TRANSPORT INPUTS AT URBAN RESIDENTIAL SITES

A Study in the Transportation
Geography of Urban Areas

by

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We have carefully read the thesis entitled Transport Inputs at Urban Residential Sites : A Study in the Transportation Geography of Urban Areas. submitted by Duane Francis Marble in partial fulfillment of the requirements of the degree of Doctor of Philosophy and recommend its acceptance. In support of this recommendation we present the following joint statement of evaluation to be filed with the thesis.

This dissertation is an examination of factors which influence household-to-household variations in the use of transportation. Although there has long been great interest in this topic, the topic has not been previously subjected to a detailed and systematic examination. Information developed by this study will be of great value to persons engaged in planning and operating urban transportation systems.

The author examines available theoretical and empirical works, and attempts to articulate these somewhat diverse efforts. On the basis of this review three factors - the socio-economic structure of the household, the availability of transport to the household, and the spatial situation of the household's residential site - were set forth as possible determinants of the level of transportation use by the household. Detailed data on the travel patterns of individual households were then used to test the validity of these theoretical assertions. In light of the empirical findings the author presents a complex model of individual decision-making in space which includes specific suggestions for the direction of future research.

The thesis reading committee members regard this thesis as a creditable and thoughtful professional research effort and regard the findings as a significant contribution to knowledge.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TRANSPORT INPUTS AT URBAN RESIDENTIAL SITES

A Study in the Transportation Geography of Urban Areas

CHAPTER I

INTRODUCTION

The large urban center represents one of the highest levels of spatial organization observable today, and the maintenance of this level of organization is dependent upon the efficient functioning of the city's transportation system.[1] The flows of goods, people, and other less tangible items which take place within this system are a result of the high degree of specialization which characterizes our modern economic system.

Spatial agglomerations of people largely engaged in non-agricultural activities have existed for thousands of years, but the rapid urbanization of large portions of the western world has been a phenomenon of relatively recent years. Medieval towns were small and at first were bastions of defense or centers of administration for surrounding agricultural areas.

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[1]The importance of the role of transportation is pointed out in: Edward L. Ullman, "The Role of Transporation and the Bases for Interaction," in William L. Thomas, Jr. (ed.), Man's Role in Changing the Face of the Earth (Chicago: University of Chicago Press, 1956), pp. 862-880.

There were few problems of goods and persons' movements within towns.[2] By and large, there was no spatial separation of home and work, and people had few social contacts to draw them to other parts of the city.

Separation of home and work occurred when the new industrialism brought higher levels of specialization which, in turn, demanded the concentration of large masses of workers in a single location. As time passed, rapid technological advances taking place in transportation began to make themselves felt in segregation of land uses within the city. Workers no longer needed to live within walking distance of their places of employment, and residential developments grew up in areas at some distance from the older sections of the city.

As the city developed, the complex of areal specialization of activity, spatial segregation of land uses, and sheer size increased both the volume and the importance of the movement of persons and goods in the life of the city.[3] The

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[2]Although this was true in general, one case to the contrary might be cited. In ancient Rome traffic congestion grew so severe that Caesar in 46 B. C. restricted the use of streets during the daylight hours to the movements of persons. No goods carts were allowed into the city during the day, and those that had entered the previous night were compelled to remain stationary after dawn. See Jerome Carcopino, Daily Life in Ancient Rome (London: n.p., 1941), pp. 48-51.

[3]This growth has brought with it certain problems of congestion, standards of efficiency, etc. See Wilfred Owen, The Metropolitan Transportation Problem (Washington: The Brookings Institution, 1956).

nature of some of these flows, and the factors which condition them, have been the subject of study at various times.[4] However, most of these studies have been directed toward analysis upon a highly aggregative level, and the analysis of the behavior patterns of individual decision-making units has been largely neglected.

Households must undertake movements within the urban transport system because the maintenance of their very existence requires them to interact with spatially separated activities. The movements of the individual members of the household may be thought of as generating the transport inputs which are necessary for the continued functioning of the household.

While many of these movements tend to be routine and repetitive in nature, they represent the interactions which make the city a functional unit. Yet, despite their obvious importance, geographers have largely neglected them, and current information regarding their nature and the factors which condition them is slight.

