Predicting Future Demand for Urban Area Transportation

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This paper summarizes the results of a study of current principles and techniques for predicting the present and future demand for urban area transportation, often referred to as traffic estimation and assignment.

Emphasis is placed on the transportation planning process as a total process, requiring the integration of many of the interacting characteristics of the urban environment. The principal phases of the total process outlined are (a) inventories of existing conditions, such as land use, population, vehicle ownership, vehicular and personal travel, transportation facilities, and monetary resources; (b) estimates of future urban area growth in terms of population, economic activity, vehicle ownership, land use, and available transportation network; and (c) determination of future travel demand based on trip generation, modal split, interzonal transfers, and the assignment of traffic to transportation facilities. The feedback from level of service supplied by available facilities to traffic demand is stressed. Features of the transportation planning process where current methods appear inadequate are pointed out and recommendations are suggested for future research. An annotated bibliography includes 177 items pertaining to literature on predicting the future demand for urban area transportation.

• THIS PAPER presents a brief summary of a recently published compendium on current principles and techniques for predicting future demand for urban area transportation, often referred to as traffic estimation and assignment (1). This study was a joint highway research project of the Department of Civil Engineering, Massachusetts Institute of Technology, and the Massachusetts Department of Public Works.

The full report reviews the diversified methods and techniques available at the time of this writing, and published in numerous reports, books, magazines, and special conference papers. Alternate methods are compared, their basic assumptions identified, and their advantages and disadvantages qualitatively and quantitatively explored. The relation of traffic estimation and assignment to the transportation planning process is developed. Areas of weakness in current methods, where additional research and development work is needed, are identified and specific research topics suggested. The annotated bibliography is appended.

OBJECTIVES OF URBAN AREA TRANSPORTATION

Before proceeding to a discussion of the transportation planning process, some of the major objectives sought in providing adequate urban transportation is outlined as follows:

1. To provide sufficient capacity in the network of transportation facilities* to insure a specified level or levels of quality of service in speed and convenience of movement between or within all portions of the urban area. This implies that adequate facilities, satisfying the demand for trips concentrated in time during the day and in geographic location within the urban area, be available as needed.
2. To provide an adequate level of accessibility to and from all portions of the urban area, including the central business district. This is particularly relevant in considering improvements to or extensions of mass transportation facilities.
3. To provide the radial and circumferential facilities capable of handling the diffuse demand patterns created by large-scale low-density residential, commercial, and industrial development.
4. To provide the facilities made necessary by increased per capita automobile ownership and personal expenditures on transportation.
5. To satisfy the general demand for high-quality facilities offering increased vehicular speeds, personal safety, confort, and convenience.

The extent to which these objectives may be achieved will depend on resources available and over-all benefits derived. This report, however, deals only with procedures and methods for measuring and predicting objective requirements.

TRANSPORTATION PLANNING PROCESS

In determining both present and future requirements for facilities, the transportation planning process, as exemplified by the work of various urban transportation studies, is being increasingly utilized to effectuate comprehensive, region-wide planning. In the planning process,** consideration is given to all forms of transportation and to the expected future economic and social development of the area. Because urban transportation studies themselves encompass many varied aspects of the urban environment, they require the cooperation, consideration, and support of all organizations and individuals engaged in shaping the future of the urban area. This would include transportation and city planners, economists, social scientists, government officials, community interest groups, and other specialized personnel. Although many phases of a comprehensive urban transportation study are not the direct responsibility of the transportation planner, still he must be continually aware of the effects his plans will have on other aspects of the urban environment.

The desired result is a practical plan for specific improvements to existing facilities and the addition of new ones. The planning process, as described in general terms in this paper, translates present-day observed travel patterns into this master plan. The planning process consists of many distinct yet interrelated phases. The three main phases are inventorying existing or present conditions, estimating future urban area growth, and determining future travel demand. These three main phases are themselves subdivided into a large number of individual phases, which can be sequential, parallel, or both to other phases. It is probably true that no individual phase of the transportation planning process is truly independent of other phases. It is highly probable that the majority of the cause-and-effect variations encountered when studying phase interrelationships are unknown. Therefore, the interactions shown between major phases of the planning process represent only the readily understood and quantifiable relationships.

The total transportation planning process as developed to date is shown in Figure 1. Here the word "total" signifies its comprehensive and systematic approach to transportation planning. The principal phases in this process are as follows:

1. The Inventory of Existing Conditions
   a. Land use
   b. Population

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*Unless otherwise indicated, the word "facilities" refers to transportation facilities in general.

**Unless otherwise indicated, the term "planning process" refers to the transportation planning process.

c. Vehicle ownership
d. Vehicular and person travel
e. Transportation facilities
f. Economic activities
g. Available monetary resources
h. Present trip generation

2. Public Policy Decisions
   a. Land use
   b. Transportation facilities
   c. Proposed transportation facilities
3. Estimates of Future Urban Area Growth
   a. Population forecast
   b. Economic activity
   c. Vehicle ownership
   d. Land use
   e. Transportation network
4. Estimates of Future Travel
   a. Future trip generation
   b. Modal split
   c. Interzonal transfers
   d. Assignment of interzonal transfers to transportation network
   e. Evaluation of the loaded network

The interactions between various phases of the planning process are shown in Figure 1 by solid lines for major relatives and by dashed lines for additional desirable interactions. The latter have not been included in most past urban transportation studies, although there has been an increasing tendency to utilize them in more recent studies. Inclusion of these interactions will produce a more flexible, responsive, and complete planning process, which in turn leads to more realistic and accurate results.

The procedure shown in Figure 1 is briefly described as follows: The planning process begins with inventorying existing conditions. These inventories are conducted simultaneously. Analysis of data collected provides the basic information necessary to determine present trip generation characteristics. The inventories also provide data from which estimates of future urban area growth can be determined. Estimates of future trip generation and a trial future transportation network are likewise determined from inventory data and from hypothesized patterns of future urban growth. From estimates of future trip generation and the proposed network, the locations and amount of future travel is determined and assigned to specific facilities. The results of this assignment are then evaluated in terms of the desired level of service plus the social and economic consequences to the community developing as a result of the trial network. Inevitably some revision to the network will be necessary or desirable, and the information obtained during this trail assignment is used to modify results obtained in earlier phases of the planning process. Then another trial assignment is made to a revised transportation network. This process is repeated until the desired results have been achieved.

Figure 1 shows the total transportation planning process in over-all perspective. Table 1 gives each phase in greater detail and the methods, procedures, and principal data are indicated.

FUTURE RESEARCH

Although much has been accomplished in formulating and improving estimation and assignment techniques, the study has revealed many aspects of the planning process as warranting further investigation. Time does not permit a thorough development of each of the topics suggested. Instead, they are presented as a series of unanswered questions. It is hoped that the challenge of these questions may help stimulate further research effort in this field. The coverage achieved is by no means complete; rather it represents a planning-orientated sample of work that must eventually be accomplished.

The propositions are presented in the same general order as shown in Figure 1 and

outlined previously. Phases under "Inventory of Existing Conditions" are not included because they represent the accumulation and manipulation of past data. Three blocks under "Estimates of Urban Area Growth" (Population Forecast, Economic Activity, and Vehicle Ownership) are likewise omitted, because they relate to disciplines somewhat removed from the recognized professions of transportation and urban planning.

Public Policy Decisions

1. General.—Basic to all transportation planning studies is a consideration of the goals of urban transportation and means for satisfying them.

