

DEVELOPMENT OF A MATHEMATICAL
MODEL AND INFORMATION SYSTEM
FOR FORECASTING INTERCITY TRIP
DEMANDS FOR THE TAIPEI,
TAIWAN METROPOLITAN AREA

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This is to certify that the
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ABSTRACT

DEVELOPMENT OF A MATHEMATICAL MODEL AND INFORMATION SYSTEM FOR FORECASTING INTERCITY TRIP DEMANDS FOR THE TAIPEI, TAIWAN METROPOLITAN AREA

By

David T. Lee

This research study defines the factors affecting intercity travel and uses the identified factors with existing traffic models to predict intercity travel.

The basic data used in the study were the origin-and-destination survey and home interview study conducted for Taipei in 1968 and 1970, from which commonly available data on a series of social and economic indicators were selected and recorded on tape for the study area.

The trip data from all the origin-and-destination studies were summarized by trip purposes and divided into the fringe and core areas. A stepwise regression analysis computer program was used to determine relationships between trips and other factors.

The significant findings of this research include the following:

1. Population characteristics combined with travel time appear to be the major indicators of trip distribution. Although other

social and economic variables appear to be as significant as population characteristics, in certain instances the regression analysis showed that population characteristics were selected consistently as a principal independent variable in the formulation of the intercity distribution formulas.

2. Use of social and economic factors and stratification of cities by size and by social and economic characteristics appears to be significant in the development of trip generation formulas. The research has indicated that population relationships alone are not sufficient to predict trip generation even though this variable, with time, did correlate well with the origin-and-destination data as far as distribution was concerned. Analysis of data by population stratification indicates that additional research, relating the social and economic structure of a city to trip generations is needed.

3. The research indicates that two views are possible in developing prediction equations for intercity travel. One stance involves the development of a single equation or family of equations to predict generation and distribution simultaneously. The second view holds that two sets of equations should be developed-the first to predict generation based on social and economic factors and the second to predict distribution using population and time relationships. Both procedures have been investigated in this study. However, because the problem of intercity trip estimation seems to be in the area of generation, it is anticipated that procedures which estimate generation and distribution separately will be directed to further classification of this method.

4. Existing trip prediction tools can be successfully used as the basis for developing intercity travel prediction equations providing some control can be exercised over the origin-and-destination data collection procedures. The lack of data standardization has introduced some error and additional processing effort into the study.

Intercity travel estimating procedure described in this report are a major first step in the continuing development of more accurate predicting procedures for this type of travel in Taiwan. To date, this type of study has been concerned with highway vehicle trips stratified by trip purpose and city size. In the work which follows and builds on the findings described herein, attention should be given to the refinement of these factors and to the inclusion of additional studies of recreation time, travel mode, trips defined as production and attraction, trip generation, and travel time and travel cost controls. In refining the procedures and in developing alternate methodologies, it will be necessary to expand data coverage to determine whether regional influence significantly affects the results derived from the special and size interrelations as reported herein.

The equations developed here will provide a reasonably accurate description of intercity travel in most areas of Taiwan. With the additional refinements, however, the ability to predict intercity travel to the same standards of accuracy as is currently possible for intra-city travel is nearly assured.

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FOR THE TAIPEI, TAIWAN METROPOLITAN AREA

By

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CHAPTER I

INTRODUCTION

Planners and decision makers must perform analyses capable of explaining present conditions, predicting future circumstances, needs, assets and deficiencies and translating information into systematic models. Richard Meier defines information from such research as a set of factual data which the observer receives and interprets within the construct of his own specific problem situation. Research may indicate more about a decision that must be made, necessary related decisions, and the risks associated with the alternatives, as well as providing some hints as to a new path of action. These analyses make possible the formulation of specific objectives and criteria which, in turn, provide the basis for design and analysis of broader alternatives.¹

The planning operation can also be regarded as the controlling point in a changing system. The system is composed of those human activities and communications which have a locational or spatial element. Our information system must be "a description of the system we seek to control".² The logical extension of this approach, since our system is dynamic, i.e., changes through time, demands that we understand the

¹Meier, R. Development Planning. McGraw-Hill, 1965, Ch. 3.

²McLaughlin, J. Brian. Urban and Regional Planning - a System Approach. New York, Praeger, 1969.

interrelationships of the systems parts in terms of change and the resulting changes of the system as a whole. Identification of the causes of change is vital to our hopes of effective control. Retrievable information about the system's characteristics and changes should be arranged in a logical system reduced to a manageable size.

This research study attempts to develop an information framework for the transportation models. The transportation input study is geared to the requirements of both planners and decision makers. This research attempts to identify the information needed to make maximum effective use of elements in both Taiwan and the United States which provide tested applications of the forecasting models of transportation development.

A community transportation planning information system (based on trip generation, trip distribution), will be conceptually designed and examined, with application to Taiwan's community transportation problem. Hopefully, the conclusions drawn will be transferable to other communities. Furthermore, it is hoped that this approach will suggest alternatives to planners working with long-range urban and regional transportation planning problems.

The Problem

Appropriate tools, strategies, and research activities are necessary for an understanding of urban and regional development. Certain data which is of interest to planners or decision makers is, of course, available from published or official sources. Many extremely valuable sources can be studied on a comparative basis. Any system

in order to be effective must be able to utilize concepts derived from a cross cultural comparative analysis. But it is of utmost importance that any application of such a system consider the cultural context within which it must function. The most difficult problem which confronts the existing systems is the processing of requirements for additional information. Almost as difficult is the problem of securing different information units for aspects of the same problem. Such processes generally require that the data assembly and report preparation be repeated in its entirety, consuming considerable time in data preparation.

Current of transportation studies focus on problems in the larger cities and metropolitan areas. Although these transportation studies represent a concentrated attack on the most vital portions of the current transportation deficiencies, they constitute attacks on a particular urban area's transportation. On a broader scale, one must recognize that urban travel is still only a portion of a regional problem and, ultimately, of a national transportation picture; the implications of the broader picture is the concern of the present research.

The severity and magnitude of traffic difficulties are related to the size of the urban area and its related intensity of activity. Hence, the smaller cities with proportionately smaller problems have received proportionately less attention with respect to study and analysis of their particular traffic problems. No significant effort has been directed toward the smallest elements, linked together by the transportation network. In relative terms, these smallest elements might be classed as communities or municipalities.

"Linked" is perhaps a key word that helps bring into focus the chain of events leading to eventual solution of transportation problems on a national scale. The priori argument is that the solution structure of the larger problem must be based on the understanding and solution of the small contributory problems. The elemental units in the transportation network are the communities which are linked to one another and which, in turn, are linked to the small cities in whose geographic hinterlands they lie. These small cities, each with their clusters of outlying communities, comprise the hinterlands of larger cities and so on until the network is complete.

Many of the potential approaches to community transportation planning are of limited value because a coherent information system does not exist. In Taiwan, transportation development has been greatly emphasized in recent years. It was found that data was either lacking, too subjective, incorrect, or presented in an inappropriate format.³ Data processing for regional planning has been found less than comprehensive and very often not available on a continuous basis.

It is generally recognized that past transportation decisions have not always been based on a well searched inquiry into causal relationships and not all significant factors have been sufficiently considered in each case. More often than not, the transportation planning decisions have been made without a detailed appraisal of the potential impact of such a decision in terms of the additional costs and increased work load for the executing agency.

³Urban and Housing Development Committee, Council for International Economic Cooperation and Development, Executive Yuan, Republic of China, 1968.

To correct this deficiency, the prime objective of this research is the development of an information system for the application of forecasting models in transportation planning which could be applied to the task of identifying, measuring, evaluating and systematically comparing, those critical and relevant factors, such as economic base, land use, size, density, etc., which must be considered in making objective transportation planning decision.

Objective of the Research

In the decision-making process, information about available choices is combined in order to produce a decision or set of decisions, which can be expected to maximize the attainment of these goals.

The information system must specify exactly what information is required to make each set of decisions. Of the vast volume of information available, only a relatively small portion needs to be, or can be, used. However, this requires that the utmost care be exercised in the selection to insure that all of the most critical elements are properly identified, defined and incorporated in the system structure. The system must also specify a set of objectives, and a procedure for combining the inputs in such a way that planning decisions can be formulated.

This study proposes to develop and evaluate hypotheses concerning the traffic relationships that exist between communities in a geographic region, using the Taipei metropolitan region as a study area. These hypotheses are to be translated into intercommunity traffic models which will permit estimation of intercommunity traffic between

Taipei and the communities in Taiwan. Attention is to be directed toward the estimation of traffic for individual trip purposes.

This project studies the Taipei metropolitan area motor vehicle traffic between Taipei and surrounding communities. Taipei, as many other cities, is closely linked through its highway networks to the smaller communities surrounding it. These communities depend upon Taipei for many of their work, business, shopping, recreational, health care, and educational needs. Similarly, Taipei is dependent on the small communities for this support of its regional facilities. This interdependence results in traffic movement between the central city and its outlying communities.

The number and purpose of trips originating in one community and destined for another is a measure of interdependence. Interdependence results in traffic linkage between communities and is influenced by population, land use, location, and transportation factors in the communities involved, as well as by the availability, character, and location of highway facilities in the area.

Models to estimate intercommunity travel can be considered useful from several viewpoints, including a contribution to presently limited knowledge of the regional significance of highway links, smaller metropolitan areas, and fundamental concepts of traffic linkage between communities and the metropolitan area. Intercommunity traffic studies also contribute significantly to community analysis and planning in that they constitute a yardstick for measuring a community's dependence and outside sources for the satisfaction of its daily needs. Public and private interests in a community can use these data to

evaluate their competitive position against other communities concerning either existing services or proposed new ones. In addition, travel patterns are sensitive to environmental change; hence, they are one of the primary indicators of the regional importance of the particular change being evaluated or proposed.

The objectives of the transportation information system to estimating intercommunity travel are as follows:

1. To provide an accurate transportation information base which will guide planners and decision makers in formulating community policy in Taipei.
2. To develop the traffic linkage information system and the analytical framework needed to channel project investigations.
3. To identify and collect pertinent community data which may be causal in the formulation of regional travel patterns.
4. To analyze the relationships between community characteristics and intercommunity traffic and to develop corresponding traffic estimation models.
5. To draw conclusions relevant to the validity of the research information system for the development of regional transportation systems and regional land use planning.

Methodology

A wide variety of processes and activities will be utilized in the information system studies. The complexity of the proposed analysis will require reliance upon the systems analysis process. The techniques and conceptual framework of the information sciences will

be employed throughout this study. A large amount of general and specialized survey data was made available through completion of the home interview and origin-destination traffic studies for the Taipei metropolitan area.

In an effort to obtain mutual benefits between practitioners and the individual researcher, organizations such as the Urban and Regional Information Systems Association (URISA) and the Federal Urban Information System Inter-Agency Committee (USAC) have recently been formed. Present research efforts in the uses and misuses of information in public and private policy formulation will test the effectiveness of private policy formulation in problem solving. This type of research includes studies of social indicators, gaming and simulation methods, management information systems, and regional economic information systems, and regional economic information systems. This research attempts to develop a useful approach to acquiring community information compatible with the knowledge gained from earlier work in this field.

In the field of regional analysis and planning there is a growing need to develop, test, and refine fundamental relationships that offer insight into the structure of regions and promote solutions to regional development problems, such as those hypothesized in numerous forecasting models. Intercommunity traffic data can be used to establish these relationships, to assist in defining planning regions, and to estimate the extent to which regional land use facilities are needed and will be used.

Intercommunity traffic studies also contribute significantly to community analysis and planning in that they constitute a yardstick

for measuring a community's dependence on outside sources for the satisfaction of its daily needs. Public and private interests in a community can use these data to evaluate their competitive position against other communities concerning either existing or proposed services.

Impact studies, or those investigations determining the effect and significance of change in some local or regional facility, can use the output of reliable traffic models. Travel patterns, besides being flexible and sensitive to environmental change, are one of the primary indicators of the regional importance of the particular change being evaluated or proposed.

Scope of the Study

This research is concerned with the development of an information system for forecasting model application. Inasmuch as this research will attempt to provide a new approach to the problems of creating communities within an established region, it is necessary to provide a theoretical and methodological guideline for such an adaptation.

In transportation planning for an existing city or community in the U.S., travel forecasting models are calibrated using data on existing transportation movements, socio-economic distributions of activity, and transportation networks. Such an approach is not possible in Taipei, because reliable information for existing patterns is obviously not available; the transportation information system in communities having not yet been developed in Taiwan. In this situation,

it is necessary to assume values for model parameters, based on previous experience. Throughout the analysis, these assumptions are subjected to logical tests, wherever possible.

Moreover communities will be an integral part of the Taipei Metropolitan region and although undoubtedly they will retain unique identity and environment, they are nonetheless interrelated with the existing patterns. Therefore, in analyzing future levels of passenger usage of a transit system in communities, it is necessary to analyze the pattern of transportation movements in the Taipei corridor, with attention devoted primarily to flows within communities. Secondly, transportation flow between communities and the already existing portions of the region must be analyzed in terms of their effect on competition for trips within that area. Finally, an overview of the entire region as it related to the community facilities must be accounted for within the total transportation complex.

It is important at the beginning to describe the underlying philosophy and long-range goals of new community transportation information system research. Hopefully, the efforts will provide opportunities for expanded urban and regional services, which will strengthen and improve the effectiveness of the system for formulating and implementing public and private policy. The organization of the research is as follows:

1. A description of the elements of systems analysis and development, the rules and elements, of the planning process, and the data needs of the transportation planning process. This outline is designed to provide an information framework for expanding the network of concepts necessary for research development.

2. Present the conceptual development of traffic-linkage information and include a discussion of the transportation models and its modification to allow for separation of produced and attracted trips, and to account for competition between communities in the study region.

3. An application of selected forecasting models in a regional community setting, including an evaluation of the test criteria for determining the adequacy of a model.

4. Conceptual development of a community transportation information system for Taiwan utilizing the tested framework of the forecasting models.

In the development of this research, systematic analysis is used for analyzing a specific information system. It is not limited to particular details but is viewed broadly as a guideline for planners and future planning activities in a systematic and coordinated process of data collection, analysis, synthesis, control and implementation.

CHAPTER II

A PLANNING PROCESS FOR TRANSPORTATION SYSTEMS

The concept of systems approach has been used in many planning studies in an attempt to provide a more rational format for transportation planning. A fundamental premise of the approach is that research has to be conceived as an aggregate, and not approached in a piecemeal fashion. A meaningful analysis of research in transportation must consider eventual consequences of such research for the environment as a whole rather than limit its concern to the effect of transportation per se. This chapter, therefore, will employ the current concept of a systems approach to provide systematic planning processes appropriate to transportation problems. It must be realized that concepts are changing through time.

A comprehensive analysis of the role of transportation would ideally, require consideration of all components of the environment; that is, the area must be conceived as fulfilling the needs for transportation that are generated by the social, political, economic and physical environment of that region. A transportation system is not and end in itself. It provides the means by which certain social, economic and political goals are achieved.

A system may be defined as a set of elements that are or organized in such a way as to direct the behavior of the system toward specific goals or objectives. An important implication of the use of a system as a planning concept is that the concept embraces a universe of elements and provides a unified understanding of its functions. This is an alternative to the disjointed incrementalistic approach, which does not provide an understanding of the relationships of a system's parts to the whole.

Transportation System Characteristics

The major focus in developing a systems approach emphasizes system objectives, and is sometimes referred to as the mission of the system. The system objectives may be defined as a set of operational definitions that identifies the needs that a system must attempt to satisfy.¹ In this sense the objectives provide the connection between the system and environment; objectives also transmit an image of the ideal system to the systems planner. Two of the most important objectives of the systems approach are: 1) the formulation of an overall structure of objectives as a framework for organizing individual projects and 2) the development of objectives and plans for individual projects consistent with the overall structure.² The most prominent objectives for a transportation study would be:

¹Martin, Brian V. Traffic System Analysis. McGraw-Hill, 1967.

²The Transportation Center. Analysis of Urban Transportation Research. Northwestern University, Evanston, Ill.

1. To maximize transportation safety and minimize costs.
2. To maximize accuracy of projections of future size and character of the region to be serviced.
3. To make possible more desirable arrangements of land use and development patterns.
4. To maximize the ease of travel within the regions.

The goal of the transportation system would be to develop a transportation system that represents the best blend of the above stated objectives. To achieve this goal it is necessary to: first, prepare a transportation facilities plan, and, second, provide the basic understanding and facts needed for continuing review and appraisal of the plan by responsible public officials.

The development of value components for these objectives is difficult since no general theory of value is readily available. At present, the most frequently measured unit of value is the economic value of a good or service. Although there are significant non-economic factors to be considered in an analysis of transportation system, the necessary monetary figures are more readily available for economic consideration.

The major input variable associated with a transportation system is the demand for the movement of persons and goods between land use areas. A major effort in transportation planning to date has been the development of forecasting procedures for planning transportation system structures.