The study reported upon here examines the factors which influence variations in the level of transport inputs from household to household. Chapter II contains a discussion of certain scattered and unarticulated theoretical constructs

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[4]See for instance: Jerome D. Fellmann, Truck Transportation Patterns of Chicago University of Chicago, Department of Geography, Research Paper No. 12 (September, 1950).

which bear upon the problem. A very limited number of empirical studies is available and Chapter III contains a review of their findings and an attempt to articulate them with the theoretical constructs reviewed in Chapter II.

As a result of the analysis of previous work three factors which influence the level of transport inputs are defined. In Chapter IV these factors are used in an effort to explain observed variations in the transport inputs to a sample of households in Cedar Rapids, Iowa. Chapter V contains a discussion of certain theoretical implications of the study, and present a tentative analysis of the decision-making process of the individual moving in space.

CHAPTER II

RELEVANT THEORETICAL CONSTRUCTS

The structure of transport inputs to individual households, or the demand for travel by consumers, has received little attention in the past. Theoretical constructs pertinent to this topic are few in number and, unfortunately, are generally not articulated with each other. This chapter contains a review of currently available theory and attempts, from this review, to construct an articulated theoretical structure.

Contributions of General Location Theory

General location theory represents an attempt to explain the influence of space upon various forms of human social and economic activity. The current status of the body of knowledge pertaining to this topic is summarized in recent works by Isard and Lefeber.[1]

The amount of specific information about patterns of individual behavior in space which may be obtained from this body of theory is unfortunately very small. However, general

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[1]Walter Isard, Location and Space-Economy (New York: John Wiley & Sons, 1956). Louis Lefeber, Allocation in Space (Amsterdam: North-Holland Publishing Co., 1958).

location theory does provide a set of organizing concepts which have proved invaluable in the past, and which we may well expect to be of considerable use in the present analysis. A review of these general concepts would be impractical in the present context, and therefore attention will be directed toward those portions of this body of theory which deal specifically with the topic of transport inputs to individual households.

Although emphasis in location theory has been upon models dealing with higher levels of aggregation than the individual decision-making unit, Isard does point out the operation of scale and substitution effects in determining patterns of consumer behavior.[2] He also emphasizes how little is known about individual behavior in space when he says:

> From the standpoint of society, however, when consumers are actively responsible for the transportation of the item, another set of transport inputs may be involved. If the consumers are other producers farther along in the stage of manufacture, then this transportation appears as transport inputs on raw material from a point source in these producer's calculations; and again no extension of our analysis is required. On the other hand, if consumers are households, we are not able thus far to account for the transport inputs for which they are actively responsible. To do so would take us into the realms of sociology and social psychology.[3]

Isard emphasizes here his idea that spatial relationships are not the only factors of importance in determining

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[2]*Op. cit.*, pp. 87-88.

[3]*Ibid.*, p. 144.

the level of transport inputs to a household or individual. Different individuals placed in the same spatial situation, with identical levels of information, may behave differently. Isard postulates that these differences in spatial behavior are associated with differences in the space preferences (desired levels of social contact) of the individuals. These space preferences are held to be determined by social and psychological factors exogenous to the spatial system.

Troxel's Theory of Demand

One exposition of the theory of the demand for travel by individuals is that presented by Troxel.[4] His analysis deals only with certain movement types, specifically regular patterns of person movements defined on the basis of the individual person or household. Among the movement types specifically excluded are those which are directly associated with the movement of goods, as well as movements for governmental and military purposes.

Basic to Troxel's discussion are four major concepts pertaining to the movement of persons. These concepts are: (1) the home as a base, (2) the round trip unit of travel, (3) the differentiation of travel purposes, and (4) recurring

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[4]Emery Troxel, Economics of Transport (New York: Rhinehart & Co., 1955), pp. 144-168.

patterns of movement. The demand for movement in space is viewed as originating in either a point or some other limited area in space. Many demand points exist either potentially or actually in any sizable land area, and convenient identifications such as home, farm, factory, etc., have been given to them. Home locations are common organization points in family and community life, and they are frequent reference points in the actual behavior of travelers. Thus, the home may be recognized as a basic starting and ending point in most journeys.