Often one hears the statement that transportation planning is more a function of unpredictable public policy decisions than one based on the detailed plans and estimates of responsible professional engineers and planners. This statement itself indicates the importance of studying the institutions and contributors involved in formulating transportation policies. Specifically, through what institutions are public policy decisions affecting transportation made? How can the channels of communication, required coordination, and the specific process of evaluating the proposed alternatives be improved between the many formal and informal, public and private transportation policy groups, so that the seeming endless conflicts can be minimized? What additional legislative and judicial arrangements should be implemented to assist in public participation and review of transportation alternatives, and to minimize the excessive or adverse influ-

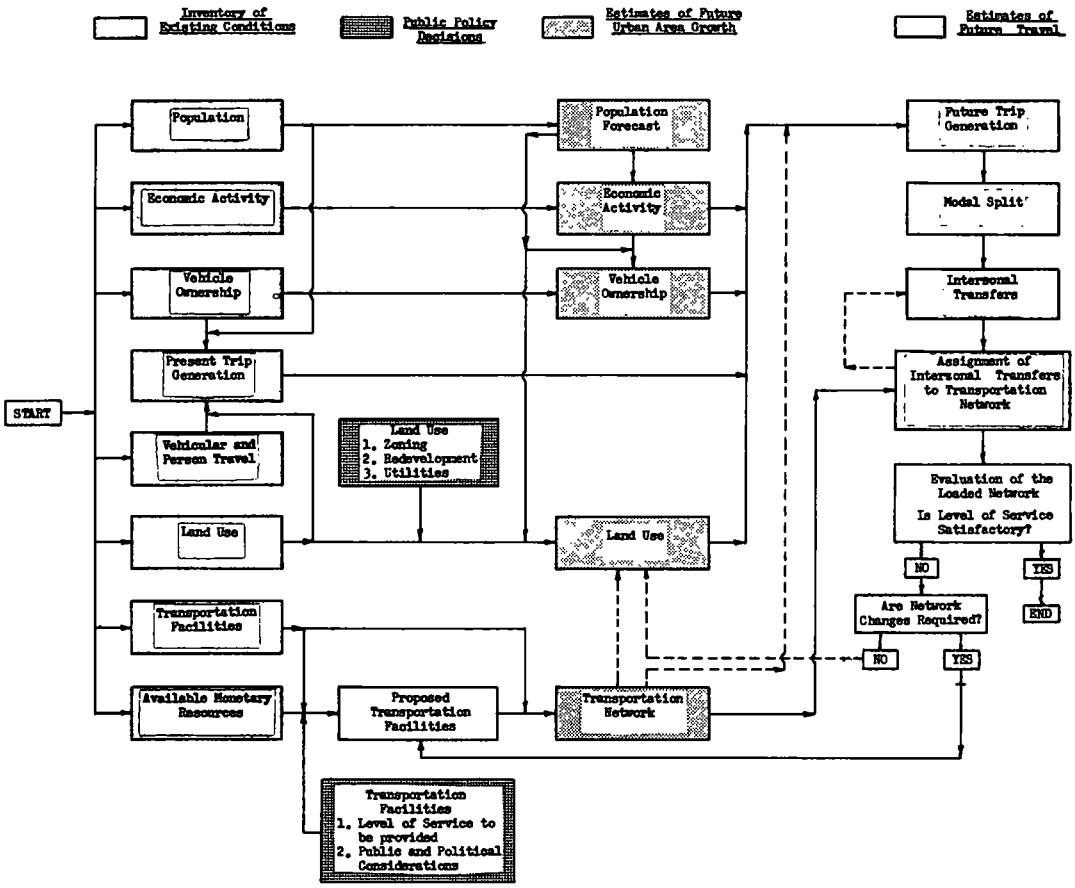

Figure 1. The total transportation planning process.

TABLE 1

METHODS, PROCEDURES, AND PRINCIPAL DATA OF THE TOTAL TRANSPORTATION PLANNING PROCESS

Phase	Method or Procedure Used to Determine Required Information	Data Required or Information Determined
1 Inventories of Existing Conditions		
a Land Use	1 Home Interview Origin and Destination Survey (Urban Area Transportation Study) 2 Planning Board, City Assessor etc Data	Kinds of Activity and Intensity of Site Usage Taking Place on Land
b Population	1 Decennial Census Tract Information (U S Bureau of the Census) 2 Home Interview Origin and Destination Survey (Urban Area Transportation Study)	Persons per Unit Area and Per Zone
c Vehicle Ownership	1 Home Interview Origin and Destination Survey (Urban Area Transportation Study) 2 State Motor Vehicle Registration Bureau	1 Automobiles (private commercial and taxis) 2 Trucks (light medium heavy) 3 Mass Transportation Vehicles (busses streetcars) per unit area and per zone)
d Vehicular and Person Travel	Origin and Destination Surveys (home interview cordon line truck taxi mass transportation and screen line)	Trips per person or vehicle per day
e Transportation Facilities	1 Survey of the Physical Characteristics of Transportation Facilities 2 Survey of the Operational Characteristics of Transportation Facilities	Miles of highway by class; travel times speeds and capacity by time of day
f Economic Activities	1 Economic Reports of Existing Urban Area Economic Study Groups 2 U S Bureau of Labor Statistics Employment Data 3 U S Bureau of the Census Budget Study Information	1 Employment 2 Per Capita Income
g Available Monetary Resources	1 Review of Present Expenditures for Transportation Facilities 2 Estimate of Future Income	Federal State County and Urban Area (city town etc) Funds Available for Expenditure on Transportation Facilities
h Present Trip Generation	Analysis of Trips by Trip Purpose Family Income Vehicle Ownership Land Use at Origin Distance from the CBD Length of Trip Mode Land Use at Destination and Time of Day	Trip Generation Characteristics and Rates (person and vehicle)
2 Public Policy Decisions		
a Land Use		1 Estimate of the Future Zoning 2 Public and Private Redevelopment and Urban Renewal Plans 3 Availability of Utilities and Community Services within the Urban Area
b Transportation Facilities		1 The Future Level of Service to be Provided 2 Political Considerations 3 Expressed Wishes of the General Public
c Proposed Transportation Facilities	1 Location of Present and Expected Future Deficiencies in Capacity 2 Theoretical Considerations on the Spacing of Transportation Facilities	Master Plan of Additional Transportation Facilities
3 Estimates of Future Urban Area Growth		
a Population Forecast	Methods developed by the U S Bureau of the Census	Persons per Unit Area and per Zone
b Economic Activity	1 Ratio of Employment to Population 2 Simple Trend Analysis 3 Expansion from Manufacturing Employment 4 Input-Output Model	1 Employment 2 Per Capita Income
c Vehicle Ownership	1 Automobiles: Budget Study Time Series and Combined Budget Study and Time Series 2 Trucks: Trend Analysis 3 Mass Transportation Vehicles: Assumed Constant	Number of Automobiles (private commercial and taxis) Trucks (light, medium and heavy) and Mass Transportation Vehicles (busses) per Unit Area and per Zone
d Land Use	1 Intuitive Judgement 2 Land Use Accounting 3 Combination of Intuitive Judgement and Land Use Accounting	Expected Future Zonal Uses of Presently Vacant Land Densities of Development and Quantity to be Absorbed into Urban Uses by a Specific Date (or Dates)
e Transportation Network	Combining the Proposed Transportation Facilities with the Present Transportation Facilities	Master Plan of the Future Transportation Network
4 Estimates of Future Travel		
a Future Trip Generation	Combining the Estimates of Future Economic Activity Vehicle Ownership and Land Use with Present Trip Generation Information	1 Future Trip Generation Characteristics 2 Future Zonal Estimates of Person and Vehicle Trips
b Modal Split	Trend Analysis	The Number of Person Trips Using Mass Transportation
c Interzonal Transfers	1 Growth Factor Methods (Uniform Factor Average Factor Fratar and Detroit) 2 Inter-Area Formula Methods (Gravity Model Interactance Model and Opportunity Model)	Estimate of the Future Number of Zone-to-Zone Vehicle Trips
d Assignment of Interzonal Transfers to Transportation Network	1 Without Capacity Restraint (Diverson Curve or All or Nothing" Assignment) 2 With Capacity Restraints (Proportional or All or Nothing Assignment)	Directional or Non-Directional Traffic Volumes Using Transportation Facilities
e Evaluation of the Loaded Network	1 Inspection of the Traffic Assignment Made 2 Determination of the Level of Service Provided 3 Economic Analysis of the Proposed Facilities to Determine Feasibility	1 Volume-Capacity Ratios 2 Vehicle Speeds by Time of Day 3 Economic Return (Benefit-Cost Ratios Rate of Return or Annual Cost)

ence often exerted by interest groups? The need to improve the public administration and functional organization of transportation planning is great, and must be done if this planning is to be removed from the political to the professional level.