An important characteristic of a transportation system is that the flows of persons and goods on the links of the network

provide the functional connection between the input and output variables. The output variables associated with a transportation system are operating costs, capital costs, accident rates, travel times, and miles of travel per unit of time. These output variables associated with a transportation system are operating costs, capital costs, accident rates, travel times, and miles of travel per unit of time. These output variables are normally multidimensional and may be measured and expressed in a great variety of units, such as dollars, hours, miles. It has already been established that the system objectives provide the basis for assigning the relative desirabilities of the output variables. A mechanism is, therefore, required which transforms output variables into the system objectives; the objectives are the aggregate of the output variables.

It has already been established that the objectives ideally should be expressed in terms of a common unit of value. The value functions serve to transform the magnitude of the output variables expressed in a variety of units into a common measurement scale which conveys the degree to which the objectives are fulfilled. For example, the value function developed for the Chicago Area Transportation Study was applied to only a limited number of objectives. The objectives were measured in dollar units, and value functions were synthesized which allowed such diverse output variables as travel times and accident rates to be transformed into the common value unit. Figure 1 attempts to show graphically the interrelationship of the elements.

TRANSPORTATION SYSTEM CHARACTERISTICS

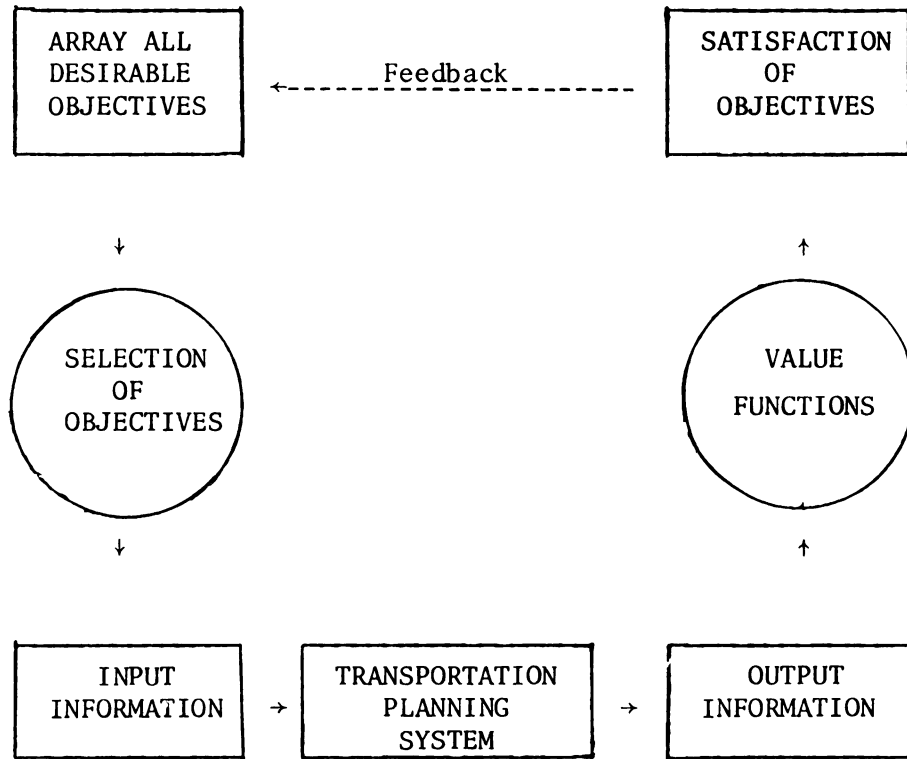


FIGURE 1

A Conceptual Model of Systems Approach to Transportation Planning

An important premise of the systems approach is that an analysis of a given system (here, transportation) should be conducted within the context of an analysis of the environmental system of which it is a part. Therefore, although attention in this study is focused upon the transportation system, the relationships of the transportation system to all components of the environment, e.g., work, recreation, be identified.

Also, in conducting a systems analysis of transportation, it is important to consider separately the various activities necessary to change the system. In the immediate and shortrun futures these activities are usually called systems controls. In the longer-run the activity of specifying system change is called planning.

There is an important need for more comprehensive models of urban phenomena which provide more adequate means for relating the social and political as well as the physical and economic aspects of these systems.

The transportation system model identifies three major flows and four functional subsystems that are involved in the supply of units of transport service. The flows are the movement of people, goods, and information. The functional subsystems are the terminal, vehicle, way, and control systems. This model helps to identify what must be done to produce units of transport service in any real transportation system.

The Planning Process

There is no absolute procedure which can provide the best solution to transportation systems problems. However, a number of elements and general characteristics have been established in the structuring of the planning process. The steps leading from the accumulation of facts to a completed plan involve, essentially, forecasting urban growth, simulating the traffic consequences of this growth and, finally, measuring the impact of this traffic growth on existing and proposed transportation systems. Six major activities are generally recognized in the transportation systems planning process:

1. Problem definition
2. Determination of system elements or variables
3. Formulation of system models
4. Plan preparation
5. Testing and evaluation
6. Implementation and problem redefinition

Problem definition. The first step of any problem-solving process is to develop an explicit statement of the problem. An important principle that should guide the development of a problem statement is that the number of possible solutions to a problem increases with the generality and comprehensiveness of the initial problem definition. It is generally recognized that the problem definition consists of five components which are: system objectives, system inputs and outputs, value functions, decision criteria and system constraints.

Problem definition also involves the identification of the boundaries of the problem as well as the interrelationships between the system and the environment. No formal conditions can be established for identifying the scope of a problem. Objectives, constraints, inputs, and outputs may be used by the planner to define the interrelationships between system and environment. Value functions and decision criteria are the tools available to the planner for assessing the degree of compatibility between the system and the environment.

Determination of system elements or variables. This step involves identification and specification of those system variables that in one way or another are related to or affect the system measures of effectiveness, e. g., population forecast, economic activity forecast, and land use forecast. All of these variables would indicate the magnitude of urban growth, and in the process of estimating the amount of land to be developed would indicate a procedure for distributing these new activities geographically. While many of these variables will be self-evident, undoubtedly there will be some whose relationship to the dependent variable cannot be determined.

Formulation of system models. The model, whether a series of logical procedures, a mathematical abstraction, or a mental process, expresses the outcome as a function of the system in terms of its elements. Simply, it permits the planner to predict with some degree of certainty. If, for example, future land use, economic activity and future population variables are changing, all these variables can be translated into future travel in order to enhance the planning process.

The process of formulation of the model for forecasting travel starts with a forecast of land use. The number of trips beginning and ending in each small area can then be estimated. These beginning and endings are connected, finally, when the impact of this travel demand upon a transportation system is studied. This knowledge is a necessary base for the stage of designing the new transportation system.

Plan preparation. Up to this point, the planning process has consisted of forecasts of future conditions. These estimates of future land uses and traffic demands give the dimensions of the problems which must be solved by planning, and some of the limits which control solutions. At this point, judgment and ability must be applied in order to arrange transportation facilities which will function more efficiently than those of the past. Planning a new transportation system is thus a creative process.

Evaluation and testing of the system plan. This step of the overall planning process involves the utilization of system models or predictive techniques to measure and, in turn, evaluate the consequences of alternative system plans; that is, the process of testing is similar to the process of forecasting the over-all travel demand. The difference is that the traffic demand generated by future land uses is assigned to a planned new transportation network. The results are measured quantitatively and specifically. These test results must then be evaluated. In this evaluation stage, the objectives are viewed in terms of objectives and value functions. The results may be inconsistent or uncover undesirable effects. In other words, if the planner has made a conscious effort to inform the decision

maker or politician and the general public of the economic consequences or costs of these alternatives, a more rational and consistent set of values for social objectives should emerge.

Implementation and problem redefinition. Considerations of systems operation are fundamental to the planning process and to all preceding steps. Without an appreciation of how a system will actually operate under specific conditions, one cannot predict system performance, traffic demand, cost, and other consequences reliably - in effect cannot plan properly.

Problem redefinition is included here merely to emphasize that the task of planning and the plan is a continuous one. The planner must be constantly aware of the actual results of implementing a particular project and must detect how this affects the goals and objectives of society in the future. Thus, when facing a similar problem in the future, the planner is able to use goals and objectives conditioned by solutions offered in the past.

Figure 2 shows graphically the interrelationship of these elements of the planning process.

First, inventories are taken of travel, land use and transportation facilities. Second, forecasts of population, economic activity and land use are prepared as inputs to the process of forecasting travel demands. The number of steps in this process depend on the rules of travel developed from the major inventories. The plan preparation stage utilizes these forecasts of travel demand and through successive imposition of limits, including objectives and goals, develops one or more plans. These are then tested by developing



traffic volumes on all routes, the tests are then evaluated. Final checking includes a redefinition of the problem and eventual implementation.

Information Systems in the Transportation Planning Process

The lack of systematically collected basic data and other types of information of reference to geographical regions is a major obstacle to the efficient preparation and implementation of regional development effort. In transportation, the necessity of an extended information base to assist in the development of a transportation system has been strongly felt in the planning field.³ This information system should be based upon the types of systems identified in the theory and the kinds of activities which constitute the field of urban transportation. The information can provide a comprehensive means of structuring knowledge or the need for knowledge in the field. Also, the information system should offer a technique based on planning principles and be helpful in analyzing problems in the transportation system.

In the last decade, it is interesting to note, the information systems developed in the transportation planning field have been essentially the ad hoc systems needed to produce data for the transportation planning models and to meet the predominantly single-purpose needs of these studies, i.e., traffic forecasting.

³Highway Research Board. Information Systems for Land Use and Transportation Planning. Number 194.

The information system presented in this study is what E. Horwood defined as a plan-test system for information.⁴ This information test system can evaluate the effectiveness of plan, policies, and alternate proposals could be tested in a variety of ways ranging from simple techniques to complex mathematical models. In the transportation planning field, gravity and accessibility growth models are typically used for preplan testing purposes and have been found to be substantially successful. It is the purpose of this research, however, to present the travel pattern as an example of a plan-test system. Consequently, there should be process utilizing models for all efficient and effective transportation planning.

The Analysis of Travel Patterns

It is a basic assumption of transportation theory that there is order in human travel behavior in urban areas which can be measured and described. This order provides the basis for intelligent forecasting. So too, it could be assumed that all household, firms, physical facilities, and land parcels also exist in a pattern of order and regularity. In analysis of travel demand, it is necessary to consider a number of such types of groupings. In all cases, however, there are two important factors to consider: (a) the uses to which the information is to be put, and (b) one's capabilities and resources for dealing with large quantities of data.

⁴Highway Research Board. Information Systems for Land Use and Transportation Planning. Bulletin, no. 297.

Appropriate bases for effective analysis of spatial organization of the interacting forces at the urban level are extremely complex. Although a number of very interesting models have been developed to represent some of the more significant of these interactions, suitable theories of the overall operation of even the spatial component of the total market remain to be advanced. Such understanding is needed as a basis for predicting future spatial travel patterns.

Once the spatial patterns of travel-producing entities have been identified, the transportation analyst must find means to aggregate the many types of units of transport demand which are generated by them. Again, assuming the use to which this information is to be put specifies the actual types of aggregations to be used, several approaches to the aggregation of trips can be used.

One approach might be to view the problem of aggregation as one of simplifying the measures used to represent each of the components of the vector unit of transport service, this could consider only the scope or only the analysis sect. This may be classed by activity types, household characteristics, route characteristics, origin or destination locations, time scale, and so on. By representing individual trips in terms of the vector unit of transport demand, the actual approximations or assumptions underlying these aggregation are made explicit. Importantly, functional as well as spatial groupings of trips can be analyzed in this fashion. Since residential zones are very often quite heterogeneous with respect to household or trip

types, it may be very useful to analyze the travel patterns upon an assumed travel behavior for an entire zone.

In summary, it is held that aggregated, operationally useful models of travel behavior can be developed from detailed analyses of households and firms. Significantly, these analyses - either of the mobility of activities and facilities in urban space or the movement of objects in it - are based primarily upon observable, measurable characteristics which can be summarized conveniently using the vector or austere unit of transport. It is further assumed that the strategy of economic analysis can be used to explain these observed phenomena. The limitations in computational capabilities, which to date have precluded the development of such descriptive analyses, are steadily being surmounted. Therefore, the potential opportunities for development of macroscopic analysis of travel behavior appear particularly promising.

CHAPTER III

THE STATE OF THE ART IN TRANSPORTATION MODELS

Preparing a long-range transportation plan for an urban community is a task of considerable scale and complexity. It involves developing reliable predictions about the future living and travel habits of a dynamic, rapidly changing urban society. Moreover, the forecasts must consider many difficult variables that are nevertheless basic indices of growth.

During the 1950's, several increasingly comprehensive urban transportation studies were carried out by special ad hoc agencies and other organizations. Significant improvements in both basic study philosophy and analysis methodology have greatly increased understanding of the complexity of the transportation problem and the development of a theoretical understanding of travel patterns.

Theories of travel are developed to explain regularities in travel likely to last over a long time period, to make traffic forecasting sufficiently reliable for use in long-range planning.

To plan a transportation system for dynamic urban areas, it is necessary to be able to forecast the changes in travel patterns and travel demands which would result from anticipated or proposed changes in the land use patterns and/or transportation systems. This realization has resulted in an effort to develop an urban transportation

planning process capable of providing quantitative information about the future transportation movements to enable cities to make an informed choice between alternate land uses and transportation programs.

Several such procedures, generally referred to as "transportation models," have been developed. The opportunity model developed by the Chicago Area Transportation Study has been used in both Chicago and Pittsburgh.¹ Fratar Model, a growth model, has been utilized by the Detroit Area Transportation Study.² Another model, and the one most widely applied, is the gravity model. Studies based on this procedure have been conducted in Hartford, Connecticut; Baltimore, Maryland; and several cities in Iowa.³ The California Division of Highways developed a multiple regression model of forecasting transportation volumes as another technique.

This chapter first lists the different models which have been employed. These models are then discussed in turn. This is followed by a consideration of present and expected future developments of travel forecasting studies.

Travel Forecasting Models

Trip forecasting models have widely differing approaches. Models are described as being analytic or synthetic, as employing

¹Creighton, Roger L. Urban Transportation Planning. University of Illinois Press, Chapter 3, 1970.

²Highway Research Board. Highway Research Record. No. 114.

³Highway Research Board. Highway Research Record. No. 347, 1962.

opportunity or gravity principles. This results from each researcher's attempt to reconcile the objective of simplicity with the objective of a correct mathematical interpretation of underlying causal relationships.

Mathematical descriptions of the models often show little similarity to one another. Nevertheless, it is possible to see an underlying principle in each of the proposed formulae and models, namely, that travel between any two points in space will increase with greater attraction for such travel, but will decrease as the resistance to travel increases. In addition, if trip generation and distribution is considered merely as the development of linkages between given origins and destinations, then travel from any point will be directly proportional to and dependent on the number of trip origins at that point. It has already been stressed that there is a complex feedback in the relationship which must not be ignored. Thus, factors in the distribution of trips or its subsequent assignment might tend to cause the generation of more or fewer trips at a particular point. However, to explain the process of trip distribution more simply, it will be assumed throughout that trip distribution is concerned with given numbers of trip origins and destinations.

Thus, it can be stated that the distribution of trips from an origin to a destination is directly proportional to: (1) the number of trips generated at the origin, and (2) the attraction of the destination for such trips. Trip distribution is inversely proportional to the resistance to travel between the origin and destination. Each model uses the same measure of trip origins, although in some cases trips at

the origin which is independent of the trip distribution, except, as stated, in one instance.

The principal differences between the models lie in the manner in which they theoretically define and measure attraction for and resistance to travel. In some of the models, the factors are used as directly measured quantities in a formula, while in others they are only implicit within the actual items in the formula.

Much thought and effort in recent years has gone into attempts to explain the human behavioral patterns which produce particular patterns of travel. Research in this area has concerned disciplines ranging from sociology to traffic engineering. Indeed, some of the earliest notions come from sociologists.⁴ Thus, the measures of attraction and resistance which are used represent a variety of approaches to the problem.

Measures of attraction include population, retail employment, total employment, and retail sales floor area. Population, the measure used in early sociological studies, is of lesser concern with the growth of the importance of trip purpose in travel studies. Certain methods representing a more empirical approach have used trip ends themselves as a measure of attraction. In these methods the true independent variables are implied, since the existence of trip ends indicates that travel attractions exist also.

The first measure of resistance to travel, again used by the sociologists, was distance. Several methods use distance, either

⁴Carrothers, G.A.P. "An Historical Review of the Gravity and Potential Concepts of Human Interaction." Journal, American Institute of Planners, vol. 22, no. 2, 1956.

actual distance or straight-line distance. Increasing use is now being made of the time parameter, studies indicate that time is of greater significance than distance, especially in the central urban area and for peak-hour travel. Another resistance measurement is cost, either as estimated overall travel cost or as specific cost "bottle-necks" caused by toll facilities. As in the case of travel attraction, resistance to travel is implied within some models which use trip ends alone to calculate the distribution of trips.