Given the concept of the home as the primary demand point in the movement of persons, travel is then expressed primarily in terms of round trip movements to and from this point. A person or household has a desire to go out from the home location and to return to it, and within this structure most trips by persons may be considered as round trip units of travel. It should be noted that the definition of a trip as posed by Troxel differs radically from most other definitions. To the traffic engineer and planner, a trip is commonly considered to consist of the movement between two stops made for the attainment of some purpose. Under this latter definition, a person going from home to a grocery store, hence to a drug store, and then returning home would be considered to have made three separate trips rather than one round trip with multiple stops.

The trip end points beyond the home afford a variety of products and services, and persons show a willingness to move different distances and to incur different time outlays for different end results. This has been observed empirically many times (see Table I). There seems to be a definite differentiation of travel purposes in terms of both frequency of occurrence and distance traveled.

Movement through space requires the expenditure of some amount of time by the traveler; an amount of time that varies with the distance traveled and mode of travel. Movement occurrences tend to be expressed repetitiously through successive time periods, and the week period appears to be a common one in family travel patterns.

The sources of the demand relation for movement are the products of being at home and not at home--the difference between what may be obtained away from home and what must be foregone at home and vica versa, since a person or household foregoes something that is obtainable at home during the amount of time used traveling away from the home location. In the following discussion it is assumed that residential locations are given, no distinctions are made between transport techniques, and no specific time period is designated.

The Total Travel Product

The total anticipated product of travel for a person or a household commonly varies with the total time that the

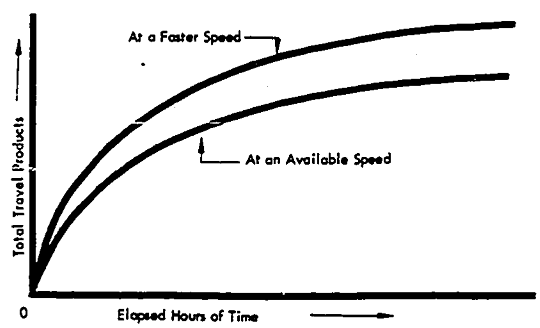
TABLE I

TRIP PURPOSES AND DISTANCES IN FOUR STATES*

Purpose	Average Trip Length (Miles)	Vehicle Miles (Percent)	Number of Trips (Percent)
Shopping	3.7	6.0	13.4
Educational, Civic, & Religious	5.0	2.8	4.6
To and From Work	5.9	22.7	32.2
Business and Farming	10.4	21.3	17.0
Pleasure Riding	13.0	14.1	9.0
Medical and Dental	15.5	2.5	1.3
Vacations	249.7	4.8	0.2
Other Purposes	--	25.8	22.3

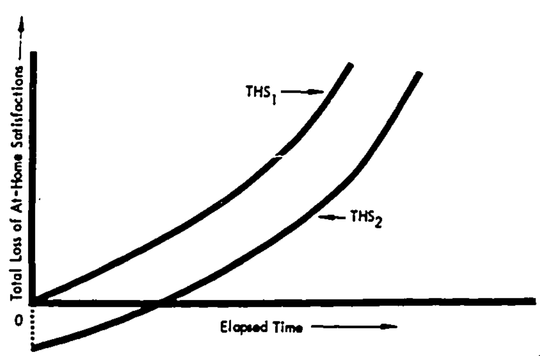
* Adapted from material in Thurley A. Bostick, Roy T. Messer, and Clarance A. Steele, "Motor-Vehicle-Use Studies in Six States," Public Roads, 28: 99-125, (1954).

person or family is absent from the home location. The total product of travel--the income from more hours of work, shopping bargains from more searching around, and the many other factors--increases as time away from home increases. But the total travel product, as suggested in Figure 1, presumably increases more slowly after some limit of elapsed time is reached. This decreasing amount of increase may be inferred in part from differences in travel purposes. In Figure 1 the order is from the largest to the least travel product per successive time unit, i.e., a maximum travel product is obtained at any limit of elapsed time. Taking the most productive purposes first and distributing his time and movement in some order of product expectation, the traveler comes to lesser purposes in the later time units. Decreasing amounts of total products may be inferred, too, from the probability of less satisfaction from successive time units that are devoted to the same travel purposes. As also illustrated in Figure 1, the speed of available movement affects the anticipated travel products in relation to the available travel time. A higher speed (or any other increase in the efficiency of the transport system) allows the traveler to achieve more purposes or to obtain more products within any trip purpose in a given time period.