It has long been recognized that transportation planning is only one phase of general urban planning. Numerous phases of planning are common to both transportation and urban planning. Specifically, what policies, plans, and programs are the primary concern of urban planning? What phases of the planning process can best be handled within the transportation study framework envisioned in this paper? What phases of transportation planning are separable, and what phases require coordination between transportation and urban planners? The area of delineating responsibilities, improving interagency communication channels, and creating adequate governmental machinery to help bring about desired urban goals is one of major importance. This area has a great potential for the development and application of new ideas, because the resulting form and character of urban areas are a direct reflection of the planning accomplished and control exercised over the policies and programs of all contributing individuals and groups.

2. Land Use. —In predicting the character and form of urban areas in the future, planners begin with land use. Land use refers to the activities taking place on the land, the density of persons, and rate of change of use. Land use is greatly affected by public policies, both now and in the future. What community land-use policies, evidenced by zoning ordinances, slum clearance and redevelopment projects, community industrial land use promotion, etc., are relatively stable with time? What policies are subject to gradual changes through local or regional political and economic processes? What is the nature of the broad changes expected in public policy towards urban land use in the future, indicated in part by the changes occurring during the past several decades? How do the socioeconomic characteristics of the local or regional population affect the resultant policy decisions relating to land use? Can public policy decisions towards future land use be predicted with a reasonable degree of certainty? What changes will be necessary in public policies towards land use densities in order to efficiently accommodate the estimated future urban population? While public policies are open to speculation as to their predictableness, research can indicate those policies that will most likely occur in the future, and over which the greatest amount of public control can be exercised.

3. Transportation Facilities. —The amount and service characteristics that various types of transportation facilities should provide are of vital concern, although specific answers are for the most part unknown. What level or quality of service should the facilities provide? What is quality of service, how can it be defined and measured? What variables influence quality of service, and in what manner and to what extent? In designing and planning for new facilities, what level of service should be selected? Is there a rational economic basis to the selection of an appropriate level of service? Should the future transportation network provide a higher, similar, or lower level of service as compared with the present? Research directed at answering these is essential because it points to a fundamental question: What quantity and quality of facilities is necessary and desirable to satisfy the demands placed on the transportation network?

Estimates of Future Urban Area Growth

1. Land Use —Transportation planning is a major portion of general urban planning. As such it relies heavily on concepts of and plans for the urban area. Unfortunately, the fundamentals of urban planning are often elusive and are presently largely undefined, resulting in a considerable amount of confusion and controversy. What kind of cities are wanted in the future? What will be their form, characteristics, and functions? What will be their land-use requirements by types of activities, density of persons, and location of future development? To reshape present cities to those patterns and structures desired for the future gives rise to the question: What patterns of urban land-use development should be encouraged today? What are the alternative types of cities among which there is a possible choice? What groups will have a decisive role

in influencing the form and characteristics of these cities? This series of questions is basic and fundamental. Its importance becomes apparent when one realizes that decisions concerning urban goals must necessarily take precedence over transportation planning (although it will be influenced somewhat by transportation considerations).

Looking at the other side of the coin, how important is the transportation network in influencing the location, density, and timing of urban growth? How can this cause and effect relationship be recognized and evaluated? How should land-use and building controls be utilized to guide constructively, rather than hinder, this process of urban evolution? What techniques are available to test the effects that hypothesized transportation networks have on urban growth and change? How can these techniques be improved to indicate the consequences of transportation plans better? Although some research is currently in progress, much remains to be accomplished, especially in determining the precise impact that transportation facilties have on adjacent land uses.

Many factors underlie the observed changes taking place in urban land uses over time. How do such factors as the quality and capacity of a community's sewer and water facilities, building and subdivision controls, land cost and availability of suitably sized tracts for real estate development, community land use promotion, tax rates, and prestige affect the type and density of land use and its rate of change? Further research and development of land-use models for distributing future population and employment to small areas is a promising area of endeavor. The work done to date has been exploratory; refined land-use models will explicitly recognize and account for all variables that can be qualitatively identified as affecting urban area growth and change.

2. Transportation Network. —Observed urban travel patterns need questioning and the following propositions seriously pondered. How much of present urban travel is really necessary, or considering the regional or national economy, desirable or tolerable? Where is the separation between productive and nonproductive travel? At what point do rising costs associated with user's time, vehicle operation, and driver comfort and convenience become a serious detriment to travel within the urban area? What criteria must be used to establish a rational balance between minimum and maximum travel? Obviously too many transportation facilities are as economically wasteful as too few, because they encourage unnecessary personal expenditures on transportation and violate sound investment practices. Research can provide a clearer answer on the quantity of urban transportation that is really desirable.

The proper location of facilities directly affects the success of the transportation network in meeting the potential demand for transportation. Equally important is the operation of present facilities and their adaptability to changing operational demands. What can be done to insure that proposed transportation facilities are located to advance over-all community objectives? How can better use be made of existing facilities? How can flexibility in the present and proposed facilities be retained so that they can be more adaptable to changes brought about by technological developments? Proper location, efficient use, and flexibility (to prevent premature obsolescence) of transportation facilities are operating characteristics explicitly recognized today as being important. Unfortunately, the techniques necessary to insure proper recognition or preservation of these characteristics through time have not yet been perfected.

Transportation today consists of the loose grouping of different modes, industries, and individual efforts. It is this illogical grouping that has caused many existing problems. How can highway and mass transportation planning be better integrated to: (a) make advantageous and efficient use of existing facilities, to minimize the requirements for additional facilities; (b) eliminate various forms of destructive competition between different modes of transportation; and (c) provide efficient intermodal transfer facilities, thereby encouraging the continued use of public and private transportation for those portions of the trip where each is most advantageous? Comprehensive research aimed at developing new methods for the efficient and effective integration of all forms of urban transportation is vitally needed.

Estimates of Future Travel

1. Future Trip Generation. —Transportation planners have long sought to establish

definitive relationships between person or vehicle travel and land use. These trip generation factors are determined for observed conditions and used to predict the amount of travel occurring at some point in the future. Constancy of trip generation factors with time is often assumed. Do these trip generation factors, or rates, remain static over time? Results from repeat origin and destination surveys have indicated that this assumption is probably not true, and if assumed, can lead to large errors in future estimates. Ways of modifying present trip generation characteristics to reflect probable future conditions better need immediate development.

Today, urban transportation represents an unstable compromise between the large, partially unsatisfied, demand for transportation and the available supply of physical facilities. In most urban areas the transportation demand is to an appreciable extent "throttled" by lack of facilities. What trip generation rates would occur if an unlimited network of facilities was available? What retards this trip generation potential from being fully realized? How does the completion of a new facility affect adjacent land-use trip generation rates? Research is urgently needed to determine the probable magnitude and implications of trip generation potential under specified traffic and environmental conditions, and to determine the manner in which present facilities retard or advance trip making.