It is now appropriate to introduce the first basic equation of trip distribution. Hopefully, the various methods considered will indicate how each expresses this basic relationship.

$$t_{i-j} = t_i \times k_{i-j}$$

where

t_{i-j} = number of one-way trips from origin zone i
to destination zone j

t_i = number of generated trip origins in zone i

k_{i-j} = distribution factor representing the attraction
of zone j for trips from zone i and the resistance to travel from zone i to zone j

There are two basic types of methods for forecasting traffic distribution, the expansion or growth factor method and the analytic or gravity model method. Some of the later methods have developed to a point where it is no longer possible to classify them directly under the above headings. Nevertheless, their development from these two will be traced.

As it has been explained above, each method must consider the fact that the volume of travel will become greater as the rate of attraction for such travel increases, but travel volume will decrease

with the increased resistance to such travel. This fact is considered either directly within some mathematical relationship or is implicit within the method of forecasting.

The basic assumption of the growth factor method is that the present travel pattern, as obtained by traffic counts and origin and destination data, can be multiplied by a suitable measure of growth to calculate a future travel pattern. The resistance to travel is also implicit in present travel data, but is assumed to remain constant in the future.

The analytic method is a general term for several different gravity model forecasting methods, which do not base forecasting on present patterns, except assuming constant trip generation characteristics of different type of land use and trip purpose. A formula is set up which directly relates number of trips to some measure of attraction such as population, and inversely relates number of trips to some measure of resistance such as distance, time, or cost. The precise values of these measures are taken from observation of actual travel patterns as obtained by traffic counts and origin and destination data.

The more recently developed Opportunity methods are quite different from either the expansion or the analytic methods. They have brought the theory of probability into the field of trip forecasting. While this is certainly a new approach, it will be shown that the same basic trip forecasting equation is still applied.

The Growth Factor Models of Travel

A very basic approach to the problem of forecasting future travel patterns would be to take present-day figures for trips between zones, estimate the growth factor for the whole area, and using this as a multiplier, calculate the resulting future trips between all zones. This is an extremely simple means of carrying out the forecast and contains a number of errors and inconsistencies. It does, nevertheless, illustrate the principle of the growth factor models.

There are four different methods of this type which can be classified as the uniform factor, the average factor, the Fratar method, and the Detroit method. For each method a growth factor for each zone is calculated from projections of land use and trip generation. The result is a factor which gives the increase for each zone of trip ends over those measured at the particular date from which projections have been made. Trip ends are the total trip origins and trip destinations in a particular zone. Thus the sum of trip ends in all zones is equal to twice the total trips in all zones. The methods differ in the way they combine the zonal growth factors to give different expansion factor E.

The expansion factor E relates the forecasted trip interchange with the present trip interchange:

$$T_{i-j} = t_{i-j} \times E$$

It will be noted that the growth factor methods calculate the numbers of two-way trips T_{ij} between zones, rather than one-way trips T_{i-j} which were included in the basic forecasting equation.

The formulas for the growth factor methods can be expressed in these forms:

$$T_{i-j} = t_{i-j} \times \text{expansion factor } E$$

$$T_{i-j} = (T_i)_{tg} \times \text{distribution factor } k_{i-j}$$

The uniform and average factor and Detroit methods have simple expansion factors which result from their method of development. The Fratar method develops the distribution factor shown, which has more meaning than the distribution factors for the other methods.

The purpose of the inclusion of both factors for all methods, however, is to illustrate that each can be expressed in both ways. The formulas have the form of the basic equation of trip forecasting:

$$T_{i-j} = t_i \times k_{i-j}$$

or rather $T_{i-j} = (T_i)_{tg} \times K_{i-j}$ for forecast trips.

Also, they are all growth factor methods inasmuch as they forecast future trips by multiplying present trips by an expansion factor which combines zonal growth factors and trip data.

This illustrates the proposition that both the measure of trip attraction and of trip resistance in this method are implied within the formula rather than directly measured and stated. The future levels of trip attraction are obtained by using those implied by the present trip interchange level multiplied by an estimated measure of growth. The resistance to travel is also implied in the present trip interchange figures, but is assumed to remain constant in the future.

Growth factor methods were the first developed on any major scale for use in trip pattern forecasts. The reason for this illustrates the advantages of the methods. They are simple and they require little

or no fundamental understanding of the basic causal relationships of traffic movement. They require for input only a knowledge of the existing trip interchange and an estimation of simple zonal growth factors. They were ideal methods for their times, when large quantities of traffic data were being collected in extensive but elementary origins and destinations surveys and when the complex nature of trip motivations was barely beginning to be understood.

The major disadvantage of the growth factor methods is that they do not provide the large changes in numbers of trips generated. They are totally unable to provide for the situation where no trip interchanges exist at present, since the methods multiply the existing number of trip interchanges to obtain future values. In addition, where there are only small numbers of existing trip interchanges, the chances of statistical error in forecasting is high. The methods are also unable to forecast changes in trip interchange which result from large changes in accessibility. As an example of this, consider the theoretical case of two cities divided by an impassable gorge. No trip interchange will exist. If the gorge is bridged, the growth factor methods have no way of forecasting the traffic which will result between the cities.⁵ A method has been suggested whereby this major defect of the growth factor methods might be overcome by a combination of neighboring zones with small existing number of trips.⁶ it is clear

⁵Lynch, J. T. and others. Panel Discussion on Inter-Area Travel Formulas. HRB Bulletin, 253, 1960.

⁶Ibid.

if this has met with any success and if indeed it overcomes the problem of statistical error with small samples.

One of the errors which comes into the use of the growth factor methods is the exclusion of trips which have their destination in the zone of origin. These "lost trips" add to the errors in the data and methods and increase the need for operation. While identification of such trips may be difficult, their omission is not justifiable.

The question of statistical error associated with the different methods and their ability to handle quantities of data effectively is an important one. Another drawback to the growth factor methods is that any errors in the original survey data which is used for the forecast will be magnified in the forecasting process. Each of the proponents of the different methods has discussed the question of accuracy and data handling. Only one paper has made comparisons between methods on any large scale, however.⁷ The result of this study was to suggest that the average factor, Fratar, and Detroit methods have comparable accuracy. The Fratar method converges faster than the other two, but because of its greater complexity, it gives no great saving in computer time.

The Opportunity Model of Travel

The theory of probability was first introduced in the Chicago and Pittsburgh studies by Schneider in what is called the opportunity method.⁸ It has subsequently been used in the Penn-Jersey study under

⁷Brock, G. E. and W. L. Mertz. Evaluating Trip Forecasting Methods with an Electronic Computer. HRB Bulletin, 203, 1958.

⁸Chicago Area Transportation Study. Final Report, vol. II, July, 1960.

the name of the Method of Competing Opportunities.⁹ This last differs from the Chicago method, however, in that it tries to use more directly the basic concepts of elementary probability theory.

Both the Chicago and Penn-Jersey methods can be represented simply as follows:

$$T_{i-j} = T_i \times P(S_j)$$

where T_{i-j} = the calculated trips from zone i to zone j

T_i = the total trip origins generated by zone i

$P(S_j)$ = the probability of a trip stopping in zone j

It should be noted that T_{i-j} is a measure of one-way trips, which is different from T_{ij} , the total trip interchange between zones i and j which is measured in several of the other methods.

It is immediately apparent that the probability factor is directly equivalent to the distribution factor in the basic distribution equation:

$$T_{i-j} = T_i \times K_{i-j}$$

The two methods differ in the way in which they calculate $P(S_j)$, the probability of a trip stopping in zone j. Included within the probability term is a measure of the attractiveness of the destination zone j for trips from origin zone i in terms of trip destinations or opportunities calculated in the trip generation study. The measure of residents to travel is that of time, although it is also possible to account for such resistance, or frictions, as toll bridges. The use of time to measure this resistance is by means of the concept of minimum time path.

⁹Tomazinis, A. R. A New Method of Trip Distribution in an Urban Area. HRB Bulletin, 347, 1962.

The Gravity Factor Models of Travel

Behind the analytic methods of trip distribution forecasting lies the belief that the future travel pattern cannot be obtained merely through upgrading by a factor or factors of the present pattern. The methods are called analytic because it is necessary to analyze existing travel data in order to set up direct relationships between trips and the measures of attraction and resistance.

The central method of this type is the gravity model. Other methods are similar or have developed from it, but the gravity model form was the first one in which an attempt was made to forecast trips in terms of the complex, underlying causes of such trips. The title "gravity model" was given for the reason that the relationship has a similar mathematical form to that of Newton's law of gravity. This is certainly true but may be rather unfortunate because of the implication that sociological behavior can be explained in the same precise manner as more physical phenomena.

John Stewart was one of the first to generalize the gravity concept around 1920's. The general hypothesis is that the interaction between two population centers varies directly with some function of their population size, and indirectly with some function of the distance between them. The hypothesis can be expressed in the form:

$$T_{ij} = k \frac{P_i P_j}{D_{ij}}$$

where:

- $P_i P_j$ = the population of cities i and j , respectively
 T_{ij} = the number of trips between i and j
 D_{ij} = the distance between i and j
 k = a constant factor

In the 1920's, the Swedish investigator Pallin used the gravity formula with a distance exponent of "2" to determine intercity travel flows.¹⁰ In 1954, Carroll used the gravity formula to help determine the area over which urban centers have influence.¹¹ In testing the theory proposed, he used both long distance telephone calls and intercity travel. The test indicated that the exponent of distance varied from 2.8 to 3.0.¹² Carroll concluded that a city's influence decreases according to a figure approaching the cube of the distance.

Since that time, the distance factor in the gravity formula has been the subject of much debate. The evidence developed by Reilly,¹³ Pallin, and Carroll suggests that the impact of distance is not uniform and that its relationship is not a simple inverse one, but one in which distance is raised to some power other than unity. As one might suspect, one of the underlying problems of determining values for the exponent is the variation of the measure used to express distance. If airline distance is used, one exponent would result; if over-the-road distance or time were used, another would result.

¹⁰ Carroll, J. D. Spatial Interactions and the Urban Metropolitan Description. Traffic Quarterly, April 1955.

¹¹ Ibid.

¹² Ibid.

¹³ Ibid.

Very early attempts to apply the gravity model formula to the problem of determining intercity or urban area travel patterns also used the formulation. The exponent generally used was again "2". However, as these gravity model studies were analyzed and compared with known traffic volumes it appeared that the exponent should be about 1.6 for total urban area travel. Studies in San Diego, Detroit, and Toronto during the mid 1950's seemed to substantiate these results.¹⁴

About the same time, Alan Voorhees, who perhaps more than anyone else has been responsible for the development of the traffic model field, undertook some basic research in an attempt to further quantify this exponential value of spatial separation varied by trip purpose. When spatial separation was expressed as driving time between zone centroids, Voorhees found that the exponent for work trips was about 1.0, for social trips and convenience shopping trips about 3.0, and for other shopping trips about 2.0. Consistent with these results were those observed by Carroll in Grand Rapids, Michigan. By using driving time between zones as the measure of spatial separation, Carroll found that the exponent for work trips was about 0.9, for social trips about 2.1 and shopping trips about 2.0. In addition, the exponent for total trips was about 1.5 which is consistent with the value found in other areas previously mentioned.

Comparison of the exponent for total travel between cities (about 2.5) with that for intercity travel (about 1.5) reflects to some

¹⁴Callard, W. B. Traffic Forecasting for Freeway Planning. JAIP, vol. 25, No. May, 1959.

extent the effect of using different parameters to express the spatial separation between the areas under consideration. Airline distance has generally been used for travel, between cities, while over-the-road distance or time has been used for intercity travel. The variation between these two exponents, however, also reflects the fact that neither of the spatial separation parameters took into account terminal time.

Inasmuch as the distance appears in the denominator of the gravity model formula, a decrease in the exponent means that spatial separation becomes a less restrictive factor. In short, the variation in the exponent means that people are willing to travel farther for the more important purposes such as work than for other purposes such as shopping and school.

In addition to a variation in the exponent by trip purpose, Voorhees has shown that the exponent may not remain constant but may increase as the spatial separation increases. This is particularly true if terminal times are not added to driving times in determining spatial separation. The variation was not evident for all trip purposes but involved mainly work trips. Several other researchers have since substantiated this work. Lefkowitz, for example, found that for peak-hour trips in San Mateo, California (which includes mostly work trips) this exponent varied considerably, as shown in Table 1, when driving time was used as a measure of spatial separation.

Hansen, in his research using Washington, D.C., data has also shown that the exponent is not constant for all time increments. He concluded that all the curves would have been linear, if the exponents had been constant.

TABLE 1.--Variation in Exponents for Work Trips - San Mateo, California

Time Classes (in minutes)	Gravity Factor Model Exponent
0 - 4	0.0
4 - 6	0.3
6 - 11	0.5
11 - 16	0.55
16 - 36	1.10
36 and over	1.20

Source: U.S. Dept. of Commerce, Bureau of Public Roads, Office of Planning. "Calibrating and Testing a Gravity Model with a Small Computer." Oct. 1963.

Besides these, and other field studies which have shown the need for a variable exponent in the gravity model, there is also a theoretical consideration which substantiates this need. It has been pointed out by Tanner in Britain,¹⁵ and shown mathematically, that a constant exponent cannot give reasonable results for both short trips and long trips unless the range between the longest and the shortest trip in the area is small.

Although the exponent for total trips remains approximately constant from urban area to urban area, it has been shown by Voorhees that this exponent may vary by trip purpose. Table 2 shows that exponent

¹⁵Tanner, J. C. Factor Affecting the Amount of Travel. Department of Scientific and Industrial Research, Road Research Technical Paper, no. 51, London, 1961.

for work trips in several urban areas than in the smaller ones. Comparison of factors indicating the effect of separation on trip interchanges, as found in several recent studies, shows that this variation does exist among urban areas. This comparison also shows, however, that variables in addition to population size may influence these factors, e.g., density of development.

Table 2.--Variation in Travel Time Exponent for Work Trips in Areas of Different Population Size

Area	Approximate Population	Gravity Factor Model Exponent
Fort Wayne, Indiana	172,000	0.805
South Bend, Indiana	192,000	0.703
Wichita, Kansas	283,000	0.680
Oklahoma City, Oklahoma	374,000	0.745
Baltimore, Maryland	1,300,000	0.647

Source: U.S. Dept. of Commerce, Bureau of Public Roads, Office of Planning. "Calibrating and Testing a Gravity Model with a Small Computer." Oct. 1963.

Finally, Hansen and others have demonstrated that factors other than the use of land and the type and extent of transportation facilities available in an area also influence trip distribution patterns. Travel patterns are also affected to a considerable extent by the social and economic characteristics of the people who make trips.

CHAPTER IV

TRIP GENERATION AND DISTRIBUTION MODELS

The forecasting of travel patterns in any community will require a set of forecasting models which are easy to apply, yet have sufficient sensitivity to provide reliable comparisons.

To satisfy these criteria a component type of modeling system is recommended, i.e., various models are formed as separate procedures which can be operated either singly or together, depending on the requirement. The required components of models are trip generation and trip distribution.

In some applications the various models may be used independently. For example, a change in the transportation system will affect the distribution and modes of travel, but not the number of trips generated. To test the effect of such change, only the distribution model would be required. Similarly, some aspects of environmental modeling require a knowledge of the amount of traffic generated and the parking impacts rather than the pattern of movement. In many cases, particularly when a given alternative contains no element of any other alternative, all the model would be used.

This study is a discussion of issues relevant to the establishment of specific model development procedures, as well as a formulation of the procedures and the model relationships. An attempt

is made also to put together the elements into a process and to describe its mechanics. The various models developed are also described. Finally, the factors considered in the choice of the most appropriate model for generating and distributing travel forecasts are summarized and evaluated.

Trip Generation Model

The key to predicting future travel patterns is an understanding of the varied, interacting relationships between travel characteristics and the surrounding urban environment. Trip generation, the term commonly used to denote the study of these relationships, usually refers to the study of resident person and vehicular travel. The trip generation model can be used by itself for determining the amount of traffic which would be generated by a proposed development, or it may be used on a wider basis as the first step in a community transportation forecasting procedure.

The relationship between trip purpose and base (trips are either home-based or nonhome-based) is vital. A home-based trip is one which has either its origin or destination at the tripmaker's place of residence. For home-based trips, the trip ends are labeled wither as "productions" or "attractions." Productions are the trip ends at the tripmaker's place of residence, and attractions refer to the non-home ends of the trips. Different techniques are used for estimating productions and attractions. Home-based trip productions are found to be a function of basic household variables. Regression analysis may be used for analyzing relationships during the initial stages of the work.

The estimate of future trips that will be generated by each of the transportation areas can be made by conversion of the data obtained by the land-use forecasting method. The method produces estimates of the number of people living in the area, the number of workers employed in an industrial or commercial area, and the number of cars owned. These statistics can then be converted into volume of trips by applying the relationships developed for trip generation by the mathematical model technique.

If the forecasting of future land use is done by some other method, the forecast may produce estimates in terms of acres of land for various uses - residential, commercial, industrial, etc. The conversion of land use to trip generation should then be made on the basis of parameters established for trip generation characteristics.

