficients of the equation were evaluated from data on 696 cases in the work-trip survey carried out at IIT Research Institute.

The mean age of the 696 persons is 34.2 years (Fig. 22). The curve of transit use as a function of age of the worker, representing the combined effects of the linear and quadratic terms of the equation, is concave, with a calculated minimum at 33.7 years. Age emerges as a prominent factor influencing transit usage in this analysis.

The mean number of drivers per household is 1.84 in the work-trip survey. The effect on transit use of varying the number of drivers per worker's household, while holding all other basic variables at their mean values, is shown in Fig. 23. The number of drivers manifests its effect in the equation through the variable cars-to-drivers ratio. As the number of drivers increases, the worker is more likely to use public transportation. This is the relationship to be expected because of competition for a limited number of cars.

There is a strong effect of number of cars per household on transit use by workers (Fig. 24). The mean number of cars owned by members of the household is 1.24. If no cars are owned within the household, the worker can still travel as a car passenger. There is a large decrement in transit use with ownership of a car, and further decrements as the number of cars increases to two and three.

Functional relationships between transit use as the dependent variable and automobile and transit trip times as independent variables are shown in Figures 25 and 26. The mean automobile trip time is 35.8 min, the mean transit trip time 58.1 min. Transit use is a strongly decreasing function of transit trip time and an increasing function of automobile trip time.

An additional aspect of transit trips involving time was found to have a significant effect on transit use. This factor is the time spent waiting for vehicles. The mean time from the survey data is 11.0 min per trip. The relationship between waiting time and transit use is shown in Figure 27.

The final relationship depicted is that between transit use and transit trip cost (Fig. 28). The mean cost for transit trips is $0.554. With other variables held at their mean values, transit use is quite sensitive to transit trip cost.

Other variables found to have significant influence on transit use are car drivership, travel distance, and straight-line distance. The mean value for drivership (where 1 signifies that the person is licensed to drive, 2 that he is not) is 1.08, for travel distance is 14.2 mi, and for straight-line distance is 10.8 mi.

The variation among persons with respect to use of private automobiles or public transportation for work trips is only partly explained by even a fairly large number of items of objective information. This conclusion is based on the results of discriminant analysis of data from the 1956 survey by the Cook County Highway Department and also on the results of multiple-regression analysis of data from the IITRI work-trip survey. The free-response data from the latter survey throw light on this point. The large number of factors cited as important in travel decisions, and the different attitudes taken toward the same factor, make the observed degree of unpredictability understandable. An example is the attitude toward driving; many persons referred to the strain and effort of driving as disadvantages, yet a substantial number reported that they like to drive.

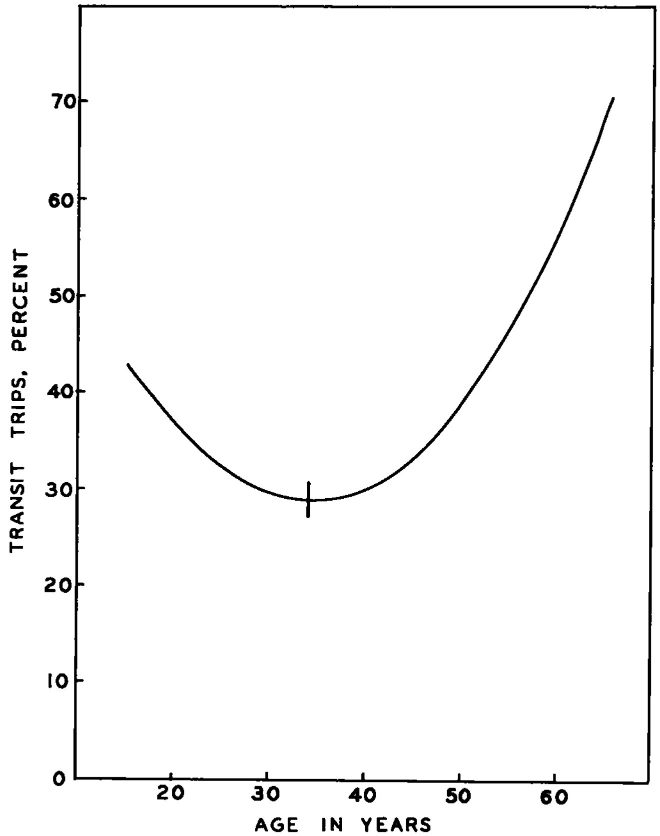

Figure 22. Transit use as a function of age.