Present trip generation data are invariably based on empirical observations, and do not attempt to answer basic questions, such as: (a) why do people make trips at all; (b) what motivations are most significant in influencing all facets of trip generation; (c) what decisions does an individual make and what decision process does he use in determining whether to make a trip; (d) what criteria of selection or measures of effectiveness do individuals use in arriving at a resultant trip decision; and (e) what precise values do individuals place on trip purpose, time of day, route, mode, and terminal conditions? A great need is to uncover the basic motivations of trip makers. Research along this line will enable making more rational estimates of future trip generation.

Often trip generation is assumed to be independent of the quality of the transportation network, although this is incorrect. Occasionally, percentage modifications are made to account for facility-generated traffic. This traffic is referred to as induced traffic and can be readily observed on recently completed expressway-type facilities. What is induced traffic? On the completion of new transportation facilities, what factors make entirely new trips "now worthwhile?" What type of trips are induced; e.g., time of day, purpose, destination? Where are the person or vehicle trip ends of induced travel? Research can uncover the cause and effects underlying induced travel, and will assist in developing a satisfactory method for including this effect in the planning process.

2. Modal Split.—Perhaps one of the largest areas of uncertainty is the future division of trips between different modes. To a large extent the success of mass transportation planning depends on the accurate prediction of its potential riders. What factors cause people to shift from one mode of transportation to another—an effect which has occurred extensively in the past decade? What are the social and economic characteristics of those induced to shift modes? What are the precise characteristics of the captive mass transportation rider, of those who are able to choose between either personal or mass transportation, and of those who exclusively use private transportation? What values are placed on quality of service, travel time, vehicle and terminal comfort, esthetics and cleanliness, user convenience, route or time flexibility, and cost by users of different modes of transportation? Research in this area will develop the tools that transportation planners need to identify and quantify the dynamic relationships involved so that future predictions involving the use of different modes of transportation can be based on more than an extension of past trends.

3. Interzonal Transfers.—During the past two decades, various mathematical procedures have been developed for distributing generated trips between small areas, or zones. Various growth factor methods and inter-area travel formulas are currently available. Unfortunately little comparative information between different techniques exists. For each technique, what is the accuracy of the obtained results, as compared with observed results through time; the cost of securing the necessary imput data; the cost of computer distributive techniques; and the stability of the model attraction and

resistance parameters with time? These techniques are based on different concepts of travel. Therefore, research is needed to develop necessary comparative measures so that a qualitative and quantitative evaluation of existing interzonal transfer methods can be made.

Looking further at inter-area travel formulas, are there better attraction and resistance parameters available for use in interzonal transfer methods? An attraction parameter combining zonal and retail employment, sales volume, and general type of business might be a better measure of zonal attraction for commercial trips than one containing only retail employment. Likewise, a resistance parameter combining travel time, ground distance, and the general level or quality of service offered by applicable facilities would be a better measure of travel resistance than travel time or distance alone. There is a definite need for refined, representative parameters suitable for use in interzonal transfer models.

4. Assignment of Interzonal Transfers to Transportation Network. —Assignment of interzonal transfer trips to transportation facilities must eventually recognize the capacity limitations of the physical facilities and intersections between portions of the network. Obviously, no more traffic should be assigned to a facility than it is capable of handling. Capacity restraints are a tool used to prevent possible overassignment and maintain system balance. How should capacity restraints be used in the assignment process? How do capacity restraints affect interzonal transfers and trip generation? What modifications to existing assignment techniques are necessary to utilize fully the philosphy represented by capacity restraints? The inclusion of capacity restraints in a traffic assignment program is a relatively recent development, and further investigation is required to determine the extent of the feedback process (to the assignment, the interzonal transfer, or the future trip generation phases) and the most economical use of capacity restraints in the assignment program.

The assignment process today evolves around the use of electronic computers to perform the tedious process of distributing interzonal transfers. Nevertheless, many questions regarding the proper role and function of computers remain unanswered. How much of the existing network of transportation facilities should be coded for use in the computer assignment process? What are the costs involved, in terms of accuracy, representation, computer size, and required assignment time? More information on cost vs accuracy and capabilities of assignment programs would definitely aid future transportation studies in a better selection of both program and computer.

CONCLUSION

This paper has summarized the transportation planning process as developed to date (1961) by major urban area transportation studies. In addition, it has focused attention on a few of the areas where research will be useful and profitable.

The major advantage of the planning process is that it is a systematic, rational method for determining the need for improved or additional facilities and of allocating the amount, timing, and specific purpose of governmental expenditures on transportation facilities. It also gives a strong impetus to coordinating transportation and urban planning, so that the many conflicting goals involving the form, function, characteristics, and transportation in the city of the future can be minimized.

The planning process as presently practiced does have weaknesses. In the interest of expediency, methods are commonly applied that are in fact an oversimplification of the problem. Factors exhibiting a high degree of correlation with travel patterns are generally used, whereas, other factors of a more subjective nature, but of considerable importance, are neglected. Many studies tend to portray future urban travel as an extention of past trends. Such an assumption implies a perpetuation of current conditions and neglects the inevitable changes occurring in urban socio-economic characteristics, regional political, and governmental structure, and technology, which are sure to develop.

Imaginative, basic research offers the best potential means of providing the additional information and techniques required to achieve better advance transportation planning. This research must draw on the knowledge, talents, and disciplines of the social and

physical sciences as well as those of transportation and city planning. Efforts should continually be increased to understand the interacting forces shaping cities and the resulting movements of persons and goods, for the decisions of today directly affect the quality of future cities.

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Appendix

ANNOTATED BIBLIOGRAPHY ON TRAFFIC ESTIMATION AND ASSIGNMENT

Principal Categories of Traffic Estimation and Assignment	Bibliography Reference Numbers
Assignment programs	21-24, 28, 124, 126, 135, 154, 169
Assignment techniques	6, 23, 24, 30, 38, 45, 81, 88, 92, 101, 129, 141, 153, 168, 169
Diversion curves	6, 30, 31, 45, 114, 119, 126-129, 134, 137, 141, 153, 160, 168
Economic analysis	25, 27, 43, 62, 84, 86, 139, 143, 153
General	4, 7, 32, 35, 37, 40, 41, 47, 53, 56, 57, 61, 63, 94, 107, 110, 120, 125, 138, 141, 151, 153, 164
Interzonal transfer methods	8, 12, 17, 19, 20, 29, 36, 37, 43, 54, 58, 59, 79, 104, 108, 109, 116, 132, 141, 153, 159, 161-163, 165, 170, 172, 173, 177
Land use	5, 16, 25, 26, 27, 67, 70, 73-77, 93, 117, 118, 125, 140-145, 153, 166
Modal split	1, 2, 17, 89, 90, 125, 131, 141, 145, 147, 153
Origin and destination surveys	3, 33, 42, 83, 98, 111-113, 115, 120, 121, 125, 130, 138, 141, 155, 156, 174
Population forecasts	105, 106, 144
Transportation facilities	48-50, 95-97, 136, 153, 164, 170, 171, 174
Transportation studies (all categories)	18, 34, 44, 55, 80, 82, 152, 171
Travel time	60, 66, 93, 99, 125, 126, 136, 141, 160
Trip generation	9-11, 13-15, 39, 46, 51-53, 64, 65, 67-72, 78, 85, 87, 91, 98, 100, 102, 103, 108, 109, 117, 118, 122, 123, 125, 133, 141, 146, 148, 149, 150, 153, 157, 158, 167, 175, 176

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14. Blake, G.W., "First Work Trips." PATS Research Letter, 1:1-11 (Nov. 1959).

    Summary of modal split, length of trip, car occupancy, and land use at destination for first work trips, as determined from O-D data of Pittsburgh Area Transportation Study.

15. Blake, G.W., "Trip Linking Rationale." PATS Research Letter, 1:12-16 (Dec. 1959).

    Discussion of method used in Pittsburgh Area Transportation Study for combining change of mode or serve passenger trip purposes with more basic trip purposes.