In addition, forecasts will have to be broken down into various types of trips in order to allow for variations in trip distribution as related to different land use activities. This trip purpose breakdown should be based on the criteria developed during the analysis of the trips generated in the community.

Trip Purpose

Several research activities have allocated trips produced by residential areas to nonresidential attractions, while others have questioned the basis by which to distribute trips produced by one part of a community to all other parts.

As a general rule, it is desirable to take into consideration the number of trips in each category, the trip length characteristics for each of the trip purpose categories, and the model's ability to

forecast the categories separately. Several studies in urban areas have used the following trip purpose categories in their transportation model with satisfactory results:

1. Home-based, work: Those trips between a person's place of residence and his place of employment for the purpose of work.
2. Home-based, shop: Those trips between a person's place of residence and a commercial establishment for the purpose of shopping.
3. Home-based, social-recreation: Those trips between a person's place of residence and places of cultural, social, and recreational purposes.
4. Home-based, school: Those trips by students between the place of residence and school for the purpose of attending classes.
5. Home-based, miscellaneous: All other trips between a person's place of residence and some form of land use for any other trip purpose.
6. Nonhome-based: Any trip which has neither origin nor destination at home regardless of its purpose.
7. Truck trips and taxi trips.

Socio-Economic and Land Use Data

In order to provide an effective analysis of travel patterns and trip generation, the following data should be available:

1. Population by age group
2. Average family income
3. Employment by industry and occupation
4. Land use by type
5. Car ownership
6. Number of dwelling units

These data will provide the information for estimating trip production and trip attraction values.

Trip Generation with the Regression Model

Trip generation encompasses the detailed analysis and study of a number of different variables and their interrelationships. It ties person and vehicular travel to the urban environment in which it takes place. If the hypothesis is made that trip generation characteristics remain stable with time, then future person and vehicular travel can be estimated utilizing present trip generation characteristics as one of the necessary inputs.

The models can be developed by the correlation technique. This technique is a statistical tool for discovering and measuring the relationships between variables expressed in a brief formula termed the regression (estimating) equation. Associated with the correlation technique are the following types of measurements:

(1) A measure of the degree of relationship or correlation (R) between the variables. The coefficient of determination (R^2) indicates the proportion of the variance of the dependent variable which has been explained or determined by the independent variable or variables. The coefficient of non-determination ($1-R^2$) indicates the proportion of the dependent variable not explained by the independent variables.

(2) A measure of the divergence of the observed values of the dependent variable from those estimated by the regression equation. This measure is called the "standard error of the estimate."

(3) A measure of the relative contribution of a new independent variable added to the estimating equation. This measure is termed the "coefficient of partial correlation."

Different degrees of correlation occur between pairs of variables, ranging qualitatively from poor to excellent. Correlation is a measure of the strength of association between variables and is measured by means of correlation coefficients. These coefficients range from 0 when there is no correlation to ± 1.00 for perfect correlation.

The model employs standard multiple regression techniques to determine relationships among variables as indicated by the following equation:

$$T_p = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5$$

where T_p = trip per person

a = intercept on the T_p axis

$b_1, b_2, \dots, b_5$ = multiple regression coefficients of trips per person, family income, vehicle ownership, residency, distance from CBD

x_1 = auto ownership

x_2 = family income

x_3 = residential density

x_4 = distance from the CBD

This technique requires the simultaneous solution of five equations to determine the intercept and multiple regression coefficients. It makes possible the measurement of the relative importance of each variable when the effect of all the others acting simultaneously is taken into account.

Relationships of the Trip Generation Variables

In order to establish the relationship between the determinants of trip generation on a more precise basis, many examples have drawn freely from the existing field studies.

Land Use and Person-Trips

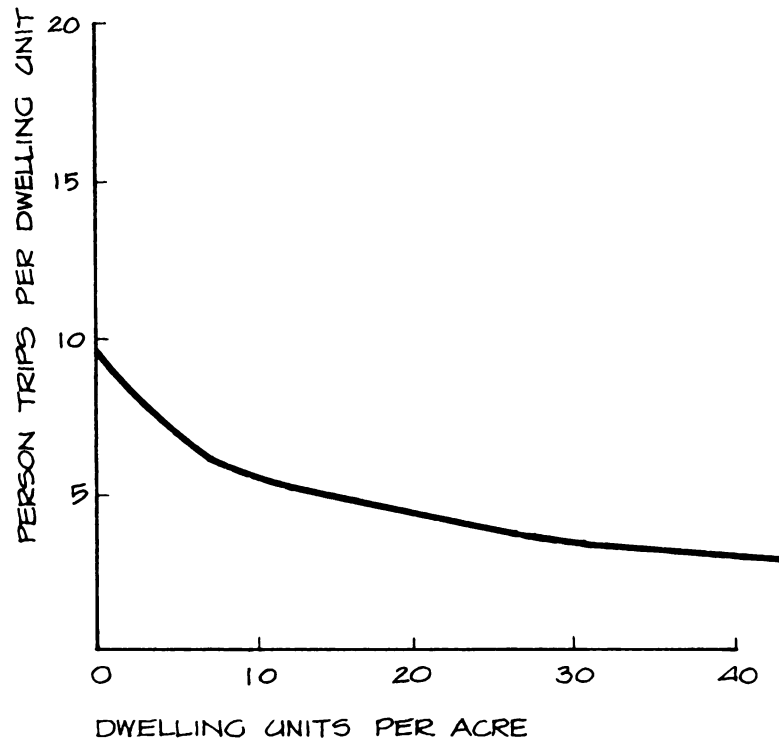
In evaluating the relationship between land use and demand for transportation in the area, it is convenient to sort out three major land use classes - residential, commercial, and industrial - placing particular emphasis on the transportation demand generated in the residential category.

Martin, Memmott, and Bone have shown the inverse relationship that exists between residential density and person-trips per dwelling. Figure 3 indicates that a residential density of 10 dwelling units per acre can be expected to generate approximately 4.3 person-trips per dwelling place per day or a daily total of 43 person-trips per residential acre.

The Pittsburgh Area Transportation Study (PATs) of 1961 developed the following regression equation relating residential density and person trips:

$$Y_1 = 9.62 - 4.19 \log x$$

Y_1 represents person-trips per day per dwelling and x represents the number of dwelling units per residential acre. This regression curve, shown in Figure 1, indicates the negative relationship between density and person trips per dwelling. According to the PATs equation, a density of 10 dwellings per acre is likely to produce a little more than five



PERSON TRIPS PER DWELLING UNIT

FIGURE 3

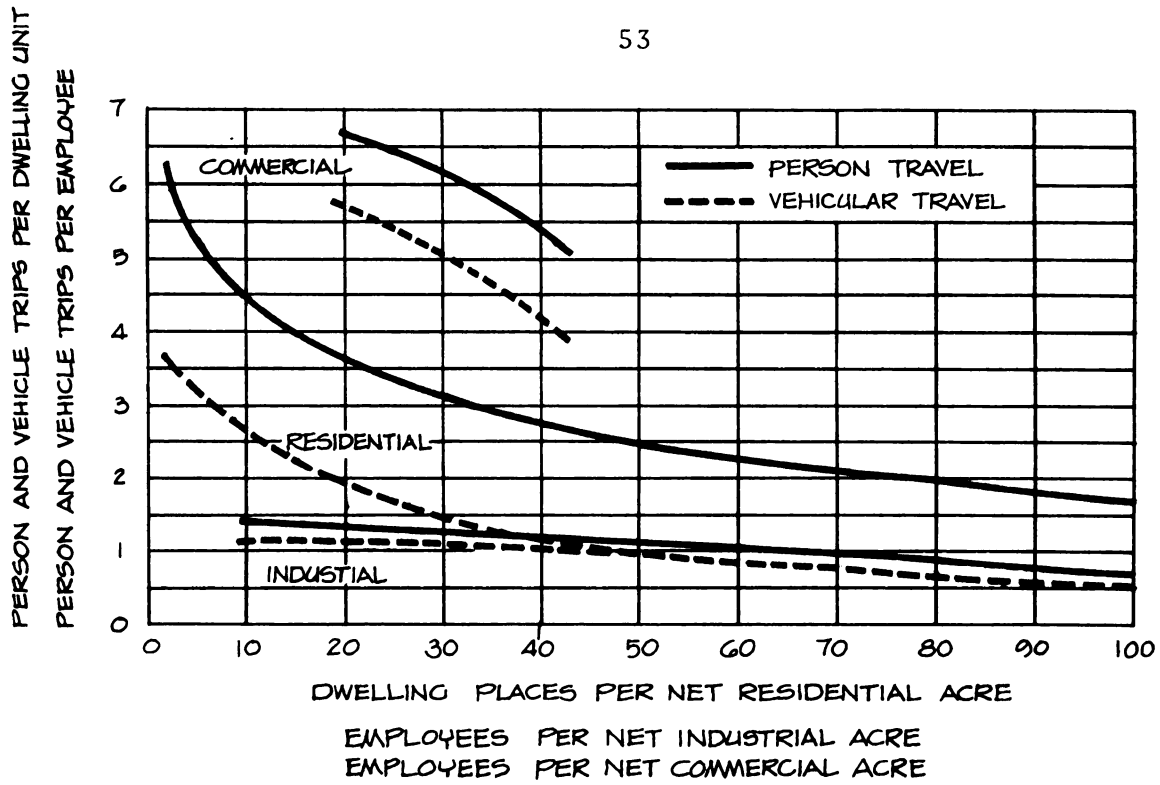
person-trips per day, but when this density increases to 40 dwellings per acre, a typical row house density, only 3 person-trips are produced per household.

Increasing residential density is often associated with increased access to commercial activities. Frequently such trip destinations are brought within walking distance, as in the case of multi-level, high-density residential structures that have shopping areas located on the ground level. This leads to the conclusion that the negative relationship noted in the studies cited above is in part a reflection of the decreasing necessity to make person-trips as the distance between place of residence and place of socio-economic activities decreases.

The relationship between industrial and commercial land densities, usually measured in employees per acre, and trip generation is not as clearly defined as in the case of residential land use. While the generated curves of Figure 4 indicate decreasing tendencies in the number of person-trips as employee densities increase, the relationship is greatly complicated by the wide diversity of industrial and commercial landscape in existence.

Socio-Economic Variables

Land use alone does not determine travel patterns. Among other variables, automobile ownership has been found to offer the highest correlation with person-trips per dwelling unit of any of the trip characteristics examined. The Pittsburgh Area Transportation Study derived the following regression equation:



PERSON AND VEHICLE TRIPS AS A FUNCTION OF LAND USE DENSITY

FIGURE 4

$$Y_1 = -.29 + 6.51 X_1$$

Y_1 is person trips per dwelling unit and X_1 is automobiles per dwelling unit. The coefficient of correlation in this case was +.91.

Using material gathered from a different source, Martin, Memmott, and Bone found a regression equation which reads as follows:

$$X_1 = 2.88 + 4.60 X_2$$

X_1 is resident trips per dwelling unit and X_2 is automobile ownership. Here the coefficient of correlation was +0.827. Both of these regression curves are shown in Figure 5 with an indication of average auto ownership.

Besides auto ownership, family income has been shown to influence trip production in the following regression on equation:

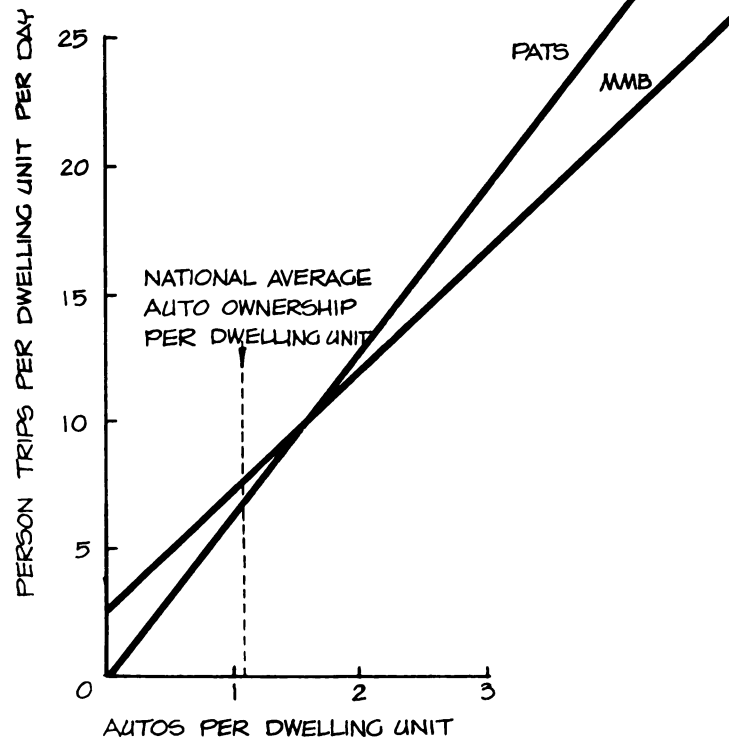
$$X_1 = 3.07 + 0.44 X_5$$

X_1 is resident trips per dwelling unit and X_5 is average family income in thousands of dollars. The coefficient of correlation here was +0.655.

Access Factor

Distance from the Central Business District (CBD) of a metropolitan area has been identified by many transportation studies as a significant influence on the production of person-trips. As a physical characteristic, distance from the CBD has been shown to bear a close inverse relationship to density of land use and to some extent correlates positively with behicle ownership.¹ Generally, increasing

¹Martin, Brian B. and others. Principles and Techniques of Predicting Future Demand for Urban Area Transportation. The M.I.T. Press, 1966.



AUTO OWNERSHIP AND PERSON TRIPS

FIGURE 5

distance from the CBD leads to an increase in the number of trips per person. Figure 6 portrays graphically the influence of distance from the CBD on the number of trips per day found in the Pittsburgh Area Transportation Study,

Trip Distribution Model

Model Theory

The gravity model formulation, one of the most widely used trip distribution techniques, is based upon the hypothesis that the trips produced at an origin and attracted to a destination are directly proportional to the total trip production at the origin, the total trip attraction at the destination, a calibration term, and a socio-economic adjustment factor. This relationship may be expressed as follows:

$$T_{ij} \propto P_i A_j F_{ij} K_{ij}$$

T_{ij} = trips produced at i and attracted to j

P_i = total trip production at i

A_j = Total trip attraction to j

F_{ij} = calibration term for interchange ij

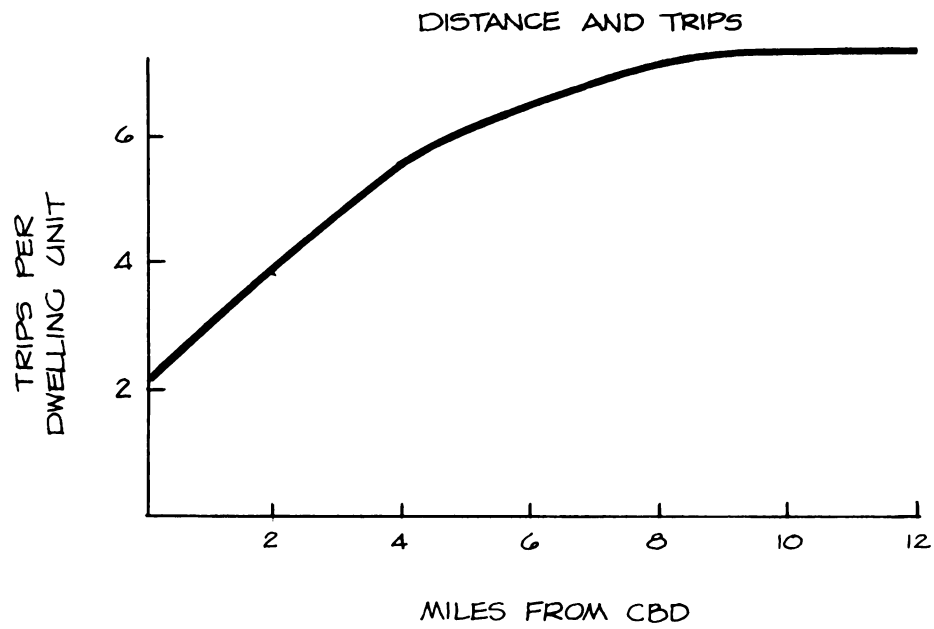
K_{ij} = socio-economic adjustment factor for interchange ij

i = an origin zone number, $i=1,2,\dots,n$ and

n = number of zones

The relationship may be written as an equation by introducing a constant term, C , as follows:

$$T_{ij} = CP_i A_j F_{ij} K_{ij}$$



DISTANCE AND TRIPS

FIGURE 6

A value for constant C for any origin zone i may be established when it is specified that the sum of all T_{ij} for origin i must be equal to P_i :

$$\begin{aligned} P_i &= \sum_{j=1}^n T_{ij} = \sum_{j=1}^n C_i P_i A_j F_{ij} K_{ij} \\ &= C_i P_i \sum_{j=1}^n [A_j F_{ij} K_{ij}] \quad i=1,2,\dots,n \end{aligned}$$

therefore,
$$C_i = \frac{1}{\sum_{j=1}^n [A_j F_{ij} K_{ij}]} \quad , \quad i=1,2,\dots,n$$

and the equation becomes

$$T_{ij} = \frac{P_i A_j F_{ij} K_{ij}}{\sum_{j=1}^n [A_j F_{ij} K_{ij}]} \quad , \quad i=1,2,\dots,n \quad (1)$$

which is the standard gravity model formula.