Total Travel Products

FIGURE 1



Total Travel Losses

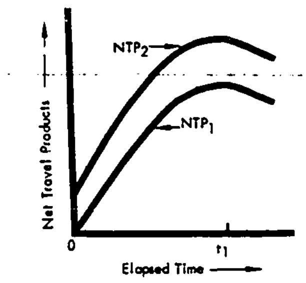
FIGURE 2

Deductions from the Total Travel Product

Implicit in the foregoing discussion is the idea of deductions from the total travel product. Traveling is not all profit; the traveler must deduct for losses of products or satisfactions which would be generated by remaining at home. This loss curve is displayed in Figure 2. In consequence of the rational behavior of the traveler, the curve of the losses in total satisfaction shows increasing amounts of increase as the elapsed time increases (it should also be recognized that to some persons there is a net loss in being too much at home--this is illustrated by the negative value of the first portion of the THS_2 curve in Figure 2). Other deductions must be made from the total travel product due to the effort involved in movement.

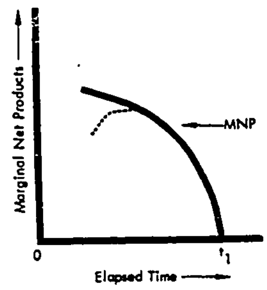
The Net Travel Product Schedule

Having established an aggregate travel product in an elapsed time relation as well as a function of deductions from the total travel product, it is now possible to combine them to produce a net product schedule. This net travel products schedule (shown in Figure 3) indicates that the traveler reaches an amount of elapsed time when further additions in travel involve decrements in the net product, and these decrements can increase as more time passes. From the net travel product schedule, the schedule of marginal net



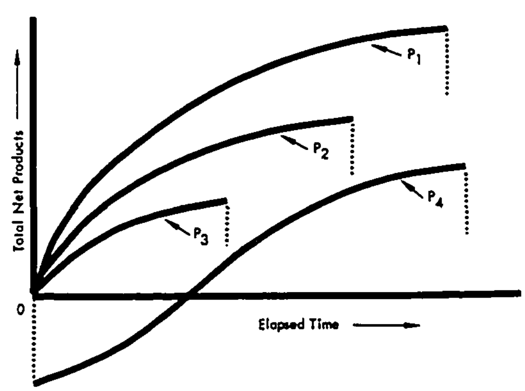
Net Travel Products

FIGURE 3



Marginal Net Products

FIGURE 4



Net Products of Various Trip Types

FIGURE 5

products (the first derivative of the NTP curve) is obtained (see Figure 4). This marginal product curve slopes downward, becomes zero, and passes on to minus values. This action on its part is indicative of the downward turn of the NTP curve after reaching some maximal point (t_1). The zero limit of the MNP curve is the equivalent of a zero price limit, i.e., beyond time t_1 the traveler must be paid to travel further. The curve of the MNP schedule conforms in its general shape to a travel demand schedule. If the product values are turned into prices of payment, the MNP curve becomes a traditional demand price schedule in units of elapsed time.

Referring again to Figure 1, it may be inferred that the marginal net product will increase as the available speed of movement increases. Increases in travel demands can be expected as more speed, more safety, etc., affect access to more net products per time period. The schedule of marginal net products is also a function of the spatial limits within which alternative movements can be chosen. If the limits of possible travel are restricted, then the marginal net product curve decreases, i.e., if the maximum radial distance beyond the home location is reduced successively, then the marginal net product values (travel demand) in units of elapsed time can be expected to decrease also. This effect follows because, within lesser spatial limits, the access to net products (or range of alternative choices) is reduced.

Differentiation of Total Net Products

The total net products of travel may be differentiated among various transport situations. For instance, there are possible differences between individuals, age groups, occupational groups, and so forth. Variations between purposes are also evident. Additional time is not used to one end if, as an expectation, it promises a larger addition to the net product in some other use. Thus, in terms of the elapsed time where the marginal net return equals zero, purposes are not expected to come out as equivalents. More adult time away from home commonly goes into employment or recreation than into medical care or luxury shopping (see Figure 5).