16. Blumenfeld, H., "Are Land Use Patterns Predictable?" Jour., Amer. Insti. of Planners, 25:61-66 (May 1959).

    Identification of some key variables affecting urban growth patterns. Distance and density patterns shown to follow concentric ring pattern and "crest of the wave" theory of urban growth.

17. Booth, J., and Morris, R., "Transit vs Auto Travel in the Future." Jour., Amer. Inst. of Planners, 25:90-95 (May 1959).

    Description of mathematical model used to predict future traffic volumes that would occur on proposed highway system if specific mass transportation improvements were made. Model used for estimating and predicting future traffic patterns in Baltimore region.

18. Boston College Seminar on Urban Research, "Travel in the Boston Region 1959-1980." Vol. 1 (Jan. 1960); Vol. 2 (Feb. 1961); Vol. 3 (April 1961).

    Vol. 1: Describes techniques and procedures used, and presents initial findings. Vol. 2: Describes in detail use of Gravity Model for determining geographical pattern of trips. Vol. 3: When published, will give final results of travel in region for 1980, and present consequent implications on need for future highway and transit improvements in Boston area by 1980.

19. Brokke, G.E., "Evaluating Trip Forecasting Methods with an Electronic Computer." HRB Bull. 203, 52-75 (1958).

    Average Factor, Detroit, and Fratar methods of forecasting trip distribution

were tested with aid of computer. Maximum accuracy reached in second approximation of Fratar method, but four or more approximations usually required with the other methods.

20. Brokke, G.E., and Mertz, W.L., "Evaluating Trip Forecasting Methods with an Electronic Computer." Public Roads, 30:77-87 (Oct. 1958).

    Essentially the same as reference 19.

21. Brokke, G.E., "Program for Assigning Traffic to a Highway Network." HRB Bull. 224, 89-97 (1959).

    Techniques used in Washington for estimating distribution of traffic among various routes are described. Nine-stage electronic programming system used can provide data on any given traffic situation and on effectiveness of new highway design. Program described uses Bureau of Public Roads time diversion curve, and is suitable for use on IBM 704 computer.

22. Brokke, G.E., "Assigning Traffic to a Highway Network." Public Roads, 30:227-233 (Oct. 1959).

    Essentially the same as reference 21.

23. Brown, J.H., and Wilson, J.S., "Traffic Assignment to a Highway Network by Minimum Path Method." Traffic Planning Seminar, Mass. Insti. of Tech., (Nov. 1960).

    Gives detailed description of techniques used in applying Bureau of Public Roads IBM 704 traffic assignment program to Washington Area Transportation Study.

24. Brown, R.M., and Weaver, H.H., "Traffic Assignment Using IBM Computations." HRB Bull. 130, 47-58 (1956).

    Presents probable distribution of traffic on arterial street systems of Lafayette and West Lafayette, Ind., after completion of construction of Wabash River Bridge.

25. Browning, C.E., "The Distribution of Available Industrial Land in the Chicago Area." CATS Research News, 2:11-16 (Jan. 17, 1958).

    Tabulation of available industrial land in Chicago area, showing spatial differences (ring and sector) between zoned industrial land and that currently available.

26. Browning, C.E., "Selected Relationships of Land Use and Distance from City Center." CATS Research News, 2:3-12 (Feb. 14, 1958).

    Discusses proportion of land developed or in use by distance from CBD; land-use proportions by distance from CBD; and distribution of area in different land uses by 1-mi distance rings.

27. Browning, C.E., "Industrial Worker Densities in the CATS Area." CATS Research News, 2:9-16 (April 25, 1958).

    Presentation of distribution of industrial worker densities in Chicago area. Constant and relatively even decline in industrial worker density found as distance from the CBD increases, although significant differences occurred from sector to sector and between districts.

28. Bureau of Public Roads, "Electronic Computer Program for Assignment of Traffic to Street and Freeway Systems." Bureau of Public Roads Program T6. Annotated description.

29. Calland, W.B., "Traffic Forecasting for Freeway Planning." Jour. Amer. Insti. of Planners, 25:82-86 (May 1959).

Discussion of gravity model used in San Diego area. Model relates trips between zones to total trips generated by each zone and distance between those zones.

30. Campbell, E.W., "A Mechanical Method for Assigning Traffic to Expressways." HRB Bull. 130, 27-46 (1956).

Coding techniques and machine procedures used in Detroit Area Study outlined, and obtained results analyzed.

31. Campbell, E.W., and McCarger, R.S., "Objective and Subjective Correlates of Expressway Use." HRB Bull. 119, 17-38 (1956).

To assist in assigning traffic to proposed expressway network, and to develop a family of diversion curves relating distance ratio and speed ratio to expressway usage, data were obtained from studies of diversion to five expressways. Relationships between expressway usage, objective measurements of time, distance and speed, and subjective processes involved in a driver's choice of route were studied.

32. Campbell, E.W., "Organizing a Continuing Agency for a Metropolitan Area Transportation Study." HRB Proc., 38:1-8 (1959).

Account of functions, staffing, activities, and organization of body which is to continue work of Chicago Area Transportation Study. Body to be called Urban Research Section and be a major part of Illinois Division of Highways Bureau of Research and Planning.

33. Carlisle, G., and Taylor, W.T., Jr., "Minimum Time Periods for Origin-Destination Surveys." HRB Proc., 28:340-347 (1948).

Discusses accuracy to be expected from short sampling time O-D surveys.

34. Carril, R.R., "Traffic Forecast Based on Anticipated Land Use and Current Travel Habits." HRB Proc., 31:386-410 (1952).

Method used for forecasting traffic in San Juan, Puerto Rico, Metropolitan Area on basis of anticipated land use and current travel habits is discussed.

35. Carroll, J.D., Jr., "Some Uses of Computers in O-D Studies." Proc., Insti. of Traffic Engineers, pp. 57-63 (1957).

Description of two special types of electronic data processing machines used at CATS, and experimental work done developing a network analog computer.

36. Carroll, J.D., Jr., "Future Traffic Predictions for the Detroit Area." HRB Proc., 36:680-685 (1957).

Procedure developed for forecasting probable travel movements between zones in 1980, based on forecasts of population, land usage, economic activity, and relation of traffic to population.

37. Carroll, J.D., Jr., and Bevis, H.W., "Predicting Local Travel in Urban Regions." Regional Science Association Papers and Proc., 3:183-197 (1957).

Discussion of urban transportation forecasting including prediction of future levels of personal automobile travel. Some current methods used by transportation studies discussed, and conceptual traffic prediction model presented. Reference to work done by Detroit Area Transportation Study.

38. Carroll, J.D., Jr., "A Method of Traffic Assignment to an Urban Network." HRB Bull. 224, 64-71 (1959).

Illustrated description of electronic computing technique used to determine traffic flow on different parts of road network in urban area of Chicago. Programming method, which allows for all possible route combinations, based on research by E.F. Moore on systematic and economical method of finding shortest path through a maze.

39. Carroll, J.D., Jr., "Trip Length Frequency Distribution and Its Effect on Highway Planning." CATS Research News, 3:No. 4 (Nov. 13, 1959).

Description of significance of "trip length" in measuring demand for highways.

40. Carroll, J.D., Jr., and Creighton, R.L., "Planning and Urban Area Transportation Studies." HRB Proc., 36:1-7 (1957).

Need for integrated transportation planning process discussed. Individual steps of process described, and "feedback" links, which need to be incorporated in future planning methods, indicated.

41. Cherniack, N., "Passenger Data for Urban Transportation Planning." Proc., ASCE, 85:No. HW4, pp. 37-54 (Dec. 1959).

General description of what urban area transportation is, including the varied demands made on it, and physical types of urban transportation available. Using travel across Hudson River in metropolitan New York area as example, variation of travel demands and services with time is discussed.