The calibrating term, F_{ij} , is generally found to be an inverse exponential function of impedance. However, it is not necessary that it be presented in that particular form.

When all trip interchanges have been computed according to the equation, production (row) totals will be corrected because of the structure of Equation 1, the gravity model formula. However, attraction (volume) totals will not necessarily match their desired values. An iterative procedure is employed to refine calculated interchanges until actual attraction totals closely match the desired results.

After each iteration, adjusted attraction factors are calculated according to the following formula:

$$A_{jk} = \frac{A_j}{C_{j(k-1)}} A_{j(k-1)}$$

A_{jk} = adjusted attraction factor for attraction zone (column) j, iteration k

$A_{jk} = A_j$ when $k=1$

C_{jk} = actual attraction (column) total for zone j, iteration k

A_j = desired attraction total for attraction zone (column) j

j = attraction zone number, $j=1,2,\dots,m$

n = number of zones

k = iteration number, $k=1,2,\dots,n$

n = number of iterations

In each iteration, the gravity model formula is applied to calculate zonal trip interchanges using the adjusted attraction factors obtained from the preceding iteration. In practice, the gravity model formula thus becomes:

$$T_{ijk} = \left[\frac{P_i A_{jk} F_{ij} K_{ij}}{\sum_{j=1}^n (A F K O)} \right]^p$$

T_{ijk} is the trip interchange between i and j for iteration k and $A_{jk} = A_j$, when $k=1$. Subscript j goes through one complete cycle every time k changes. The equation is enclosed in brackets which are subscripted p to indicate that the complete process is carried out for each trip purpose. It is equivalent to placing a subscript p on every variable in the equation.

The calibration term, F_{ij} , is usually a function of trip time. Its usage is generalized, however, by using a table rather than a formula to obtain values for F_{ij} . The user thus supplies a table

of F-values for each trip purpose. Individual values are related to increments of trip time. Tables of interzonal travel time are supplied by the user. The F-value chosen for each interchange is thus a function of trip time for that interchange.

It is quite evident, however, that the F-table supplied by the user for a particular trip purpose could easily represent something other than a continuous inverse exponential function. It is equally evident that the contents of the highway network and trip volume supplied by the user could reflect some other measures of impedance than time alone. This feature of the model makes it a more general technique.

Trip Production and Trip Attraction

For the gravity model formulation shown, four separate parameters are required before the trip interchanges T_{ij} can be computed. Two of the basic parameters, the number of trips "produced" (P_i) and the number of trips "attracted" (A_j) by each traffic zone in the study area, are related to the use of the land and to the socio-economic characteristics of the people who make trips.

The gravity model distributes trips from production zone to attraction zone, while the other travel models in use distribute trips from origin zone to destination zone. To demonstrate the production and attraction definition, it is first necessary to class trips as home-based or nonhome based. Nonhome-based trips have neither end at the residence of the trip maker.

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Distance

The spatial separation between zones can be measured by one of several parameters. To date, the most effective measure seems to be travel time.

The total travel time between zones is the sum of the minimum path driving time between zones plus the terminal times at both ends of the trip. Terminal times are added in order to allow for differences in parking and walking times in these zones as caused by differences in congestion and parking facilities. This provides a more realistic measure of the actual spatial separation in time between zones as it is likely to influence where automobile drivers decide to work and shop.

Travel Time Factors

Travel time factors (F_{ij}) express the effect that spatial separation exerts on trip interchange. They indicate the impedance to interzonal travel caused by spatial separation between zones. In effect, these factors measure the probability of tripmaking at each one-minute increment of travel time.

To obtain travel time factors for the present period, it is currently necessary to go through a process of trial and adjustment. Today's travel time factors are usually assumed to remain the same into the future. The validity of this assumption has never been definitely proven, but evidence from studies of work trip travel patterns in Columbia, Maryland, indicates that there is some basis for making this assumption.

Zone-to-Zone Adjustment Factors

The remaining input to the gravity model formula reflects the effect on travel patterns of social and economical characteristics of particular zones or portions of the study area. These are represented by the zone-to-zone adjustment factor K_{ij} . These characteristics are not otherwise accounted for in the use of the model. If found to be necessary to relate the adjustment factors to characteristics of the zones, they may be forecast as a function of the socio-economic conditions estimated for the future land use plan.

Inventories and Decisions

This section discusses the information which must be available and the decisions which must be made concerning the data from the various inventories so that it will provide the required results used in the various phases of the planning process.

Origin-Destination Survey: The desired data can best be collected through a comprehensive home interview survey using direct person-to-person interviews. Under certain circumstances, however, satisfactory data might be obtained through telephone interviews, pick-up cards, or mailed questionnaires. In all cases, sufficient controls must be exercised to assure that the resulting travel data are complete and statistically unbiased. It is also important that information pertaining to the following items be obtained from each dwelling unit contacted:

1. Address of dwelling unit
2. Number of persons residing in dwelling unit

3. Number of cars owned by residents of dwelling units
4. Occupation of household head
5. Each trip taken by each resident of the dwelling unit.

Small O-D sample sizes ranging from 0.1 to 1 percent have been used in several transportation studies, including Columbia, Maryland. Those using such small samples for calibrating the gravity model feel that they are adequate to develop a total study area universe of trips. Others question such claims and argue that this procedure should be used only to update the original survey. Research has shown, however, that a small sample yields very little information on trip making by zone. Trip production and trip attraction rates cannot be obtained on a zonal basis from this type of survey. Consequently, some assumption has to be made as to how the total universe of trip productions and attractions will be distributed on a zonal basis. Procedures and assumptions which have been used in various studies to synthesize zonal production and attraction rates without a comprehensive O-D home interview survey have been documented. However, at the present time, the small random sample technique is considered useful only for broad and general studies or updates of comprehensive studies.

Operation of the Distribution Model

A traffic model is a mathematical statement of traffic movement based on observed relationships. One model operates on the theory that all trips produced by a residential area are attracted by various land uses. The strength of attraction varies directly with the

intensity of development of the attracting land uses and indirectly with the time-distance between the attracting land use and the residential areas.

Commonly, the model is applied in this manner: the study area is divided into "zones"; a system of "links" connects the "centroids" of the zones; each zone is defined as "producing" and "attracting" trips. The production of trips by a zone is based on the number of dwelling units in that zone and the number of trips to or from work or shopping or other trips produced per dwelling unit. A zone attracts work trips based on employment in the zone. Shopping trips are attracted on the basis of total retail sales or commercial floor area in a zone. The attraction of "other" trips to a zone usually is based on the number of dwelling units in the attracting zone.

External stations are established on the parameter of the study area to deal with traffic moving into or out of the area.

All traffic flows, internal and external, are summarized on the system of links. The summarized traffic is assigned to an existing or proposed street network, and an analysis is made of the ability and efficiency of the street network to carry the assigned traffic.

A practical method has been devised to test the reliability of traffic models and to modify them before projecting future traffic if necessary. A model is prepared for a given year for which land use data are available. Theoretical flows across the screen lines are totalled. Traffic counts then are made to determine actual traffic flows across the same screen lines, and these are compared with theorized

traffic. Adjustments of the model are not considered necessary if actual and theoretical counts differ by less than 10 percent.²

Generally, the models have proved reliable.

Screen line tests always are of value, especially where traffic flow is well established. However, where the magnitude of expected growth is great, the necessity of first checking the model to correct it for subtleties that will change or disappear with rapid growth is questionable. Under these conditions, a model may be used to project future traffic without checking current traffic, as developed by the model against screen line counts.

Model Development

The establishment of a theoretical framework is necessary in developing statistical models for estimating intercommunity traffic between central city and the surrounding communities. The underlying assumption is that a community's ability to produce or attract trips is a measurable quality and is conditioned by trip relief factors represented by the adequacy of a city's own facilities and by the regional competition among cities.

The basic hypotheses and formulas developed to predict travel desire between cities in general terms are:

1. The larger a population center, the more traffic it generates and the more traffic it attracts.

²Heald, K. L. "Discussion of the Iowa Gravity Model Traffic Distribution Program." Iowa State Highway Commission, Ames, Iowa, 1960.

2. The mathematical form of the law of attraction between physical masses, $F = M_1 M_2 / D^2$, might be applicable to social masses in the form of $F = \text{POP.}_1 \times \text{POP.}_2 / D^2$. Where POP. stands for the population and D stands for the shortest distance.

3. The greater the distance between two population centers the less travel between them.

4. The population of a region or city is a strong index of its economic importance and thus a measure of its traffic attraction.

Basic Conceptual Development

The gravitation concept hypothesizes that an attractive force of interaction between two populated areas is established by the population masses of the two areas, and that spatial separation of the two areas is a condition to this interaction. A basic model in functional form is:

$$T_{ij} = F \frac{M_i \cdot M_u}{D_{ij}}$$

or
$$T_{ij} = F (P_i P_j \frac{1}{D_{ij}})$$

More specifically, a simple formulation is

$$T_{ij} = k \frac{P_i P_j}{D_{ij}^b}$$

Where:

T_{ij} = the total traffic between area i and area j

$M_i M_j$ = the measure of the traffic generating potential of area i and area j

$P_i P_j$ = the population of area i and area j

D_{ij} = the distance between area i and area j

F = notation of functional relationship

where k and b are parameters to be determined empirically. In the case of network-generation models, the value of b should be that which makes T_{ij} the best predictor of transportation flows. Since the value of k is applied to each city-pair within the system, it is dropped from the calculation of the objective function. Although this basic model has been criticised and modified, its simplicity, and the fact that it seems in many instances to perform as well as more complex ones, continues to make it worthy of consideration.

This model would be theoretically applicable to the estimation of traffic interchange between pairs of areas, zones, cities, etc., but it would have some limitations as a new town or regional model. The first limitation is the implication that the two areas under consideration are more or less in a state of isolation. It can be readily seen that such an isolated condition is not practical as the basis for a regional approach to the estimation of traffic interchange. The model in its present form would yield only total travel interchange and would conceal any differences in the ability of the two areas to either produce or attract trips. Differences in this ability vary considerably among the communities of a region; therefore, provision must be made to allow for the incorporation of such differences in regional traffic models. It is necessary in developing an analytical framework to provide opportunity for the investigation of both attracted and produced vehicle trips within a concept of regional integration instead of isolation.

The Regional Model

The above model can be converted to a regional model by changing the subscripts to denote whether the central city is functioning as a trip producer or an attractor of trips, and by eliminating a term in the basic model which becomes a constant under regional analysis.

a. Trips attracted by the central city - if the subscript i refers to any trip producing community in the region such as a new town and the subscript j indicates central city as the attracting community, then the basic model can be expressed as:

$$\text{The total Traffic}_{ij} = \frac{\text{traffic generating in the community and the central city}}{\text{the distance between } i \text{ and } j}$$

Furthermore, as the central city attractor for trips produced by all outlying communities, central city's measure of attractiveness M_j would appear in each function relating a trip producing community to central city (attractor). This is equivalent to multiplying each community index $M_{i,s}$ by a constant term M_j . Thus, it is possible to eliminate the value M_j because it affects all $M_{i,s}$ in the same proportion and consequently has no bearing on the development of the analytical framework for regional models. The model can be rewritten as:

$$A_{ij} = F \frac{M_i}{D_{ij}}$$

and represents trips produced elsewhere in the region but attracted to the central city.

b. Trips produced by central city - the regional model, expressing trips produced by the central city as a function of the attractive index of an outlying community and the distance to that community, then becomes:

$$A_{ji} = F \frac{M_j}{D_{ji}} .$$

CHAPTER V

APPLICATION OF THE MODELS TO TAIPEI, TAIWAN

This research asks how each of several models performs as a simulation technique for trip generation and distribution patterns. One of this research's most significant values in answering this question is that for the first time all tests used previously with one model have been applied to the results of the models. Each test is evaluated to determine its significance. Special emphasis is given to evaluating these tests and the data used as the major calibration control and as a basis for forecasting model parameters.

Regional Traffic Patterns

In order to gain an understanding of the relationships which may be pertinent to the development of intercommunity traffic forecasting models, it is necessary to examine the regional patterns of vehicular traffic movements to and from the central city. Typical questions kept in mind during this exploration of regional trip data were: what relationships exist between the central city's trip production and trip attraction capabilities? What is the effect of trip purpose or trip generation? Do trip distribution patterns show any significant geographical configurations? Answers to questions such as these will be helpful in formulating general hypotheses as the first step in development of regional traffic forecasting models.

A community's transportation demand patterns, including the distribution of needs within different modes of transportation, can vary dramatically depending upon its proximity to central cities, unique traffic generators and major transportation routes and facilities. Satellite communities which depend in part upon central cities for employment, commercial services, and cultural opportunities realize a much different pattern than the non-satellite community which is not under the direct influence of the central city. The non-satellite or independent community whose residents primarily live, work, and play within the local community displays a transportation pattern that differs considerably from those found in the suburban bedroom type community, the service or retail commercial trade center, and the recreation or tourism-oriented resort community.

No city is ever totally independent, having all of its citizens satisfied locally. The degree of independence, however, is important in determining transportation requirements and patterns. For example, a small city located astride an arterial corridor linking a popular resort area with a metropolitan region will have to deal with high through traffic demands on a seasonal basis. The problems and needs in a growing satellite community. This growth may cause a high peak-hour commuter demand upon the city's transportation system. Frequent commuter rail service helps to meet this need, but, at the same time, creates a conflict with local circulation system as the railroad tracks are not grade separated.

Geographical proximity to the various modes of transportation also influences the generation of traffic on the local circulation system. Direct access to a major rail line will affect the development of a city's industrial base and the generation of related truck traffic on the circulation system. The availability of rail transit has a strong influence on the overall local transportation needs.

The travel data collected during the 1971 Taipei origin-destination study pertains to three types of trips: internal trips, i.e., those trips for which both the origin and destination were within the Taipei metropolitan area; through trips, or trips for which neither the origin nor destination was within the metropolitan area; and regional trips, those trips with either the origin or destination within the Taipei urban area. Of these three types of vehicular trips, the regional ones establish the intercommunity travel patterns oriented about Taipei as the central city.

Method of Approach

Regression Modeling Approach

It has been shown in the previous chapter that the gravity model of trip generation and distribution forecasting uses an analysis of existing traffic patterns in order to assign values to factors and indices in the formulas. Thus it is a composition model based on this analysis. The method proposed by Osofsky is of the same type and principle, but more complex in that the trip interchange is represented

by a multiple regression function. This uses directly the different independent variables which influence trip distribution. It is thus essentially a combined trip generation and distribution procedure.

One of the basic assumptions of the gravity model method is that for each study a constant factor of attraction is used for a particular land use, and for each zone a value can be assigned to the index of friction depending on a single specified trip purpose. This would ignore the fact that for different zones different measures of attraction have greater significance and that different zones have varying proportions of differing land uses. This simplification of complex interrelationships by the gravity model method leads to errors.

The method of multiple regression makes the assumption that trip distribution is inversely proportional to distance between zones. In this it follows the gravity model except that the form of the distance factor is different. It should also be noted that distance rather than time or other measurement is used.

It is also assumed that trip distribution is directly proportional to population, employment, vehicle ownership, and land use. This is the major departure from the traditional gravity model which assumes an average travel pattern for each zone regardless of the social and economic characteristics of the zonal population. It also differs in the manner by which the generation process is combined with the distribution.

The multiple regression equation for each zone in turn is then:

$$t_{ij} = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 \text{ ---}$$

where the coefficients a_1, a_2, a_3, a_4 are determined by a least squares fit to existing data and the variables x refer to the destination zone.

The above represents the relation for the existing conditon. The forecast relation is:

$$T_{ij} = A_0 + A_1X_1 + A_2X_2 + A_3X_3 + A_4X_4 \text{ ---}$$

It is assumed that the effect of the independent variables on the trip distribution remain the same from the present time to the forecast year. Thus the values of the coefficients as determined for the present will remain the same in the future, $a_0 = A_0, a_1 = A_1 \text{ ---}$ etc. This again is similar to the gravity model method which assumes that the relationships which determine the attraction factor and resistance exponent remain constant with time.

The procedure involves selecting an equation form for the region and obtaining a different set of coefficients for each zone. A calculation is made of the present trip interchange which is compared with the actual trip interchange to obtain a closer fit of actual and theoretical; the coefficients are altered and the procedure repeated. When such a satisfactory fit is obtained, these coefficients are used in conjunction with the future estimated independent variables to calculate future trips.

The method clearly recognizes that trip purpose affects travel patterns. It also shows the interrelationships of trip generation and distribution. But the fact that different regions require different equations means that the methods and the value of the coefficients may not apply in the future in the regions from which they have been derived.