There is generally good agreement between relatively objective data on travel and relatively subjective evaluations. This conclusion is based on analysis of objective and subjective data of both the 1956 transportation use study of the Cook County Highway Department and the 1965 work-trip survey of the present project. In particular, the importance of travel time in modal choice is clear from analysis of data of both kinds from both sources. The strong negative

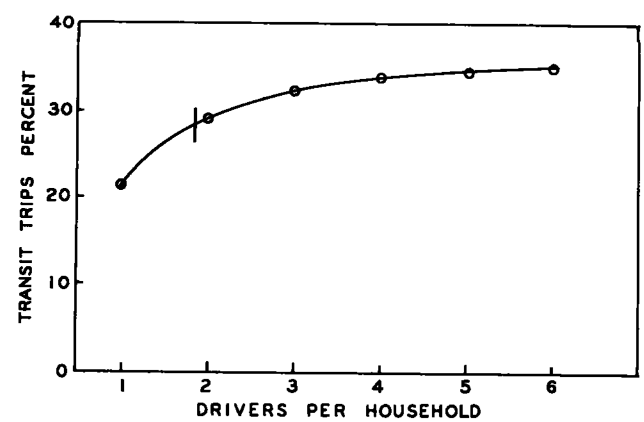

Figure 23. Transit use as a function of number of drivers in household.

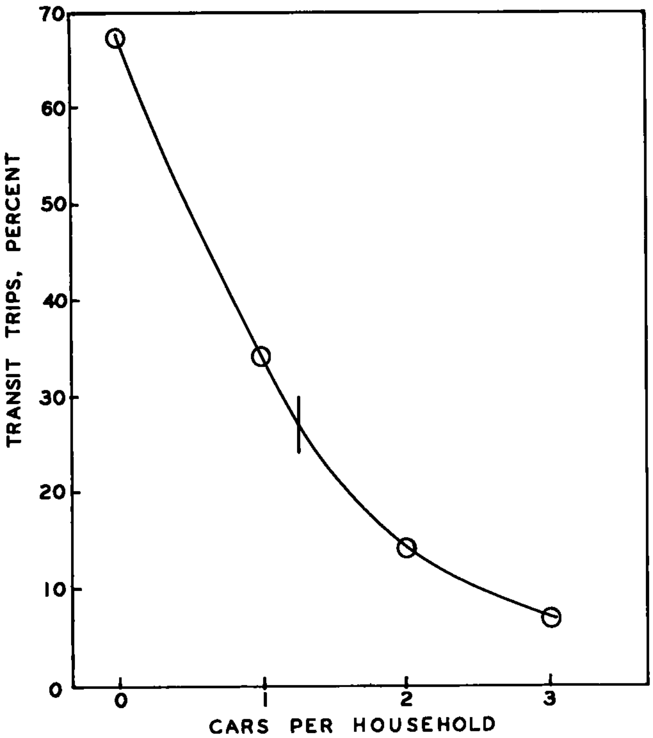

Figure 24. Transit use as a function of number of cars in household.

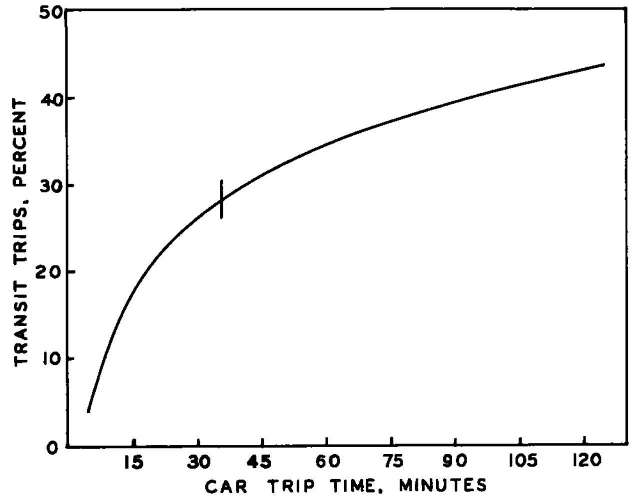

Figure 25. Transit use as a function of car trip time.

influence of waiting time on transit use is evident both from the estimating equation, in which reported waiting time is one of the independent variables, and from the free-response data, in which waiting time is frequently cited as an unfavorable aspect of transit trips.