42. Cherniack, N., Campbell, E.W., Lynch, J.T., Steele, C.A., and Howe, R.T., "Critique of Home Interview Type O-D Surveys in Urban Areas." HRB Bull. 253, 166-188 (1960).

A searching review of current home interview origin and destination survey procedures is made. Various basic improvements to present techniques and philosophy are proposed.

43. Cherniack, N., "Effects of Travel Impedance Costs." HRB Special Report 56, 99-108 (1959).

Discussion on how travel impedance costs may be used in mathematical formulas to determine traffic generation and distribution in an urban area.

44. Cherniack, N., "Chicago Area Transportation Study." Vol. 1 (1959), Vol. 2 (1960), Vol. 3 (to be published).

Vol. 1: Detailed basic information needed for long-term planning. Data presented in three sections—description of region: measured quantities for the base year, 1956: and indications of reliability of basic information. Vol. 2: Concerned with estimation of amount, kind, and location of travel likely to take place in 1980 in Chicago area. Vol. 3: To set forth criteria for planning. Plans will be developed and tested, benefits weighed against costs. Finally, a staging of work for construction of new transportation facilities.

45. Conner, M.A., Hiller, S.H., "Mechanical Methods of Traffic Assignment." HRB Bull. 130, 69-75 (1956).

Description of use made of digital and analog computers in traffic engineering by Florida State Highway Department.

46. Gorman, D.A., and Hitchcock, S.T., "Characteristics of Traffic Entering and Leaving the CBD." Public Roads, 30:213-220 (Aug. 1959).

Description of general patterns of vehicle travel into and out of CBDs of a large number of cities.

47. Creighton, R.L., "Comprehensive Transportation Planning." Proc., ASCE, 84:No. HW3 (Oct. 1958).

Discusses methods to be used in Chicago Area Transportation Study.

48. Creighton, R.L., Hoch, I., and Schneider, M., "Estimating Efficient Spacing for Arterials and Expressways." HRB Bull. 253, 1-43 (1960).

Details of study made to determine optimal spacing of arterials and expressways as function of construction cost and user cost. Relationships obtained mathematically, and appropriate data for Chicago area used in obtaining final results.

49. Creighton, R.L., and Schneider, M., "The Optimal Spacing of Arterials and Expressways." CATS Research News, 2, 10-16 (Nov. 1958).

Summary of reference 48.

50. Creighton, R.L., and Hock, I., "The Optimum Spacing of Arterials and of Expressways." Traffic Quarterly, 13:477-494 (Oct. 1959).

Essentially the same as reference 48.

51. Creighton, R.L., "Linked Home Interview Travel Data." CATS Research News, 2:3-9 (Feb. 28, 1958).

Difference in number and purpose of trips shown to be function of accounting technique used to classify trips using more than one mode of travel.

52. Creighton, R.L., "Length of Travel." CATS Research News, 3:1-7 (Feb. 20, 1959).

Statistics giving length of person-trips and vehicle-trips, and miles of person and vehicle travel for the Chicago area, presented.

53. Curran, F.B., and Stegmaier, J.T., "Travel Patterns in 50 Cities." HRB Bull. 203, 99-130 (1958).

Results of investigation by Bureau of Public Roads on purpose and mode of travel of trips made by inhabitants of 50 cities. In most cases, volume of daily trips compared to number of persons, dwelling units, and cars in particular city.

54. Davidson, R.G., "Developing a Traffic Model with a Small Sample." HRB Bull. 297, 106-108 (1961).

Describes Boston College Urban Transportation Research Program, using gravity model, with a small home interview O-D survey, to develop traffic model for metropolitan Boston area.

55. Davidson, R.G., "Detroit Area Traffic Study 1956." Vol. 1 and 2.

Vol. 1: Data Summary and Interpretation. Account of study procedure, results of inventories, and analysis of survey data. Vol. 2: Future Traffic and a Long Range Expressway Plan. Extension of trends leading to estimate of future travel desires. Methods necessary to plan adequate (in location and supply) transportation facilities for present and future traffic demands presented.

56. Fagin, H., "Fundamental Philosphy and Concepts." HRB Bull. 293, 33-36 (1961).

Discussion of fundamental principles of metropolitan area transportation planning, as applied in Penn-Jersey Transportation Study.

57. Fleisher, A., "On Prediction and Urban Traffic." Meeting, Regional Science Assoc. (Dec. 1960).

Discusses predictability of traffic in urban area.

58. Fratar, T.J., "Vehicular Trip Distribution by Successive Approximations." Traffic Quarterly, 8:53-65 (Jan. 1954).

Describes method of successive approximations useful in estimating distribution of trips between zones in urban area. Numerical example of proposed method and comparison with average factor method also included.

59. Fratar, T.J., "Forecasting Distribution of Interzonal Vehicular Trips by Successive Approximations." HRB Proc., 33:376-385 (1954).

More detailed presentation of material in reference 58.

60. Gardner, E.L., "Evaluation of Friction Measures." CATS Research News, 2:10-13 (March 14, 1958).

Results of tests to determine value of travel time as friction measure.

61. Gittens, M.J., "Methodology or Planning." HRB Bull. 293, 36-39 (1961).

General methodology of Penn-Jersey Transportation Study in terms of a single, unifying concept linking urban development, transportation movement, and growth of a metropolitan region presented.

62. Glanville, W., "Economic and Traffic Studies for Long-Birmingham Motorway." Proc., Inst. of Civil Engineers, Vol. 15 (April 1960).

Review of traffic and economic study completed before construction of London-Birmingham Motorway.

63. Hall, E.M., "Metropolitan Area Transportation Studies." Proc., Inst. of Traffic Engineers, pp. 51-62 (1956).

Describes organization and specific projects of San Diego Metropolitan Area Transportation Study.

64. Hall, E.M., "Travel Characteristics of Two San Diego Subdivision Developments." HRB Bull. 203, 1-19 (1958).

Relationships between land use and traffic generation for two San Diego subdivision developments, indicating orientation of generated traffic are developed. Standard home interview and cordon line origin and destination survey was made.

65. Hall, E.M., "Traffic Generator Studies in San Diego." Traffic Engineering, 30: 13-16 (Feb. 1960).

Essentially the same as reference 64.

66. Hall, E.M., and George, S., Jr., "Travel Time—An Effective Measure of Congestion and Level of Service." HRB Proc., 38:511-529 (1959).

Value of travel time as measure of "level of service" discussed with particular reference to San Diego Metropolitan Area Transportation Study.

67. Hamburg, J.R., "Selected Land Use and Trip Purpose Comparisons—Detroit and Chicago." CATS Research News, 2:17-20 (Feb. 28, 1958).

Trip purpose distributions within selected generated land-use categories compared for Chicago and Detroit: Comparisons revealed high degree of similarity between the two cities.

68. Hamburg, J.R., "'Walk to Work' Trips in the CATS Area." CATS Research News, 2:3-5 (April 25, 1958).

Shows absolute and percentage walk-to-work trips of total first work trips for Chicago and Detroit. Tendency for residents to walk to work maximized in central area and minimized in suburban areas.

69. Hamburg, J.R., "Summary Comparison of Trip Generation for Chicago and Detroit." CATS Research News, 2:3-5 (June 27, 1958).

Comparison of trips generated per acre of land in various uses for Detroit and Chicago. Definition and data collection differences made comparison difficult, although general similarities were noticed in both cities.

70. Hamburg, J.R., "A Comparison of Vehicle and Person Destinations by Land Use." CATS Research News, 2:12-16 (Sept. 5, 1958).

Examines trip destinations by vehicle type. Significant differences in proportions of trips generated by different land-use activities recorded for resident, taxi, and truck trips in Chicago Area Transportation Study.