The Application Process

This research describes the development of a basic set of traffic forecasting methods which will be utilized to evaluate transportation system concepts proposed for implementation in Taipei. The end products of the work reported in this study are inter-Taipei trip production and attraction models for the design year 1990, and the gravity model results.

It should be stressed that the results of this analysis will not be used for the detailed design of a transportation system in Taipei. The results presented herein are intended only for the immediate purposes of this study, i.e., the identification of which forecast system concepts are most feasible for implementation in Taipei.

A sequence of steps or program blocks used to estimate the traffic demand for alternative Taipei transportation systems include:

1. Acquisition of Data Base, which includes the partitioning of the region into zones, the coding of a highway network to obtain highway travel impedances, and the development of socio-economic data.
2. Trip generation, which estimates the aggregate number of trips into and out of each zone or small area into which Taipei was divided.

3. Trip distribution, which estimates the spatial pattern of trips among zones.

A classification rate analysis was used to estimate trip generation. Trip distribution was based on prior considerations where these are appropriate, and on a gravity model formulation where a variety of activity destinations are possible. To this point, the analysis has been concerned with all person trips. The initial model preference analysis separated walking trips from vehicle trips. In order to develop an estimate of peak demands for the purposes of defining requirements as to the capacity of the transportation system, factoring was carried out to estimate both peak-hour and 24-hour demands.

In analyzing future levels of traffic usage of a new transportation system in Taipei, it is necessary to analyze the pattern of transportation movements in the Taipei Metropolitan corridor. Attention is devoted primarily to flows within Taipei, second to flows between Taipei and the rest of the region, and third to flows to and from all parts of the region as they affect the competition for trips within, to and from Taipei.

In transportation planning for the city in this country, travel forecasting models are calibrated using data on existing transportation movements, socio-economic distributions of activity, and transportation networks. Such an approach is not possible in Taipei, for which reliable information on existing patterns is not available, therefore, it was necessary to assume values for model parameters based on previous experience. Throughout the analysis, these assumptions were subjected to logical tests, wherever possible.

This phase of the project has proven successful in highlighting various aspects of the relationships between trips in terms of their purpose, the manner in which they are generated, and the spatial distribution of their origins or destinations. Observations of the overall geographic distribution pattern of regional travel indicate that metropolitan Taipei should provide a suitable analysis region for development of intercommunity traffic estimation models. This region is shown to contain a sufficient number of communities and approximately 80 per cent of the regional motor vehicle trips indicated by the Taipei's 1970 origin-destination study.

There appear to be two distinct segments to Taipei's influence area: a segment surrounding cities with outlying communities dominated by Taipei's traffic generation, and another separating this segment from neighboring competing cities. The existence of these two segments of the region, each under different degrees of competitive influence, suggests that a model might be developed for each of the two areas. Such an approach would reduce the variables in measures designed to evaluate competition because of the more homogeneous nature of competition within the separate areas.

Trip purpose and whether the trips are attracted or produced are two other factors shown to be of considerable significance in shaping regional traffic patterns. The following two listings consolidate the material previously discussed individually by trip purpose, and show the ranking of the various trip purpose categories by number of trips and by ratio of attracted trips to produced trips. This ratio

has been used as an indication of the degree of dominance that Taipei exerts over hinterland communities, i.e., the greater the number of trips Taipei attracts in relation to the number it produces, the greater is its dominance over the outlying communities.

The ranking of trip purposes according to dominance or the degree of influence exerted by Taipei shows little resemblance to their ranking by number of trips. Three trip purposes (work, pleasure and business) account for approximately 82 per cent of the trip interchange between Taipei and outlying communities, and yet these purposes are on the lower end of the dominance scale. The work and business trip ratios of 1.4:1 still indicate some degree of dominance on the part of Taipei, but for pleasure trips the 0.8:1 ratio shows outlying areas to be slightly more attractive than the central city. The situation is probably due to outdoor recreational facilities of regional scope, a factor to be evaluated in subsequent development of traffic models. Trips for either shopping or medical purpose are the principal examples of strong regional dominance by the central city. In the first instance, trip generation is heavily unbalanced in favor of trips being attracted from the region. On the basis of these initial findings, it appears that regional travel merits analysis from the standpoints of trip attraction and trip production as functionally different trip classifications within the primary divisions consisting of the various trip purposes. In other words, not only do regional trips show significant differences among the various purposes, but also between trip production and attraction within each purpose.

The second portion of this study deals with the distribution of regional trip ends within Taipei. Its contribution is providing some direction for solving the problem of how best to measure the trip production and attraction capabilities of a community. The following general observations are based on these data, together with brief samplings of the specific types of establishments associated with regional travel for various trip purposes. These observations although made with specific reference to Taipei's facilities and characteristics, are assumed to be generally applicable to other communities. The supposition is that certain types of facilities, establishments, and land use have a similar effect on travel patterns regardless of other community differences.

Population has long been accepted as a general measure of the size of a community. With reference to the production of regional travel, population is a logical quantity to select as means of evaluating this ability in a community because it quantifies the mobile human element. However, as a measure of a community's ability to attract regional traffic, it is a question as to whether population provides an adequate representation.

The research indicates that population is a likely propose in measuring a community's potential for trip attraction as well as for trip production. Population is closely related to activities stemming from both residential and commercial land use. Together, those two uses account for 88 per cent of all produced trips and 79 per cent of all attracted trips, or 83 per cent of the total regional trips generated by Taipei. This indicates that population might suffice as a

measurement of over-all community attractiveness and implies that it may also be useful in assessing the amount of competitive influence exerted by other cities in relation to that exerted by Taipei.

Preparation of Data

It was decided that classification or typing of urban areas would facilitate analyses of how interactions of several transportation variables differ from one type of urban area to another.

It may be possible to estimate certain characteristics of travel patterns in a particular urban area on the basis of the findings in completed studies of other areas of the same type. In addition, some findings of completed studies of a small sample of urban areas of a particular type may have general application to other areas of that type.

Urban areas having similar transportation characteristics may have similar socio-economic characteristics. By establishing quantitative relationships between certain aspects of the two characteristics, a measurement is provided for forecasting future travel characteristics of an urban area type.

Empirical research was carried out with the use of data provided by the Taiwan Urban and Housing Development Committee. Data studied which pertained to travel patterns included 1970 origin-destination surveys, socio-economic data, traffic network and land use inventories. These data were available on computer tapes prepared by the committee. These data were organized and classified by the development of such indicators as trip frequencies, trip purpose, time of travel, and mode of travel for common use in areas of a particular type.

Selection of Variables

Without regard to any particular trip purpose, a general measurement of the productive capabilities of any trip-producing community should denote a quantitative capability for travel. Conceptually, this requirement is satisfied either by the population of the producing community, which represents the human element in traffic interchange, or by motor vehicle registration, which registration represents the method of intercommunity travel. Both quantities are general measurements of potential travel and are highly correlated with each other. As presently conceived, one purpose of these general indices will be to evaluate the total trip producing potential of an outlying community in the region. Consequently, the model for trips attracted by central city will require the inclusion of such an index because it evaluates the potential trips available for attraction to central city.

Conceptually, it also appears likely that general community variables such as population can serve as a measurement device for the attractive quality of a community. The reasoning is similar to that underlying the selection of trip productivity variables, namely, that such a measurement is at least an indicator of the "size" of a community and its attracting facilities.

In the case where trips attracted by an outlying community (i.e., trips produced by central city) are being considered, it is also a logical approach to seek measurements of community attractiveness related to a particular trip purpose. Consider work trips as an example. The force exerted by the attracting community upon the producing

community can be evaluated in terms of the employment data of the attractor. If the number of employed persons in the attracting community is high, the likelihood that regional work trips will be attracted is also high and vice versa. In a like manner, retail sales figures might function as a measuring device for shopping trip attraction, the number of doctors may be the yardstick for attracted medical trips, and so on.

It is further assumed that the attractiveness of any particular community for regional trips can be assessed generally by using a broad community variable such as population, and specifically by selecting a community variable in keeping with the particular purpose for which a trip is being made.

Acquisition of the Data Base

Establishing Zones

When partitioning the study areas into zones, the following criteria for delineation of zones were used:

- a. Zone boundaries do not cross neighborhood boundaries.
- b. Relatively homogeneous land used within the zones.
- c. Zones not too irregular in shape.
- d. Ease of compiling data per zone.

It has become general traffic model practice to divide the study area into zones having boundaries coterminous with neighborhood boundaries. This practice facilitates data - gathering for past and current years and provides a frame within which future land use, population, and automobile ownership can be predicted.

At the same time, this method of establishing zones complicates the assignment of traffic to a street network. The zone boundaries following neighborhood boundaries generally fall on major streets. Hence, the centroids of the zones generally do not fall on the major street network.

For this study Zone centroids were established at critical intersections on an assumed major street network. Each link connecting two centroids simulates the portion of the major street network that is the shortest route between the two centroids. This portion may be a street, or where streets are closely parallel, a corridor. In this method of establishing zones, gravity traffic flows that have been summarized on the link system are assigned directly to the street system.

Socio-economic Data

Socio-economic data were translated into zonal estimates of total dwelling units by type, total population, students by place of residence, total employment, and retail plus service employment for each zone.

Highway Network Development

A network representing all the major highways in the region can be developed to determine the time distribution of trips and socio-economic factors relative to each area. Using the metropolitan area preliminary development plan as a guide, an intra-city highway network was developed. Each link was assigned a length and speed reflective of actual driving times. Using the network data as input, a volume tree was built for each study area.

Effect of Time-Distance

Time-distance between zones was the other factor in the distribution of trips. Time-distance was measured by driving and timing the most direct route between two zone centroids a number of times and averaging the resulting times. Estimates were made of the effects that proposed street improvements or changes in development will have on driving times, to estimate future time-distance between zones.

For sparsely developed outlying areas that are expected to have considerable population and economic activity at a future period it is simpler and certainly as valid to measure time-distance on a map of proposed or projected development by assuming average peak hour speeds on various types of streets. Even in built-up areas, this easily derived time-distance is adequate for planning a street system to handle peak hour flows without congestion.

Origin and Destination Data

The basic data gathered from a Taipei traffic survey conducted in 1970 were supplemented by a home interview survey conducted in 1968. The data provide detailed information concerning the origins and destinations of traffic which passed through the screen lines; they furnish relatively complete information on the origins and destinations of cars passing through a cordon but little or no data concerning the route which was followed.

The traffic survey data were supplemented by a 1968 home interview survey which produced data on population and automobile ownership used extensively as independent variables in the regression

analysis. Other characteristics of the population, such as household dwelling units, school age population, land use, and automobile ownership ratios, were examined as independent variables.

In the 1968 survey, the amount of land area in size major categories of land use - residential, manufacturing, commercial, transportation, public buildings, public open space - were inventoried. Floor area was inventoried for the inner built-up areas of the study area. These data were used extensively in the shopping trip analysis and to varying degrees in the analysis of the other trip purposes.

The analysis of trip purposes started with the origin and destination data on the core and fringe area trips for the study areas in this research. Using all these variables, production and attraction variables were quantified on a zonal basis, transit and highway networks were coded and skin trees obtained on a zonal basis.

Average zone values were determined for each of the production and attraction variables. The nature of some of the variables, such as income, employment density, and residential density, is self explanatory.

Insofar as the travel time ratio is concerned, this study attempted to determine the actual minimum amount of travel time needed by auto and by bus to get from each zone to all others. Walk, wait, and transfer times were included in the transit travel time.

Development of the Model

The Trip Generation Model

A multiple regression analysis of the form previously indicated was performed using the observations obtained from the origin-destination and home interview surveys.

The complete analysis was performed on trips of several purposes: home-based work, school, shopping, and social and recreation and nonhome-based trips. Trips of each purpose were analyzed separately.

It has long been recognized that people will travel different distances for different purposes, and for this reason a family of gravity models must be employed rather than a single model. For each of these gravity models it will be necessary to have two sets of information: a forecast of the number of trips made for the purpose covered, and a deterrence function which describes the influence of travel time on the probability a trip will be taken. The selection of the number of different gravity models to be employed is a compromise; greater accuracy is possible through the use of a larger number of such models, but the procedure becomes more complex. In reaching this compromise attention must be paid to the fact that trip purposes are often not easily defined; work, shopping, and recreation may be combined, and work and personal business are often difficult to separate. In general, therefore, unless there are good reasons to the contrary it seems best to utilize a minimum number of separate trip purpose categories,

An examination of highway transportation begins with the analysis of residential trips. From this kind of data there are certain estimations and projections that can be made so that future urban transportation needs can be planned and provided for. Trip purpose and trip frequency will be broken into categories so that useful equations can accurately be utilized as productive tools for transportation planning. This compilation of certain statistics is essential so that a concrete base can be constructed for future populations.

TABLE 3.--Residential Trip Production by Purpose

Purpose	No. of Trips	Percentage
Home-based work	1,367,435	48.2
Home-based school	611,715	21.5
Home-based shopping	145,253	5.1
Home-based social and recreation	335,822	11.8
Total Total Home-based	2,460,225	86.8
Nonhome-based	375,537	13.3
TOTAL	2,835,762	100.0

The first table, "Residential Trip Production by Purposes," indicates the major underlying factors influencing transportation trips. The primary division of home-based and nonhome-based trips are determined with the home being the constant and the various areas of activity being the reason for the transportation need. The major categories that are utilized are work, school, shopping, and social and recreation.

The work, school, shopping, social and recreation, and nonhome-based purposes indicate what time is spent traveling for each destination. The percent portrays the time spent for transportation for each purpose; this is also an excellent breakdown of residential trip production by purpose and frequency proportion.

The purposes identified for home-based activity deal with four general and fundamental residential trip concepts. These are basic for each home and are also widespread purposes throughout the civilized

world. The work trips appropriately have the highest percentage of the listed purposes followed by school travel. Social and recreation trips form the third major classification. Shopping travel has the fourth largest percentage of travel time, as a result of shopping centers that are easily accessible to residential areas primarily by transportation corridors.

However, Table 3 does not reveal any other reasons for residential trip production purposes. There are many other areas of activity that could be included in the category of other nonhome-based purposes. For example, going to the bank and visiting a doctor, etc., are not included in any of the five listed categories. Also, if the home-based purpose can be divided into several areas of activity the nonhome-based total could, and should, be standardized into the same format - with the same categories. All of the possible existing major underlying factors are certainly not contained in Table 3.

TABLE 4.--Relative Trip Frequency by Purpose

Travel Time in minutes	Home-based Work	Home-based School	Home-based social Recreation	Home-based Shopping	Nonhome based
0-5	22.54	23.76	18.37	27.78	22.93
5-10	35.73	35.22	37.21	34.23	42.15
10-15	24.99	24.01	27.80	24.56	20.82
15-20	11.38	11.24	11.58	10.27	7.49
20-25	4.06	4.24	3.40	2.25	2.59
25-30	1.03	1.18	1.27	0.91	0.60
Over 30	0.27	0.35	0.37	0.00	0.26
Average Length	9.50	9.56	10.01	8.38	8.55

Table 4, "Relative Trip Frequency by Purpose," measures the relative influence of currently used indicators on urban travel. The purposes at the top of the graph indicate the reason for the trip, while the intervals on the left side list the travel minute coherents. This data explains the percent and the purpose of each trip in relation to the probable time it takes for each trip to occur. The numbers refer to the proportion of the total time actually spent, relative to the purposes. The average length is then given to indicate the mean travel time spent for each purpose. This table reveals that the 5-10 minute coherent for travel time occurs the most. This is the usual travel time spent for venturing from a residential area to an attraction or production location. A home is normally situated near places of activity; the 5-10 minute driving distance is near enough to be close, yet it is also far enough away so that it doesn't encroach upon the amenities of residential life. Consequently, the 5-10 minute grouping uniformly has the largest percentages for the diverse purpose components.

Suburbs throughout the world account for the second most frequently occurring cluster of 10-15 minutes for travel time. As urban centers decay and lose importance the populace frequently moves centrifugally-away from the urban core. The outward movement accounts for the positioning of the second coherent; this is considered to be the fringer area. Although many people reside in the core, they travel very little by personal transportation; the fringe (suburbia) populations account for the most travel and consequently have the greatest influence on this travel time arrangement. On the other hand, the 0-5 coherent is the third most frequently used driving time. The huge masses

of people in the central core, although they infrequently travel on highways for the four given purposes, drastically affect the relative trip frequency due to the core population density as is reflected in the trip frequency cohorts. The next four clusters of 15-20, 20-25, 25-30, and over 30 disperse in both travel time and in rank order of importance. This diminishing pattern is related to the centrifugally decreasing residential density. The travel activity, population, and willingness to travel for longer spans of time do not occur as frequently on the outer boundary of the fringe area, as compared to much more activity closer to the central urban core.

The average length figures in Table 4 reveal what activity stimulates movement the most. This is an appropriate manner in which to list the order of the importance of each travel purpose. People are willing to travel the most for recreation, then school needs, followed by work, nonhome-based functions, and finally shopping. These social patterns of importance indicate how motivation psychology is utilized throughout the analysis of transportation planning.