As a final conclusion, all the concrete results of this project, in terms of the factors that are indicated to be most influential in travel decisions, are consistent with reasonable human responses to the transportation alternatives that are available.

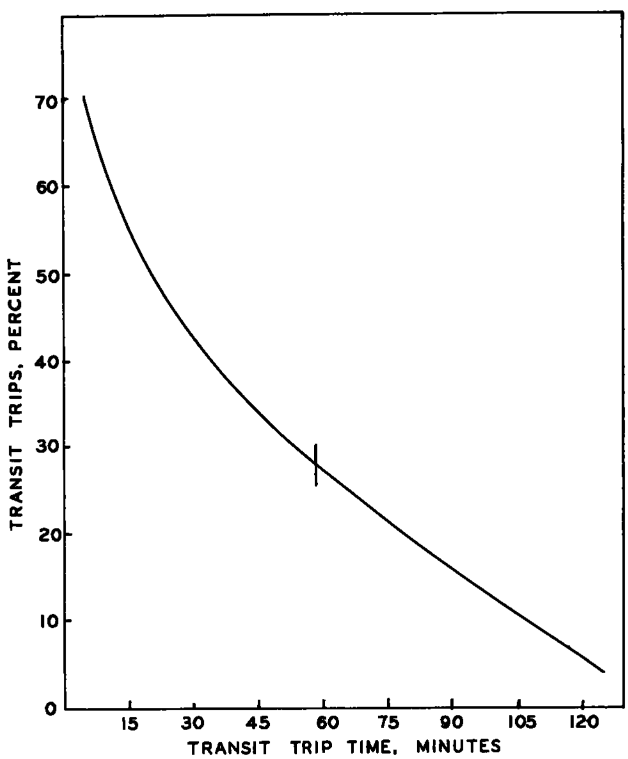

Figure 26. Transit use as a function of transit trip time.

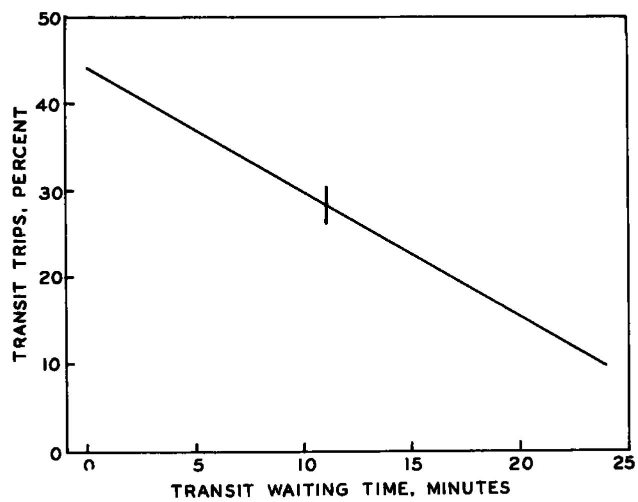

Figure 27. Transit use as a function of transit waiting time.

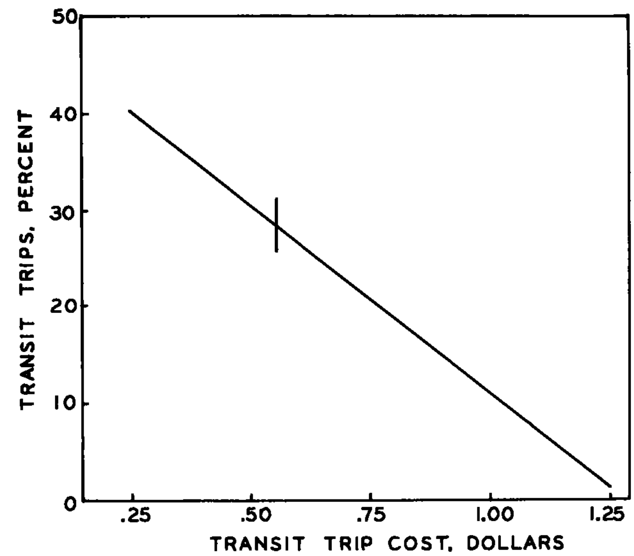

Figure 28. Transit use as a function of transit trip cost.