71. Hamburg, J.R., "A Comparison of Car Ownership and Density-Chicago and Detroit." CATS Research News, 2:3-7 (Oct. 3, 1958).

Shows that pattern of car ownership is practically the same in both Chicago and Detroit, even though physical structure of the two cities is considerably different (density, available mass transportation, size, etc.).

72. Hamburg, J.R., "Car Ownership and Trip Making in the CATS Area." CATS Research News, 3:8-12 (Feb. 20, 1959).

Review of present and predicted future car ownership and trip making in CATS area.

73. Hamburg, J.R., "Land Use Projection for Predicting Future Traffic." HRB Bull. 224, 72-84 (1959).

Forecasting procedure used for predicting land development in Chicago up to 1980 reviewed. Relationships developed between land use and trafffic used for predicting future travel.

74. Hamburg, J.R., and Creighton, R.L., "Predicting Chicago's Land Use Pattern." Jour. Amer. Insti. of Planners, 25:67-72 (May 1959).

Procedure whereby area-wide estimates of future population and economic activity can be distributed to small subareas, so that measures of local land requirements may be obtained.

75. Hansen, W.G., "How Accessibility Shapes Land Use." Jour. Amer. Inst. of Planners, 25:73-76 (May 1959).

Suggests method for determining accessibility patterns within metropolitan areas. Although model presented not yet sufficiently well refined for estimating purposes, concept and approach may be potentially useful tools for metropolitan planning purposes.

76. Hansen, W.G., "Land Use Forecasting for Transportation Planning." HRB Bull. 253, 145-151 (1960).

Essentially the same as reference 75.

77. Hansen, W.G., "Hartford Transportation Study Procedures." Highway Planning Seminar, Mass. Insti. of Tech. (Nov. 1960).

Land-use model and traffic forecasting procedure used in Hartford Area Transportation Study discussed. Model incorporates a number of unique features not previously quantified.

78. Harper, B.C.S., and Edwards, H.M., "Generation of Person Trips by Areas Within the Central Business District." HRB Bull. 253, 44-61 (1960).

Description of method developed to measure attraction of person-trips to CBD. Results of both origin-destination and categorized floor-space surveys are used.

79. Heald, K.L., "Discussion of Iowa Gravity Model Traffic Distribution Program." Computing Center, Iowa State Highway Commission (March 1960).

Complete description of gravity model and associated computer program used in seven Iowa cities' transportation study.

80. Hillier, J.A., and Whiting, P.D., "Oxford Traffic Survey: An Assessment of the Traffic Consequences of Some Proposed Road Layouts." Dep. of Scientific and Industrial Research, Road Research Laboratory, RN/3537/JAH (July 1959).

Account of techniques used in Oxford (England) Traffic Survey, 1957.

81. Hillier, J.A., "The Assessment of the Effect of Relief Roads on Traffic." Institution of Highway Engineers, Portsmouth, England (Jan. 1961).

Assessment of current techniques of traffic estimation and assignment in Great Britain as developed by Road Research Laboratory.

82. Hillier, J.A., and Whiting, P.D., "Lagos Traffic Survey 1958." Dept. of Scientific and Industrial Research, Road Research Laboratory, RN/3508/JAH, PDW (June 1959).

Account of techniques used in Lagos (Nigeria) traffic survey, 1958.

83. Hitchcock, S.T., "Continuous Origin and Destination Traffic Surveys." Proc., ASCE, 84:No. HW2, Paper 1625 (May 1958).

Advantages of continuous O-D surveys discussed, and reference made to continuous sampling program planned by New York Port Authority.

84. Hoch, I., "Forecasting Economic Activity for the Chicago Region." HRB Proc., 38:9-25 (1959).

Economic forecast for years up to 1980 made by Chicago Area Transportation Study, with a view to forecasting employment, predicting numbers of vehicles registered, and gaining some insight into effects of expanded highway facilities on the economy. Electronic computer used for most of the calculations, account being taken of increase in population, real incomes, and shift in type and location of industry. A regional input-output model employed.

85. Hoch, I., "Forecasts of Automobile Registration for the CATS Study Area." CATS Research News, 2:3-9 (June 6, 1958).

Projections of automobile registration for Chicago area made using budget-study data on consumer expenditures, and time-series data on U.S. automobile registration.

86. Hoch, I., "The CATS Employment Forecast." CATS Research News, 2:4-9 (Nov. 28, 1958).

Procedure used to determine employment forecast, and results obtained for the Chicago area.

87. Hoch, I., "Auto Registration Forecasts Revisited." CATS Research News, 3:13-20 (Feb. 20, 1959).

Final forecast of auto registration for Chicago area, obtained by combining time-series and budget-study data.

88. Hooper, C.J., "The Need for Further Research on Traffic Assignment." HRB Bull. 61, 66-70 (1952).

Summary of trends in traffic growth, with areas for further research suggested.

89. Howe, J.J., "Modal Split of CBD Trips." CATS Research News, 2:3-10 (Aug. 22, 1958).

Modal split of trips starting or ending within CBD discussed for Chicago area.

90. Howe, J.J., "Modal Split of CBD Trips." CATS Research News, 2:3-10 (Aug. 22, 1958).

Describes modal split of trips starting or ending within CBD.

91. Howe, J.J., "A Theoretical Prediction of Work-Trip Patterns." HRB Bull. 253, 155-165 (1960).

Describes theoretical model of movement of people in response to varying land uses, based on principles of electrostatics. Although predictions given by model have not been field tested, it appears capable of predicting work-trip patterns in a metropolitan area within useable limits of accuracy.

92. Irwin, N.A., Dodd, N., and Von Cube, H.G., "Capacity Restraint in Assignment Programs." HRB Bull. 297, 109-127 (1961).

Complete description of methods used to include capacity restraints in future planning of highway facilities for Toronto metropolitan area. Method includes iteration procedure to obtain system equilibrium. Results of the programs compared with observed field data.

93. Johnston, W.W., "Travel Time and Planning." Traffic Quarterly, 10:67-78 (Jan. 1956).

Discussion of travel time and its affect on development of a region, particularly land use adjacent to new highways.

94. Kanwit, E.L., and Steele, C.A., "Need We Fail in Forecasting?" HRB Bull. 257, 1-35 (1960).

Appreciation of forecasting techniques. Concerned mainly with national and state-wide forecasts of vehicle registration and usage. A "yardstick" for assessing success of a forecast is suggested, and bases of forecasts made since 1950 are reviewed.

95. Keefer, L.E., "Reporting the Results of the CATS Speed-Volume Study." CATS Research News, 2:10-16 (June 6, 1958).

Presents major findings of speed-volume relationships for various classes of roads in Chicago area.

96. Keefer, L.E., "Reporting the Results of CATS' Intersection Capacity Study." CATS Research News, 2:12-16 (Sept. 19, 1958).

Report of major findings in Chicago Area Transportation Study to determine a prediction equation for capacity of an intersection which could be used in an assignment procedure.

97. Keefer, L.E., "The Arterial Street Inventory." PATS Research Letter, 1:1-5 (March 1959).

Describes inventory methods used at PATS for measuring traffic-carrying ability and quality of service provided by major streets (arterials) within study area.

98. Keefer, L.E., "Home Interview Survey-Summary Trip Data." PATS Research Letter, 1:12-17 (Nov. 1959).

Presents some over-all trip totals from home interview survey in Pittsburgh. Comparisons made with similar data from Chicago and Detroit.

99. Keefer, L.E., "Traffic Assignment Travel Times." PATS Research Letter, 1: 1-5 (July 1959).

Discussion of various aspects of using travel time in assignment procedures.

100. Keefer, L.E., "Central Business District—Summary Trip Data." PATS Research Letter, 1:1-8 (Dec. 1959).

Presents some over-all trip totals for CBD-orientated person and vehicle travel in Pittsburgh.