The largest percentage given is under the nonhome-based category. However, since no specific nonhome activities are listed, this figure is not as meaningful as the smaller percentage that is specifically categorized (i.e., 42.15 for nonhome-based as compared to 37.21 for home-based recreation). The home-based shopping average length is the smallest of the five given categories. However, this category is the only one that has three intervals over 24.5. Consequently, although the average length for this item is the lowest, in actuality the data can also be interpreted to indicate this category has the highest

figures (proportions). Therefore, due to the extremes in this table there can be no average length appropriately portrayed. A curious note is that for this model there are no home-based shoppers listed for over 30 minutes travel time. Therefore, besides being possibly mislabeled, the table is also skewed. The overall statistics, however, do state the indicators that are relative to urban travel.

Table 5, "Trip Production and Attraction Equations (Core Area)," begins to develop mathematical regression formulas for calculating current travel specifics. The purpose of residential trips is consequently followed by a procedure for determining the statistical connotation of each variable in relation to the trip purpose.

Under production equation each formula has a constant and a variable selected for specific population characteristics. For home-based work the major determinant is the total labor force; this is an accurate scale of measurement since people who are capable of working are either driving to work or are traveling in search of work. The home-based school equation takes into account the student age over 13; this age is more appropriate than 16 or 5 since persons over 13 years of age are usually producing trips towards urban areas in search of school. In addition, 13 is the general age when young adolescents leave home for furthering their education and is also the time when they begin to explore their teenage world. Public transportation (i.e., bus) figures should be utilized so that certain assumptions can be drawn from the mass transit influence. If this data is not available, a certain age (13) will have to be used so that this type of transportation will be taken into effect. The home-based social and recreation

TABLE 5.--Trip Production and Attraction Equations (Core Area)

Purpose	Production Equation
Home-based work	$529.66 + 2.352 \times \text{total labor force}$
Home-based school	$-69.96 + 1.617 \times \text{Student Age Over 13}$
Home-based social and recreation	$93.16 + 0.124 \times \text{Inco.} + 1.572$ Cars Ownership
Home-based shopping	$60.24 + 0.326 \times \text{Household} + 0.00764 \text{ Inco.}$
Total Home-based	$799.07 + 1.566 \times \text{Pop. Age Over 5}$
Nonhome-based	$976.33 + 1.243 \times \text{Employment}$

Purpose	Attraction Equation
Home-based work	$-2440.18 + 2.863 \times \text{Total Employment}$
Home-based school	$1615.83 + 1.758 \times \text{Student Age Over 16}$
Home-based social and recreation	$1406.95 + 0.932 \times \text{Employment}$
Home-based shopping	$-1067.52 + 2.388 \times \text{Distance}$
Nonhome-based	$774.70 + 1.422 \times \text{Employment}$

grouping appropriately takes a percentage of income and cars owned for variables; these unknowns are related to recreation and social gatherings in a cause-result relationship. The home-based shopping purpose also uses household numbers and income data to determine the necessary shopping expenses needed. There is a direct relationship between these variables since the larger the family and greater the income the more the shopping will be enhanced.

The total home-based equation used the age of 5 for a chronological beginning since anyone younger than this age is usually a pre-schooler, has few independent needs, and doesn't normally require any specific transportation. The age of 5 is considered to be the year when a child can be more independent of his parents, and consequently, begins to generate and motivate individual transportation needs.

The nonhome-based formula is determined by employment since most of the travel done, without using the home for a base, is normally related to work and, consequently, returns to the employment figures. These formulas appear to be reasonable and logical, especially since the variables used apply to every urban situation. The constants and population characteristics that are utilized as variables should result in good estimates and future projections.

The attraction equations differ from the production equation in that divergent variables are used. For example, the home-based work is determined by the total employment in regard to the attraction equation, whereas the production equation for this purpose is primarily relevant to the total (possible) labor force. This means that

employment is attracted to work, even where the unemployed in the total labor force (for the attraction equation) are producing a different amount of trip production. The home-based school is also different in respect to chronological age due to the fact that the producers are those adolescents (and older) over the legal driving age of 16, while 13 is an age that only stipulates travel requirements and doesn't actually place the physical control (driving skills) over the vehicle. The home-based social and recreation attraction equation is derived from employment figures that determine the amount of travel a person can afford. This is different from the production equation since the real traveling a person will do for this purpose is more dependent on actual employment, rather than the relative range produced by income and cars owned by production employees. The home-based shopping for the attraction equation is a determinant of what distance is actually traveled. The distance variable takes distance into account rather than the less significant income-household; this is because a person is attracted to a shopping area in terms of distance, whereas the size of a household and income help to establish the production, rather than the actual miles consumed through travel. The nonhome-based attraction equation is utilizing the employment variable in its formula, similarly to the nonhome-based production equation.

The best formulas are probably going to be the ones that measure the influence of home-based work and home-based school on transportation. Undoubtedly, a lot of research has been done on these equations. However, since more accurate figures are available from employment and school sources (rather than for social, shopping, and

nonhome-based functions), these more tangible results will be the most precise.

The same "accurate conceptualization" of data is applicable for determining the best variable. The areas that the formulas are checking and balancing with the most precision are those where the employment and population facts are most readily available. Therefore, the equations that test the home-based work and home-based school purposes will (or should) have the best results; this shall be evident in the correlation coefficient model.

The variables that are the most undesirable to use are these in relation to the more subjective and varying purposes of home-based social and recreation, home-based shopping, and total nonhome-based. These are never conceived as being purely objective in nature, due to the physical, economic, social and political factors that have a definite bearing on transportation patterns. For example, a person might take a certain route of travel if the weather is nice, a paycheck was recently received, and a shopping trip was necessary to gather supplies for an office party that evening. On the other hand, if the day was rainy, a stop at a financial institution was necessary (to borrow money), a bottle of cheap wine was needed, and a certain route to avoid a police patrol was necessary, there would be a different transportation route selected. Consequently, the factors affected by human nature (through psychology) are harder to accurately measure than the more concrete employment and population figures. Whenever a formula tests subjective components, as compared to a more objective equation's results, the latter equation will usually be the most accurate. Human

nature can never be measured as precisely as physical statistical figures.

Table 5 has too many varying constants that are intertwined with apparently logical variables. If the variables are appropriate, the constants cannot always be applicable, unless their origin or limits are known. If they were derived from the means, medians, or modes of urban statistics it is difficult to conceive that they are useful or productive for all urban areas, without being skewed occasionally. Every urban area is different from the median city, mean city, or mode city. Therefore, it shall be very difficult to justify the use of these numbers as constants; they cannot be general, accurate, and specific (all at the same time) for the overall urban areas. Consequently, the derivative of these equations is in serious jeopardy and the formulas themselves are extremely questionable. The final analysis (correlation coefficient) will reveal whether these variables are or are not appropriate.

Table 6, "Trip Production and Attraction Equations (Fringe Area)," is very similar to the Table 5 that deals with the core area. However, this model explores the urban fringe travel characteristics whereas the core area table is concerned with the central business district's transportation traits. Generally speaking, the same variables are utilized with only a few alterations. The constants have all been modified to cope with the different socio-economic conditions that exist in the urban extremities. New formulas are used with the primary change being in the constants, with only slight modifications in the variables.

TABLE 6.--Trip Production and Attraction Equations (Fringe Area),"

Purpose	Production Equations
Home-based work	$1011.73 + 1.865 \times \text{Total Labor Force}$
Home-based school	$1208.70 + 2.318 \times \text{Student Age Over 16}$
Home-based social and recreation	$694.21 + 0.0314 \times \text{Income} + 0.0146 \text{ Housld.}$
Home-based shopping	$237.01 + 0.126 \times \text{Housld.} + 0.01348 \text{ Inco.}$
Total Home-based	$2942.12 + 1.079 \times \text{Pop. Age Over 5}$
Nonhome-based	$56.94 + 1.622 \times \text{Employment}$

Purpose	Attraction Equations
Home-based work	$156.88 + 1.705 \times \text{Temply}$
Home-based school	$1125.03 + 2.311 \times \text{Student Age Over 16}$
Home-based social and recreation	$2734.13 + 1.261 \times \text{Employ.} - 0.326 \text{ Distance}$
Nonhome-based	$230.84 + 2.025 \times \text{Employment}$

Under the production equation the first variation is the age given under the home-based school purpose. The fringe area age of 16 is given in place of 13 (the core area age) due to the increasing number of adolescents that drive vehicles in the suburban and other outlying areas. In the fringe area formula the home-based social and recreation purpose used the number of households in place of car ownership. The change is due to household needs of the fringe area, rather than sole reliance on car ownership. This is done because the household size determines the travel needs much more than the core car ownership variable. Suburban living results in more travel requirements and car ownership; this is not true in the core area where a car is more of a luxury. The last variable that is fringe-oriented, in respect to the same purpose (social and recreation), is listed under the attraction equation. Distance in this formula is subtracted due to the length variables that are more dominant in outlying territories. All of these variables that are changed are revised to cope with the different socio-economic patterns that exist in the fringe area, as compared to the dense core social requirements.

The major criticism of this model is the selection of different variables and diverse constants. Although a revision of the variables is needed to adjust with diversifying core and fringe sociological characteristics, the use of different variables could change the travel concept being tested. The constants should be adjusted to fluxuate with the core-fringe variations, and the variables should be consistent to give a more standardized result.

Table 7, "Correlation Coefficient of Trip Production and Attraction Equations," has the results of the formulas used in Table 5 and 6. Upon initial examination these figures appear to have a high correlation coefficient. However, upon further analysis there is a major problem.

TABLE 7.--Correlation Coefficient of Trip Production and Attraction Equation

Purposes	<u>Trip Production</u>		<u>Trip Attraction</u>	
	<u>Core</u>	<u>Fringe</u>	<u>Core</u>	<u>Fringe</u>
work	0.94	0.97	0.96	0.95
school	0.92	0.89	0.93	0.89
pleasure	0.89	0.88	0.62	0.79
shopping	0.68	0.89	0.89	0.95
Total home-based	0.91	0.97		
Nonhome-based	0.91	0.86	0.90	0.71

The correlation coefficient is very high for the individual core and fringe areas for both trip production and trip attraction purposes. However, the shopping purpose under the core segment of trip production (0.68), the social and recreation purpose of the core trip attraction (0.62), the nonhome-based fringe trip attraction (0.71), and the pleasure purpose of the fringe trip attraction (0.79) all have less positive coefficients. A better variable for the core home-based production equation, measuring the shopping influence, could possibly have been the total retail sales inside the core limits. The pleasure purposes of the core attraction could, or should, also have utilized

a different variable; this could possibly have been the total social and recreation employment, rather than just employment. The third poor coefficient, regarding the nonhome-based fringe trip attraction, could have used traffic accidents in the formula in place of the employment variable. The last low coefficient of correlation, social and recreation purpose of fringe trip attraction, could have used only the income or only the household for a more reliable variable. These suggested variables are better applicable than those used, due to the important influences the recommended variables have on the purpose being tested; these different variables should result in higher correlation coefficients.

The three purposes of social and recreation, shopping, and nonhome-based travel are categories that are difficult to examine objectively. These three classifications have many variables affecting them (i.e., weather, bargins, certain week days, etc) Consequently, these more subjective concepts are hard to accurately measure with high correlation results.

The equations used in Tables 5 and 6 will be very useful and productive for a transportation analysis. The many high correlation coefficients portray the overall accuracy of these formulas. A low rank-order correlation exists between the core and fringe areas. However, this statistical concept is not relevant in this model since there is no relationship between the core and fringe areas in respect to transportation analysis.

Table 8, "Output of Trip Comparison of Purpose," is the last transportation model. For this table the rank-order correlation between the production purpose and attraction purpose is +0.625. This low

TABLE 8.--Output of Trip Comparison of Purpose

Purpose	Equation Volume	O-D Volume	Difference
PRODUCTION:			
Home-based work	1,364,399	1,367,435	1.00
Home-based school	609,979	611,715	1.00
Home-based social and recreation	330,538	335,822	0.98
Home-based shopping	143,307	145,253	0.99
Total Home-based	2,472,826	2,460,229	0.98
Nonhome-based	270,399	271,654	1.00
Purpose	Equation Volume	O-D Volume	Difference
ATTRACTION:			
Home-based work	1,340,224	1,367,435	0.98
Home-based school	608,133	611,715	0.99
Home-based social and recreation	325,484	335,822	0.97
Home-based shopping	146,859	145,253	0.99
Nonhome-based	272,487	271,654	1.00

correlation reveals that for the sampling from which these models was derived there is very little relationship between travel for production and attraction purposes. This poor result in statistical performance makes them all nearly useless, by American textbook standards. Apparently, although there is a slight variation between these two travel motivators, they definitely are both considered to be transportation stimuli. Consequently, since the correlation coefficients are generally high, the formulas are correct. It can be assumed that there is no relationship between the production and attraction purposes, in regard to transportation planning. Therefore, these models do correctly establish a very meaningful and useful transportation planning format.

In order to establish an applicable basis for determining need, a standardized organization of material is necessary. In respect to transportation analysis the Highway Research Record stipulated that the collection of models should:

a) identify existing major underlying factors; b) measure their relative influence on currently used indicators of urban travel; c) develop mathematical equations for estimating present travel characteristics in areas where such information is not yet available; d) develop mathematical equations for estimating future travel characteristics in areas where current data are available; and e) develop a classification of urban areas based on transportation indicators and underlying factors.¹

¹Highway Research Board, Highway Research Record. Information Systems for Land Use and Transportation Planning. Bulletin 297. Washington, D.C., 1967. p. 36.

The Trip Distribution Model

In order to utilize the gravity model, it was necessary to provide input data for each trip purpose on trip productions and attractions by zone (P_i and A_j), the impedance term associated with each interzonal interchange F_{ij} , and the socio-economic adjustment factor for each interzonal interchange K_{ij} . In traditional travel analysis, the interchange parameters utilized in the gravity model are estimated by calibrating the model so that it simulates the travel patterns observed in a base-year set of origin-destination data.

Interzonal friction factors F_{ij} for the trip distribution analysis for Taipei were based solely on the estimated travel time among the zones. Such an assumption was appropriate for Taipei inasmuch as there are no usual barriers, such as a toll bridge or tunnel or a restricted set of the zones.

In making a decision an explicit trade-off between two trends was recognized. The two trends were: 1) average trip lengths increase (slowly) with increases in the population of an area, and 2) average trip lengths for suburban, relatively affluent communities in a large metropolitan area are longer than for the metropolitan area as a whole.

Socio-economic adjustment factors K_{ij} are generally utilized to explain permutations in trip distribution patterns between selected pairs of zones which cannot be explained using the other variables in the gravity model, namely the trip attractions, trip productions, and friction factors. "K" factors might be used in work trip distribution, for example, to take account of the fact that a high income suburban labor force tends to work in high income jobs located in the Central

Business District. Similarly, "K" factors are used to explain the lack of social interaction between spatially adjacent but socially disparate groups. Generally, "K" factors are derived empirically to make the gravity model trip distribution estimate replicate the actual trip distribution patterns observed in the origin-destination data when a logical hypothesis can be used to support each "K" factors's use.

An effort was made to identify communities similar to Taipei in order to ascertain the "K" factors associated with the travel patterns of these areas. As expected, it was not possible to find a community which could be used as a model for Taipei. However, in examining several relatively similar communities, it was found that "K" factors of about 1.10 were required to explain the proportion of trips originating in these communities which remained with the respective communities. Utilizing these parameters as a guide, it was decided to use "K" factor of 1.10 for trip purposes.

The mean trip length and the proportion of trips remaining in Taipei were used to evaluate the results of the gravity model analysis. In table 9, the mean trip lengths from the gravity model analysis for Taipei are compared to the mean trips previously estimated for the Taipei metropolitan area for 1990.

The Gravity Model Comparison Chart reveals a relationship between nontangible and tangible trip concepts. The gravity model utilizes numbers (population and distance) through the use of a formula; whereas, the O.D. Survey is more concrete since it uses actual survey data. The Gravity Model Comparison Chart, consequently, shows the relationship between both the individual travel purposes and a model/survey interrelationship.

TABLE 9.--Evaluation of Gravity Model Comparison of Mean Trip Length

	Gravity Model	O-D Survey	Gravity/O.D.
Home-based work	9.5794	9.4991	1.0085
Home-based school	9.5535	9.5624	0.9991
Home-based shopping	8.8417	8.3763	1.0556
Home-based social and recreation	9.7132	10.0085	1.9705
Nonhome-based	8.5411	8.5528	0.9986

The last column, where the gravity model is divided by the O-D Survey, illustrates the ranking, or possible ranking, of the most useful results. The results are the end product, by statistical manipulation, where the gravity model and O-D survey can be related, possibly ranked, and interrelated by the simple mathematical process of division.

The numbers in the final column that are the closest to 1.00 are indicative of which trip purposes can be best measured by this manner. This is due to the fact that: when the numerator and denominator are the same, or the closest, the end result will be the nearest to 1.00. Under this assumption, the home-based school purpose (0.9991) and homebased work purpose (1.0085) are the most accurate, and consequently will be the most effectively measured by utilizing this statistical process. The dismal 1.9705 result for the home-based social and recreation trip purpose reveals that this category cannot be efficiently or effectively measured in this manner.