Relation of Distance to Elapsed Time

In the foregoing discussion, the term elapsed time was used to refer to time spent away from home, with only a portion of this time used in actual movement between locations. The elapsed time and the distance traveled are related, and a distance series of marginal net products may be conceived of for a single trip for a specific purpose. The traveler can project trip paths in several directions or in a round-about fashion beyond the home location. Any such path involves a discrete series of point locations, and any traveler may have many of these trip paths that contain sequential expectations of marginal net products. As many paths exist as travel purposes, combinations of purposes, and possible path locations--a very large, but still finite number.

From Troxel's discussion we may draw the following points: (1) there exists for each individual or household some amount of travel which will maximize the net returns to the individual or household involved, and (2) this optimum will be determined by (a) the position of the individual or household in the general spatial structure of the city, (b) the availability and, in the long run, the efficiency of the various modes of transport available, and (c) individual's or household's own level of wants. This latter notion is somewhat comparable to Isard's space preference concept which was discussed earlier.

A Short-run Traffic Model

Troxel introduces problems of cost and difficulty of movement into his theory only in an implicit manner as part of the total travel losses (see Figure 2). Recently, Beckmann formulated an explicit model of highway travel which dealt with: (1) the choice of individual free speeds, (2) the selection of routes, and (3) the demand for road transportation.[5] It is this latter with which we will concern ourselves here.

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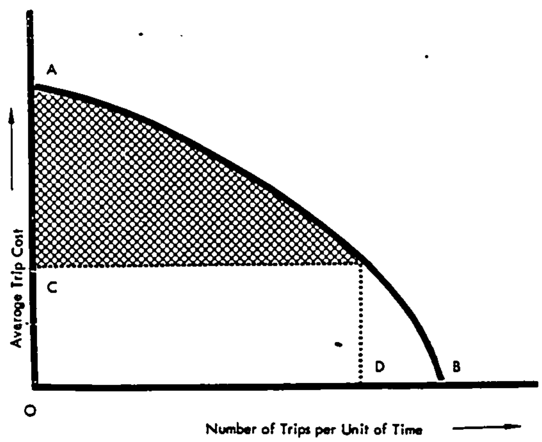
[5] Martin J. Beckmann, C. B. McGuire, and Christopher B. Winsten, Studies in the Economics of Transportation (New Haven: Yale University Press, 1956.

The demand for road transportation between a given pair of origins and destinations is assumed to be a function of the average trip cost between these locations. This assumption is based on observed behavior of individuals with respect to congestion levels, etc. The curve shown in Figure 6 indicates the number of trips per given time period which will be undertaken at various average cost levels. This, of course, is the general demand curve. In certain circumstances, when the number of trips is independent of traffic conditions (the journey to work might be a case in point), the demand may be described completely by fixed origin-destination figures. This demand curve (Figure 6) also indicates the total benefits derived by the population of road users at any given level of average trip cost (indicated in Figure 6 by the shaded area lying above the average cost line and below the demand curve).

From Beckmann's formulation we would conclude that, for some trips, the choice of destination is not independent of the condition of the system at the time the choice is made. In the short-run we would expect this to be reflected in either: (1) the substitution of alternate destinations, or (2) the postponement of the trip until a time period when a more attractive average cost level prevails.



Demand Curve for Travel Between Two Locations

FIGURE 6

A Simple Shopping Model

An individual decision model for a restricted class of trips was recently proposed by Baumol and Ide as part of their work on optimal variety in retailing.[6] Their model assumes that the shopper does not know (with certainty) whether he will obtain what he wants by shopping at a given store. It is further assumed that the greater the number of items stocked by the store, the greater is the customer's expectation of success. A function, denoted by p(N), is assigned to this expectation. The function varies between limits of 0 and 1, with a value of 1 representing certain foreknowledge of success, and a value of 0 representing certain foreknowledge of failure.