CHAPTER TWELVE

RECOMMENDATIONS

On the basis of the research performed and the results achieved in the present project the following recommendations are made:

1. Procedures for the assignment of trips to multi-modal transportation networks should be based, so far as is practicable, on the way travel opportunities are assessed by users. The way travel opportunities are assessed depends on characteristics of persons, households, locations, the kind of trip to be made, and the available transportation facilities. Estimates of the various characteristics to be taken into account in trip assignment, whether these are qualitative or quantitative, should be as realistic as possible. For example, travel times and costs by alternative modes, car ownership, or the population age distribution should be accurately represented in the assignment model.

2. Results on the present project show that relatively uncomplicated modal assignment models can incorporate nearly all the predictive power inherent in a fairly extensive set of independent variables. It is recommended that the variables found to be jointly most effective in the work done here be further tested by others.

3. Further work needs to be done on the dynamic interaction among alternative travel modes. From the results of the work-trip survey made during the present project it seems clear that there are opposing factors, some tending to favor increased use of public transportation, others having an opposite tendency. To simplify somewhat, the great advantages of journeying to and from work by automobile are freedom from schedules and saving of travel time; the great advantages of public transportation are freedom from the driving task and the ability to make use of time enroute. However, as more and more people use cars, the resulting congestion lengthens the travel time and also makes the driving task more onerous. At some point a balance will be struck between the opposing factors. A particular observation is that, just as time spent waiting for vehicles during a trip by public transportation appears more undesirable to travelers than time in motion, so highway congestion appears to have a negative effect on drivers out of proportion to the actual time delay.

4. Development and application of appropriate statistical models and methods in the field of multi-modal trip assignment should receive continuing support. The existence of relatively strong correlations among the usual predictive variables is one source of difficulty. Another is the large residual variance in individual travel choices. There is also a strong tendency toward polarization of travel patterns in individuals: many persons travel by car essentially all the time; others habitually use public transportation; few distribute their trips between the modal alternatives in anything like equal proportions. The actual set of alternatives to which it is reasonable to assign trips in particular situations may range from 1 to 2, 3, 4, or more, thus there may be multiple dependent variables constrained

to add to 100 percent. Effective procedures are needed for handling all these facets of modal assignment.

5. The proper level of aggregation or disaggregation in carrying out large-scale urban studies is a further matter not easily resolved. Questions of size of zones or other geographic units, of the extent of stratification of populations, and of the level of detail in the modeling of transportation networks are worthy of intensive study.

6. A multi-modal or composite network model—one that incorporates links of all the modes and permits all types of trips, mixed as well as pure, to be generated—will be required to adequately represent the spectrum of travel opportunities in many situations. Consideration should be given to the construction of composite network models whenever there is the possibility of real modal alternatives, of mixed-mode trips, or of interactions between the subnetworks. Care must be taken to ensure that the parameters specifying the links, paths, and subnetworks are unbiased. Various types of trips can be caused to appear by appropriate adjustment of network parameters prior to the construction of minimum-path trees.

7. The data treated in the present report should be supplemented by further data prior to extension of the analysis. The fact that both straight-line distance and travel distance entered into the multiple-regression equations derived from data of the work-trip survey suggests that further attention should be given to urban structure as a factor conditioning modal choice. It would be desirable to investigate the effectiveness of population density, size of the urban or suburban community, distance from the central business district, and other area characteristics as possible predictors of modal choice in combination with those already tested. Extension to trips having purposes other than travel to and from work is also highly desirable.