The reason the school and work purposes are more meaningful is directly related to the fact that data for these items can be easily compiled. However, information for social and recreation trips cannot be gathered as effectively or as readily. Consequently, formulas can be structured with more evidence much more effectively than with concepts dealing with more personal attributes and socially diverse variables.

Generally, the larger the spatial extent of the region for which an analysis is being conducted, the longer the mean trip lengths estimated by the gravity model even if the friction factors remain constant. Thus, it is not surprising that the mean trip lengths in the gravity model analysis for Taipei are toward the higher end of the range or marginally higher than the mean trip lengths estimated in the study areas. On the basis of these results, it was concluded that the regional gravity model used for Taipei provided a useful approximation of the regional trip length frequency distribution.

Figure 7, the "Desired Lines of Home-based Work Trips 1990" illustrates the residential-commuter concept. The nine focal points that lie outside the CBD are possible, or potential residential areas. They could be new towns, PUD's, or simply the result of urban sprawl. Regardless of their creation, the manner in which the transportation corridors are situated is of importance since they create a need for transportation routes.

The heavier lines illustrate the major thoroughfares (expressways). These go from the dense residential areas to the CBD. The short thick lines indicate that a strong attraction center lies at one end, and undoubtedly residential units are at the other end. The

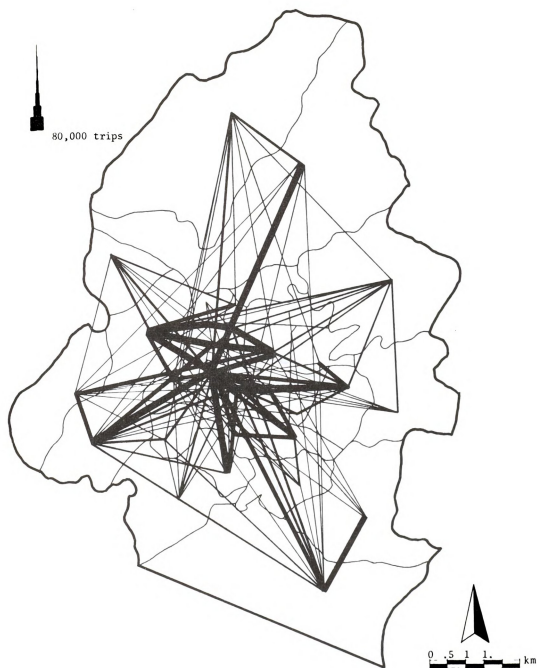


FIGURE 7

DESIRED LINES OF HOME-BASED WORK TRIPS 1990

thinner lines indicate that these routes are traveled, but not as heavily as the darker, thicker lines. The denser residential areas are areas where the outward end of the transportation routes is the thickest.

The "Desired Lines of Nonhome-based Trips," Figure 8, is a conglomeration of the work, school, shopping, social and pleasure trips. After leaving work or school, or after completing a shopping trip or a social venture, a person may proceed to another place of activity. This map should reveal that heaviest travel occurs from work and school areas to places of social and recreation activity. This map will be an overall summary of the four other ones.

Figure 9, "Desired Lines of Home-based School Trips," show the location of schools and where the children reside. (This indicates both the location of many residences and the location of the children.) The heavier lines illustrate the travel routes for school age children (and teachers). The ends closest to the CBD are the schools, with the other end of the lines being the residential areas. This map illustrates that the schools will remain primarily near the CBD, rather than in the suburban areas.

Figure 10, "Desired Lines of Home-based Shopping Trips 1990," reveals the location of shopping centers and residential concentrations. The primary focal points are the areas where the greatest centralization of shopping sites are located; it is assumed that the other end of the lines are the residential sites.



FIGURE 8

DESIRED LINES OF HOME-BASED TRIPS

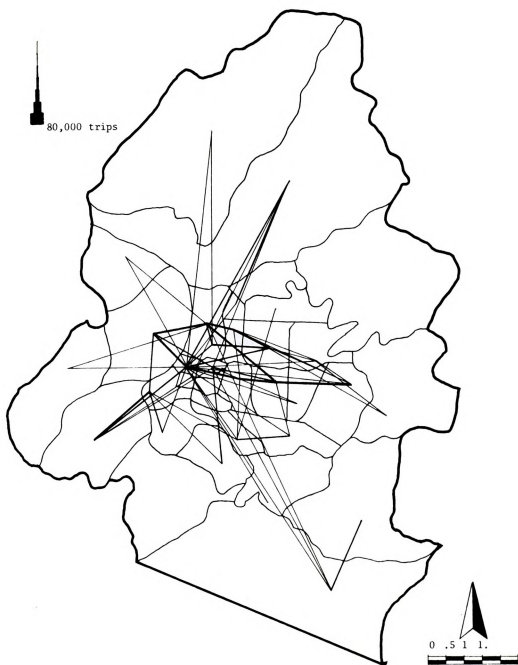


FIGURE 9

DESIRED LINES OF HOME-BASED SCHOOL TRIPS



FIGURE 10
DESIRED LINES OF HOME-BASED SHOPPING TRIPS 1990

The "Desired Lines of Home-based Social and Recreation Trips," Figure 11, illustrated the dispersal effect of personal needs. The concentration of lines center on the primary social and recreation focal points, i.e., sport arenas, cultural center, and parks. The areas on the extremities of the map will be the location of some recreational areas (parks). This map can also show the higher income areas, since the more prosperous people will be making the greatest amount of trips for pleasure purposes.



FIGURE 11

DESIRED LINES OF NONHOME-BASED TRIPS 1990

CHAPTER VI

A CRITICAL EVALUATION AND CONCLUSION

Trip generation is the term commonly used to denote the relationships which exist between the urban environment and the urban travel demand. Trip generation is usually described in two categories - trip production and trip attraction. Trip production is the measurement of the number of trips produced by the residents of a household, neighborhood, or an entire urban area as determined from various socio-economic and location factors. Trip attraction is the number of trips attracted to a given area as determined by such factors as area type and intensity of land use.

Considering trip production as Phase One of a trip generation analysis, one finds that trip generation is related to the home and to the various socio-economic characteristics of the person living there. The factors considered in this type of analysis include city size, residential density, car ownership by residents of the area, family income level, and the degree of decentralization of the area under consideration. Each of these and probably many other factors have important effects on the travel demand in the urban area.

In Phase Two of a trip generation analysis one attempts to analyze the trips by purpose with regard to the type of land use or other land use factor to which the trips are attracted. The trip

attraction ends of the trips in a study area are usually allocated to each specific zone on the basis of the intensity of the land use or the intensity of the land use factor in that zone as it relates to the total study area.

Phase One, or a trip production study, measures the number of trips produced by an area. The individual factors mentioned above are difficult to pinpoint because of the interaction between the factors. In general, trip making per unit of development or per person increases with car ownership, family income, and degree of decentralization. It also increases with decreasing residential density and city core. Past studies have shown that as tripmaking per person (or per unit of development) increases, there is a corresponding increase in the number of nonwork trips and in the number of trips made by car. These generalizations have importance and must be considered in planning facilities to meet future travel demands. In order to work with the interrelationships between urban travel and land use, it must be known, in addition, the purposes of the travel being produced. A past study of travel patterns in 50 separate cities indicated that the relative distribution of major trip purposes is somewhat uniform in cities of all sizes.¹ However, any one area in a city may exhibit a trip purpose breakdown which depends mainly upon the volume of trips per household.

The gravity model, used in many cities, assumes that the travel between two areas depends on their attractive power and the

¹ Highway Research Board, Improvements in the Transportation Planning Process. Highway Research Record, 297, 1969.

distance between them, similar to the law of gravitation. It appears to have much merit in predicting travel between cities. The following equation can be developed:

$$\text{Trips}_{ab} = K \frac{\text{population}_a \times \text{population}_b}{\text{distance}_{ab}^n}$$

The main advantages of this model are that it accounts for competition between trips to different land uses, it is sensitive to changes in travel time between zones, it is easy to apply in any urban area and it requires little travel inventory information for input data. With these advantages, future travel patterns could be predicted.

The work of earlier sociologists presented a formula which related the trip interchange directly to the trip origins. These trip origins are attracted to a destination in proportion to the attraction of all other destinations, the inverse attraction is the relative resistance to travel to alternative destinations. The earlier formula assumed that the residence measure was in terms of the square power of the distance. It was soon clear to Voorhees and others that this power was not necessarily the best one, and moreover, that the value varied for different trip purposes.

The recognition of variation in travel patterns with different purposes is one of the major contributions of the gravity model studies. Methods developed which used both different measures of trip attraction and different forms of the resistance factor for different purposes. They also avoided the assumption of the simply gravity model that an

average travel pattern is applicable to all zones within a region. In addition to a recognition of trip purpose, it is also able to provide for improvement in transportation facilities in time by reduction of distance, time, or cost of journeys. It can essentially account for differences in land uses between zones and for large changes in such uses.

One objective of travel pattern research is to derive theoretical relationships between the variables so that the planner can determine the characteristics of transportation structures and hence predict the consequences of alternative plans. The means for developing and analyzing the current travel pattern is well-established. This research concerns predicting the travel pattern at some time in the future, for it is on such a prediction that the community layout and plan must be based.

In the field of forecasting future travel, many theories have been proposed and numerous procedures have been developed. All theories recognize the fact that future travel must depend on the kind, intensity, and direction of urban development since the size and distribution of the population as well as land use patterns will determine the travel pattern.

The work of early researchers in applying the gravity model theory to travel, particularly urban travel, indicates five significant factors.

1. Spatial separation between zones appears to be the best measure of "over-the-road" driving time between zones plus some measure of terminal time in the zones at each end of the trip.

2. The exponent of travel time varies by purpose of trip.

It appears to vary roughly with the importance of the trip, generally decreasing as the trip becomes more important. For example, the more important work trips have a lower exponent than social-recreation trips.

3. The exponent of travel time is not constant for all intervals of time in the case of some trip purposes. Work trips appear to be those in which this variation is most pronounced. For these trip purposes the exponent generally increases as the time interval increases.

4. For total trips the exponent of travel time appears to be relatively constant for all urban areas and to be approximately equal to the exponent for travel between urban areas. However, by trip purpose, this exponent varies from urban area to urban area and the variation seems to be greatest in the less important trip categories. The exponents by trip purpose appear to vary roughly with city size and population density, the exponent being larger for smaller cities than it is in larger cities and in the more densely populated areas.

5. The exponent of travel time alone, does not, when considered in relationship with the use of land, completely describe the underlying motivation for travel between two points. Travel patterns are also affected to a considerable extent by various social and economic linkages which to date have not been completely identified or quantified.

Since a comparison of all the travel models is not the purpose of this section, this section will focus on the advantages of applying each model to the test area of Taiwan only. A decision must be made as to how many and what trip purpose categories will be used in the

study. There is no clear agreement on this point, and it is at least partially a function of the scope and objectives of the study, as well as the size of the urban area involved. Generally, it is desirable to take into consideration the number of trips in each of the categories, the trip length characteristics for each of the trip purpose categories, and the ability to forecast the categories separately.

In some large areas where these seven (home-based; work, shop, social-recreation, school, miscellaneous, nonhome-based, truck, and taxi) purposes have been used, it has been observed that the results could have been improved by further stratification without causing additional difficulty in forecasting. For example, in a study of travel patterns in Washington, D.C., it was observed that the gravity model results could probably have been improved if work trips had been further stratified to distinguish between convenience shopping trips (trips to grocery stores, etc.) and other shopping trips.

Most of the recent gravity model study in Washington, D.C., has employed size trip purpose categories: work, shopping, social recreation, personal business, non-home based, school. A study of travel patterns in Sioux Falls, South Dakota, showed that the differences in the accuracy obtained when using eight trip purposes as compared with three purposes (home-based work, home-based nonwork, nonhome-based trips) are insignificant in small areas. consequently, it appears that in large urban areas an eight purpose model is desirable, but in small urban areas, a three or four purpose model may be sufficient.

Once the total trip production by purpose has been determined, it is necessary to estimate the modal split of these trips. In larger

American urban areas, approximately 75 percent of total travel is by automobile. As city size decreases, automobile usage increases; in the small urban areas nearly 95 percent of all travel is by automobile.²

Each mode of travel offers certain advantages for various types of trips. The specific amount of travel in each zone by mode depends mostly upon the availability of alternate modes of transportation, family income, and residential density. Work trips, especially those oriented to the central business district, and school trips utilize transit more frequently than other trip purposes. Shopping, social-recreational, and other such types of trips generally are more dependent on the automobile.

The factors which help explain household trip production and mode of choice provide information on the kind of travel likely to occur in the future. It is expected that the average trips produced per household will increase as a result of growth in population and automobiles and declining average net residential density. Additional trip production may result as a consequence of rising family income which may result in more social-recreational trips. The multiplying effects of the several factors must be accounted for in planning for future travel demand.

Phase Two of a trip generation analysis is the trip attraction study. The analysis attempts to quantify the relationship between trips and land use or land use factor for each trip purpose. Home-based work travel has long been recognized to be the most important

²Highway Research Board. Improvements in the Transportation Planning Process. Highway Research Record, 297, 1969.

single part of total urban traffic. Past studies by the Bureau of Public Roads have shown that the number of work trips to a zone is highly correlated with the number of employees in that zone.

Home-based nonwork (particularly social-recreational) trips are increasing and are generally the second most important trip purpose category. These trips have been proportioned to zones in the past by population or dwelling unit ratios. Research has not been extensive enough to come up with definite recommendations as to what factors are best for determining trip attractions, but several factors have been used with varying degrees of success. Retail sales have been used as indices for shopping trips but the unavailability of detailed retail sales figures usually prohibits their use. Variations in shopping trips have been correlated with parking space available, floor area, customer policies, and advertising. Various land use factors have been used to allocate the attraction end of home-based nonwork trips; retail sales in terms of square feet of floor area have been used with some success for shopping trips. School acreage and the number of persons of school age within each zone have been found to be indices to school attractions.

Nonhome-based trips at both ends are associated with a combination of factors such as employment, retail sales, and population. The relative effect of each of these factors has not yet been reliably determined.

A community's capacity to produce trips to another community or to attract trips from that community is a function of the travel friction between them. This is a widely accepted and well-demonstrated

hypothesis based on the assumption that the influence of that center. Questions are raised in the literature concerning the ways of measuring travel friction or distance between communities.

Distance has been measured in terms of actual mileage or travel time. Distance has also been measured in terms of cost of motor fuel consumed, and indirect costs resulting from delay. Of these, time-distance appears to be the most appropriate to intercommunity traffic studies because it can take into account factors that affect the movement of motor vehicles, such as traffic congestion, road conditions, or topography.

The literature suggests that the impact of distance on the extent of intercommunity traffic is not uniform. It is suggested that the distance factor itself is a variable that is affected by the size of population of communities linked or by the magnitude of the distance involved. Another consideration regarding the variation in the impact of the distance factor is the difference in value of the trip. People are willing to travel longer distances for medical purposes, for example, than for shopping purposes, or for less frequent trips than for daily trips. Finally, there is a great likelihood that the impact of the distance factor will vary depending on whether trips produced or trips attracted are under consideration.

A community's capacity to produce or to attract trips is a function of its population size. This hypothesis assumes that the larger the population of a community, the greater its influence and the more likely it is to produce and attract trips. This is also a widely accepted hypothesis whose validity has been demonstrated in

several empirical studies. Population size has been used as a measure of a community's importance as a retail trade center or as a center of absorption in migration studies.

However, some researchers have criticized the use of population size as a measure of a community's traffic generation potential on the grounds that size alone does not reflect the social or economic structures of the community, factors that are believed to be of significance in traffic generation. In reply, some researchers argue that population size is a reliable indicator of a community's economic importance. In other cases population size has been modified by adding factors accounting for differences in the sex, education, and other characteristics of the population. Similarly, population size data have been supplemented with indexes of the community's economic structure, such as assessed valuation or banking resources. Still, there has been no sufficient evidence advanced to demonstrate that population size in itself is a reliable enough index of a community's ability to produce and attract trips.

A community's capacity to produce trips is a function of the extent of car ownership in the community. This hypothesis is derived from recent investigations of traffic generation of residential areas and has found application in at least one intercommunity traffic study in New Jersey.

In these studies, the average number of cars owned per dwelling unit was found to correlate highly with residential trip production. Similarly, the total number of cars in a residential area was also found to correlate highly with the number of trips produced by the area.

This method of measuring a community's capacity to produce trips may be preferable to the use of population size, because the former gives an indication of population size as well as the ability of community residents to travel. The difference between using car ownership and population size is particularly important where the per capita car ownership is not uniform for all communities linked.

Until an adequate theory for predicting travel patterns can be developed, planners are forced to rely too much upon data obtained from massive origin-destination surveys. However, the gravity model of travel eliminated the extreme dependence upon origin-destination data and enables predictions of future travel patterns. This is a major breakthrough for urban transportation planning.

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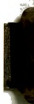
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