In travelling to, and shopping at, some particular store, the customer incurs certain costs. If the distance of the consumer from the store is given by D, then it may be assumed that costs of movement are strictly proportional to D. Total movement costs in this case would be given by C_dD, where C_d is a constant. Once he has arrived at the store the consumer is faced with the fact that while his probability of success increases with the number of items stocked, so does the difficulty of shopping. This difficulty is an additional cost, which is

[6] William J. Baumol and Edward A. Ide. "Variety in Retailing," Management Science, 3: 93-101 (October, 1956).

assumed to be directly proportional to the square root of the number of items stocked (the cube root if a multi-story building is involved). This additional cost is given by the term $C_n\sqrt{N}$. Finally, there are costs which do not vary with either the number of items stocked or the distance of the consumer from the store. The total of these opportunity costs is given by C_i. Thus the total costs of shopping are given by the sum of the three classes of cost, i.e., by

$$C_dD + C_n\sqrt{N} + C_i$$

This sum could be regarded as being roughly equivalent to Troxel's total travel losses (see Figure 2).

In this simple shopping model a consumer will shop at a given store only if, for that store, the function:

$$f(D,N) = wp(N) - v(C_dD + C_n\sqrt{N} + C_i)$$

is positive. The terms w and v in the above function represent subjective weights which are assigned to each group of factors by the consumer.

Summary

The four theoretical constructs pertaining to transport inputs of individuals or households which have been reviewed here are taken from widely scattered sources, and were apparently developed independently. Despite this lack of formal articulation, they seem to fit together fairly well. General location theory, while devoting little attention to the behavior of the individual decision-making unit, does recognize the importance of spatial location as well as certain social and psychological factors (space preference) in determining individual behavior in space.

Troxel provides the most comprehensive treatment of the individual's demand for travel, and from his work we draw the notion of an optimum level of transport inputs as well as certain suggestions regarding the factors which determine the location of this optimum. Beckmann points out the importance of the status of the transport network as a factor in travel decisions, and Baumol and Ide present a simple and explicit model of factors entering into consumer decisions regarding shopping trips.

A limited number of empirical studies are available which may be used to test these ideas against the real world. The following chapter reviews these studies and attempts to relate them to the theoretical constructs presented here.

CHAPTER III

RESULTS OF PREVIOUS EMPIRICAL STUDIES

The problem of providing for the regular and recurrent movement of goods and persons from place to place within the city is an extremely complex one. Information on this topic is needed by planners and others in order to answer urgent questions relating to the optimal location and scale of projected improvements in the urban transport system. The pressing need for solutions has brought about numerous studies pertaining to the movement of persons within the city, and from this multitude of studies it is possible to select a much smaller number which bear directly upon the topic at hand.

This chapter reviews several of the more important of these studies, and attempts to articulate their findings in light of the theoretical constructs reviewed in the previous chapter.

Urban Travel Prediction Studies

Most of the studies undertaken for purposes of predicting future levels of traffic flow in urban areas have been concerned with providing traffic forecasts through the detailed examination of existing movement patterns. These investigations, commonly known as origin-destination studies, have utilized large scale sample survey methods to determine the characteristics of traffic flow between different areas of the city. Area-to-area movement counts are made of persons or vehicles, and are usually cross-classified by type of movement (private automobile, transit, etc.) and generalized trip purposes (such as those used in Table I). The results of these surveys are normally presented in tabular or graphic form with little or no attempt at analysis of the observed flow patterns.[1]

Large amounts of time and money have been poured into the operation of these studies during the past fifteen years, and it is indeed unfortunate that the value of the information obtained has not been as high as was originally hoped. Recently, while discussing the results of the 120 origin-destination studies conducted to date, Curtiss remarked that:

> While providing accurate and useful patterns of present travel, many have fallen short of their potential value in providing means of gauging the future, not because of failure of the data but rather because of limitations in the scope and methods of analysis.[2]

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[1]A more detailed discussion of the characteristics of origin-destination studies may be found in: Robert E. Barkley, Origin-Destination Surveys and Traffic Volume Studies (Washington: Highway Research Board, 1951).

[2]C. D. Curtiss, "Urban Highway Planning: Its Increasing Importance," Traffic Quarterly, 11: 450 (October, 1957).

Since these studies impose severe restrictions upon the way in which a trip may be counted (e.g., it may not have more than one purpose), it certainly seems possible that their ability to provide accurate statements regarding present travel patterns also may be questioned.