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APPENDIX A

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APPENDIX B

IITRI WORK-TRIP SURVEY QUESTIONNAIRE

1. Name ____

2. Home address Street ______________________________
   City ____________________ Zip code ______

3. IITRI building in which you work ______________________

4. About how far is it from your residence to place of work (travel distance) in miles? ____________

5. How long have you lived at your present address?
   _____Years ______Months

6. How many persons in your household (including yourself) are 16 or older?_______ Under 16?________

7. Are you licensed to drive? Yes____ No_____ How many persons in your household (including yourself) are licensed to drive? _________

8. How many passenger cars are owned by members (including yourself) of your household? _________

9. Are you currently a member of a car pool for travel between home and work? Yes___ No___ If so, how many persons (including yourself) are in the car pool?________

10. About how far is it, in blocks or miles, from your residence to the nearest stop or station where you could or do take public transportation to work? ________________________
    What kind of public transportation is available there?
    Bus___ Subway/Elevated____ Railroad____

11. The information asked for on this page concerns the types of trips to and from work that you make, or would expect to make, in the course of a year. A trip type is defined by the <u>mode</u> or <u>combination of modes</u> of travel used during the trip. Please describe each type of trip (at most four) on a separate line by checking the mode or modes of travel used and giving estimates of trip frequency, normal travel time, cost, etc., based on your knowledge and experience. The lower set of lines refers to the same trip types as the upper; under each heading write in those factors (if any apply) that you consider most important.

Trip Type	Travel modes used (Indicate by checks)							Trip Frequency in the Course of a Year		Normal Door-to-Door Travel Time, Home to Work	Cost of One-way Trip (If you know or can readily estimate this)	Total Blocks Walked	If Public Transportation is Used		
	Walk	Car Driver	Car Passenger	Bus	Subway/El	Railroad	*	% of Trips To Work	% of Trips From Work				No. of Transfers (Bus to bus, bus to el, etc.)	Total Time Spent Waiting For Vehicles	Chance of Having a Seat
1										____Hr ____Min	$			____Min	Bus ____% El ____% R.R. ____%
2										____Hr ____Min	$			____Min	Bus ____% El ____% R.R. ____%
3										____Hr ____Min	$			____Min	Bus ____% El ____% R.R. ____%
4										____Hr ____Min	$			____Min	Bus ____% El ____% R.R. ____%
	*Other (write in)							Total: 100%	100%						

Trip Type (Same as above)	REASONS WHY THAT TYPE OF TRIP MAY BE NECESSARY For example: Bad weather, Car needed during work, Car needed for errands on way, Car not available, Etc.	DESIRABLE FEATURES OF THAT TYPE OF TRIP For example: Safety, Travel time, Economy, Comfort, Convenience, Chance to read, Like to drive, Etc.	UNDESIRABLE FEATURES OF THAT TYPE OF TRIP For example: Driving strain or effort, Congestion, Uncertainty of arrival time, Walking, Waiting, Transferring, Standing, Exposure to weather, Etc.	(Please leave blank)		
1						
2						
3						
4						

12. This question asks for a segment-by-segment description of the route you most often take in traveling from home to work. Use one line for each segment of the overall trip in the order of travel. Write in the name of the street (minor streets can be omitted), highway, express-way, bus line, subway/el line, or railroad line that you use for that segment of the trip and check the mode of travel.

Trip segment	Name or number of street, highway, expressway, or public transportation line used	Mode of travel						
		Walk	Car driver	Car passenger	Bus	Subway/El	Railroad	
1								
2								
3								
4								
5								
6								
7								
8								

13. During the time you have worked at IITRI and lived at your present address, have you switched either to or from use of public transportation for most trips between home and work? Yes___ No___

If so, was the most recent switch to greater use of public transportation? Yes___ No___ Main reason or reasons for the switch: ________________________________

____

APPENDIX C

SUMMARY OF APPENDIX ITEMS NOT PUBLISHED

Other appendix materials contained in the report as submitted by the research agency are not published herein, but are listed here for the convenience of qualified researchers in the subject area, who may obtain loan copies of any or all of the items by written request to the Program Director, NCHRP, Highway Research Board. The items available are as follows:

1. Data Obtained in 1956 from Home Interviews Conducted by the Chicago Area Transportation Study.
2. Data Obtained in 1956 from Home Interviews Conducted by the Cook County Highway Department.
3. Descriptions of the 1956 Arterial and Transit Networks Provided by the Chicago Area Transportation Study.
4. Computer Program (CBT) for the Conversion of Data on the Chicago Transit Network from the Format Used by the Chicago Area Transportation Study to the Format Used by the Bureau of Public Roads.
5. Computer Program (CBA) for the Conversion of Data on the Chicago Arterial Network from the Format Used by the Chicago Area Transportation Study to the Format Used by the Bureau of Public Roads.
6. Program (CORCB) to Correct Network Link Cards Produced by Programs CBT and CBA and to Perform General Editing on Network Link Cards in BPR Format.
7. Program (ACCESS) to Compute Accessibility of a Given Zone to All Other Zones.
8. Computer Programs for the Conversion of Data on the Chicago Arterial and Transit Networks to a Single Composite Network.
9. Tree Builder Program (TREES).
10. Computer Program to Skim and Format Trees.
11. Computer Program (TRACE) to List in Succession the Nodes, Times, and Modes Along the Minimum-Time Path Between Selected Zones.
12. Information from IITRI Work-Trip Survey as Recorded on Magnetic Tape.
13. Evaluation of the Incomplete Beta Function.
14. City Code Key and List of Expressways and Tollways in the Chicago Area.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Highway Research Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

Rep. No.	*Title*
—*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80
1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20
5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p. $3.20
7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80
8	Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., $1.00
9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., $1.60
10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., $2.80
11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80
12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80
14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00
15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00
16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60
17	Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1,) 109 p., $6.00
18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80
19	Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., $1.20
20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20
21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40
22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60
23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40
24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20
25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00
26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60
27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., $2.00
28	Surveillance Methods and Ways and Means of Communicating with Drivers (Proj. 3-2), 66 p., $2.60
29	Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., $4.00
30	Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., $1.60
31	A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., $2.00
32	Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5), 134 p., $5.00
33	Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., $3.60
34	Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2), 117 p., $5.00
35	Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3)), 117 p., $5.00
36	Highway Guardrails—A Review of Current Practice (Proj. 15-1), 33 p., $1.60
37	Tentative Skid-Resistance Requirements for Main Rural Highways (Proj. 1-7), 80 p., $3.60
38	Evaluation of Pavement Joint and Crack Sealing Materials and Practices (Proj. 9-3), 40 p., $2.00
39	Factors Involved in the Design of Asphaltic Pavement Surfaces (Proj. 1-8), 112 p., $5.00
40	Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), 40 p., $2.00
41	Effect of Control Devices on Traffic Operations (Proj. 3-6), 83 p., $3.60

* Highway Research Board Special Report 80

Rep.
No. *Title*

42 Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index (Proj. 14-1), 144 p., $5.60
43 Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5), 38 p., $2.00
44 Traffic Attraction of Rural Outdoor Recreational Areas (Proj. 7-2), 28 p., $1.40
45 Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40
46 Effects of Different Methods of Stockpiling and Handling Aggregates (Proj. 10-3), 102 p., $4.60
47 Accident Rates as Related to Design Elements of Rural Highways (Proj. 2-3), 173 p., $6.40
48 Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $3.20
49 National Survey of Transportation Attitudes and Behavior—Phase I Summary Report (Proj. 20-4), 71 p., $3.20
50 Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., $5.20
51 Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., $5.00
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54 Location, Selection, and Maintenance of Highway Guardrail and Median Barriers (Proj. 15-1(2)), 63 p., $2.60
55 Research Needs in Highway Transportation (Proj. 20-2), 66 p., $2.80
56 Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., $6.40
57 Factors Influencing Modal Trip Assignment (Proj. 8-2), 78 p., $3.20

THE NATIONAL ACADEMY OF SCIENCES is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by President Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

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THE NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

THE NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U. S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

THE DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

THE HIGHWAY RESEARCH BOARD, organized November 11, 1920, as an agency of the Division of Engineering, is a cooperative organization of the highway technologists of America operating under the auspices of the National Research 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.