101. Keefer, L.E., "Traffic Assignment—What It Is." PATS Research Letter, 2:1-9 (Feb. 1960).

General discussion of principal procedures involved in making assignments of traffic to networks.

102. Keefer, L.E., "Alternate Approaches to Trip Generation." PATS Research Letter, 2:11-21 (May 1960).

Synopsis of current approaches to trip generation.

103. Keefer, L.E., "Some Factors Influencing Average Car Loading Factors." PATS Research Letter, 2:12-16 (Sept. 1960).

Presents basic data on car loadings, as affected by different variables, based on findings in Pittsburgh Area Transportation Study.

104. Killin, E.L., "Highway-Traffic Estimation by Linear Programming." Proc., ASCE, 85:No. HW-1, Pt 1, pp. 17-33 (Jan. 1959).

Application of linear programming to traffic estimation. Linear programming considered to have the following advantages over other procedures: (a) traffic movements in final solution will automatically behave with flow into interchange; (b) judgment can likely be applied with greater degree of confidence; (c) easily applicable to computer processing.

105. Kramer, C., "Population Density Patterns." CATS Research News, 2:3-10 (Jan. 31, 1958).

Derivation of residential density distribution described for future land-use structure in Chicago area. Units used are series of rings centered around CBD.

106. Kramer, C., "The Estimation of Future Population Densities." CATS Research News, 2:9-16 (June 27, 1958).

Method used in Chicago Area Transportation Study to prepare population density estimates outlined and discussed.

107. Lapin, H.S., "Transportation Analysis in the Philadelphia Metropolitan Region." Regional Science Association Papers and Proc., 3:198-206 (1957).

Discusses some concepts, principles, and applications derived from work done by Urban Traffic and Transportation Board of the City of Philadelphia. Group was given task of preparing "an integrated plan useful over an extended period for the elimination of urban transportation congestion."

108. Lapin, H.S., "Analysis of Work Trips Based on Mathematical Relationships and Variances." Institute for Urban Studies, Univ. of Pennsylvania (1956).

Presents results of analyses of work-trip generation between residential and employment concentrations in Philadelphia. Includes mathematical equation describing inverse relationship between interzonal trip volumes and respective time-distances for peak period travel.

109. Lapin, H.S., "The Analysis of Work-Trip Data." Traffic Quarterly, 11:278-292 (April 1957).

Details of analysis of work-trip generation between residential and industrial and business districts where level of employment is high. Equation given for evaluating interzonal trip volumes for peak periods.

110. Lapin, H.S., "Report on Analysis of Urban Work Trips." HRB Bull. 224, 51-63 (1959).

Analytical techniques used in study of peak-hour urban traffic flow reviewed, and methods of improving traffic forecasts discussed. Attention drawn to kind of information likely to permit realistic forecast of traffic patterns in time as well as direction.

111. Lovejoy, W.B., "Continuous Sampling Method of Conducting Origin-Destination Surveys." HRB Bull. 224, 41-50 (1959).

Results of first year's operation by New York Port Authority of continuous sampling program at Hudson River bridges and tunnels in New York Metropolitan Area. Statistical sample described, and advantages and future application of procedure discussed.

112. Lovejoy, W.B., "Trans-Hudson River Vehicular Origin and Destination Survey." Public Roads, 31:86-99 (Oct. 1960).

Essentially the same as reference 111.

113. Lovejoy, W.B., "New York Port Authority's 1958 O-D Survey Using Continuous Sampling." HRB Bull. 253, 152-154 (1960).

Essentially the same as reference 111.

114. Lynch, J.T., "Traffic Diversion to Toll Roads." Proc., ASCE, 81:Separate No. 702 (June 1955).

Growth, generation, and diversion of traffic since 1947 discussed with special reference to Maine Turnpike. Use of turnpike by trucks also discussed.

115. Lynch, J.T., "Home-Interview Traffic Surveys and Related Research Activities." Public Roads, 30:185-186 (June 1959). Also in HRB Bull. 224, 85-88 (1959).

Review of survey methods and traffic studies includes reference to origin-and-destination formulas and electronic computer techniques being developed by Bureau of Public Roads.

115. Lynch, J.T., Brokke, G.E., Voorhees, A.M., and Schneider, M., "Panel Discussion on Inter-Area Travel Formulas." HRB Bull. 253, 128-138 (1960).

A review of interzonal travel formulas, principally Fratar method, gravity model, and opportunity model.

117. McGrath, W.R., "Land Use in Traffic Generation." HRB Bull. 224, 132-135 (1959).

Essential requirements for practical and effective method of relating land development to traffic generation. Recommendations made based on work carried out in New Haven, Conn. in connection with planning of Interstate Highway System.

118. McGrath, W.R., "Land Use Planning Related to Traffic Generation and Estimation." Proc., Inst. of Traffic Engineers, pp. 66-77 (1958).

Essentially the same as reference 117.

119. May, A.D., Jr., and Michael, H.L., "Allocation of Traffic to Bypasses." HRB Bull. 61, 38-58 (1952).

Time ratio, distance ratio, and cost index methods for diverting traffic compared to known diversion of traffic using two by-passes in Indiana. Cost index method shown to give best fit in these two cases.

120. Mayer, A.J., and Smock, R.B., "The Continuing Traffic Study: Methods of Keeping O-D Data Up-To-Date." HRB Bull. 253, 109-113 (1960).

Describes the continuing organization and its activities created as follow-up to Detroit Area Origin and Destination Survey of 1953.

121. Mayer, A.J., "Obtaining O-D Data at the Time of Driver's License Renewal." Preprint HRB Annual Meeting (Jan. 9-13, 1961).

Describes continuous sampling origin-destination survey proposed for use at time of driver's license renewal.

122. Mertz, W.L., Hamner, L.B., "A Study of Factors Related to Urban Travel." Public Roads, 29:170-174 (April 1957).

Analysis of effect of car ownership, population density, distance from CBD, and family income on number of vehicular trips made by residents of Washington, D.C.

123. Mertz, W.L., "A Study of Traffic Characteristics in Suburban Residential Areas." Public Roads, 29:208-212 (Aug. 1957).

Discusses effect that different types of suburban residential development has on traffic generation in Washington, D.C. area, using garden-type apartment development and subdivision of single family homes as basis for comparison.

124. Mertz, W.L., "Review and Evaluation of Electronic Computer Traffic Assignment Programs." HRB Bull. 297, 94-105 (1961).

Brief discussion of different assignment programs for electronic computers. Type of assignment, network size, and other factors appropriate to each program are listed.

125. Mitchell, R.B., and Rapikin, C., "Urban Traffic, A Function of Land Use." Columbia Univ. Press. (1954).

Study of relationships between land use and movement of persons, goods, and vehicles. Concepts formulated as basis for analytical framework for investigation of traffic and land use. Also briefly considered the investigation development, and testing of techniques and procedures for securing data. Suggestions for further study in limited segments of the problem.

126. Mladinov, J.K., and Hansen, R.J., "A Mechanized Procedure for Assignment of Traffic to a New Route." HRB Bull. 130, 59-68 (1956).

Machine methods of assigning traffic by travel time to proposed new route reviewed with special reference to their application in State of Washington.

127. Mortimer, W.J., "Transportation Usage Study." HRB Bull. 203, 47-51 (1958).

Objective of paper to present information aiding in assignment of traffic to arterial streets, expressways, and mass transportation facilities. Study designed to probe directly into attitudes and personal reasons involved in choice of mode of travel.

128. Mortimer, W.J., "Trends in Traffic Diversion on Edens Expressway." HRB Bull. 119, 1-38 (1956).

Diversion effects of Edens Expressway deduced by comparing screen line data obtained both before and after opening of expressway.

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