In the past few years a new type of study has grown up to take the place of the somewhat questionable origin-destination study. These new studies are known as metropolitan area transportation studies, and they operate by examining the entire transportation complex of some urban area (e.g., Chicago) in an attempt to associate levels of traffic flow with various types of land use. Prediction of future movement levels is then attempted by means of land use forecasts, rather than through direct estimation of future traffic levels.[3] While the attempt to associate traffic levels with land uses undoubtedly represents an improvement over the pure description of the origin-destination studies, the lack of theoretical orientation still leaves a great deal to be desired.

While most urban traffic has its ultimate origin and destination in the residential areas of the city, very little attention has been given to the study of either the characteristics of the traffic moving to and from these areas, or to the traffic

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[3]For instance see the Report on the Detroit Metropolitan Area Traffic Study, Parts I and II (Lansing: Michigan State Highway Department, 1956).

generating characteristics of the areas themselves.[4] The analytic studies of the latter topic which have been undertaken are few in number and, generally, are unarticulated with either theory or each other.

Gardner's Study of Baltimore

In 1949 Joseph Gardner examined twelve residential areas within the city of Baltimore in the hope of discovering some association between gross patterns of movement from the areas and the general characteristics of the areas.[5] The study areas were selected so as to represent six neighborhood types ranging from blighted areas near the central business district to outlying areas of high residential quality. Traffic flows were tabulated by area in terms of distribution by trip purpose and mode of travel, as well as by total volume of movement. The movement information was obtained from an origin-destination study of Baltimore and, as such, did not include trips made on foot. After tabulation, the traffic flows were compared with the characteristics of the generating areas to determine what associations existed.

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[4]A notable exception in the case of the first topic, is the recent study by Edward M. Hall, "Travel Characteristics of Two San Diego Subdivision Developments," in Travel Characteristics in Urban Areas (Washington: Highway Research Board, forthcoming).

[5]Joseph Gardner, "A Study of Neighborhood Travel Habits in Baltimore, Maryland" (unpublished Master's thesis, Cornell University, 1949).

The author concluded on the basis of his examination that (1) the number of work trips per resident was fairly constant from neighborhood to neighborhood, but that the number of trips made for other purposes tended to increase in proportion to the wealth of the neighborhood, (2) population characteristics such as age and occupational structure tended to have quite noticeable associations with variations in travel patterns, and (3) the total number of trips per resident increased as distance from the central city increased. The latter association seemed to be relatively independent of the economic classification of the neighborhoods involved.

While Gardner did not attempt to use any of the powerful tools of statistical inference in his study, the results which he has reported seem to be consistent with the tabulations he presents. The increase in the frequency of vehicular trips with increasing distance from the CBD might be attributed to a decrease in the number of walking trips--a point which seems to have escaped Gardner. While the use of statistical methods would have strengthened the study, it does represent the first attempt to associate the volume of traffic generated in a given residential area with selected characteristics of the area.

Hamburg's Study of Detroit

Utilizing information collected by the Detroit Metropolitan Area Traffic Study, a study was recently conducted which examined the relationship of vehicular trip frequency per dwelling place to several factors.[6] These factors included: the logarithm of the airline distance to the central business district, household income, family size, automobile ownership, and residential density of the neighborhood. All household information was imputed from sub-zone and census tract data. For instance, trips per dwelling place was obtained by dividing the total trips from a small area by the number of dwelling places in the area. Values of other variables were obtained in a similar fashion.

Multiple regression analysis was used to examine associations between variables. The author found trip frequency per dwelling place to vary in a systematic manner with the measures of residential location, family size, and automobile ownership. Measures of residential density of the neighborhood and family income were not significantly associated with trip frequency. The significant degree of association between vehicular trip frequency and residential location reported by this study (see Figure 7) represents an extremely interesting finding, but because of the elimination of walking trips it cannot be related to any of the available theoretical constructs.

<u>Mertz and Hamner's Study of Washington, D. C.</u>

A study similar to that undertaken by Hamburg in Detroit was recently completed in the Washington, D. C. area by

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[6]John R. Hamburg, "Some Social and Economic Factors Related to Intra-City Movement" (unpublished Master's thesis, Wayne State University, Detroit, 1957).

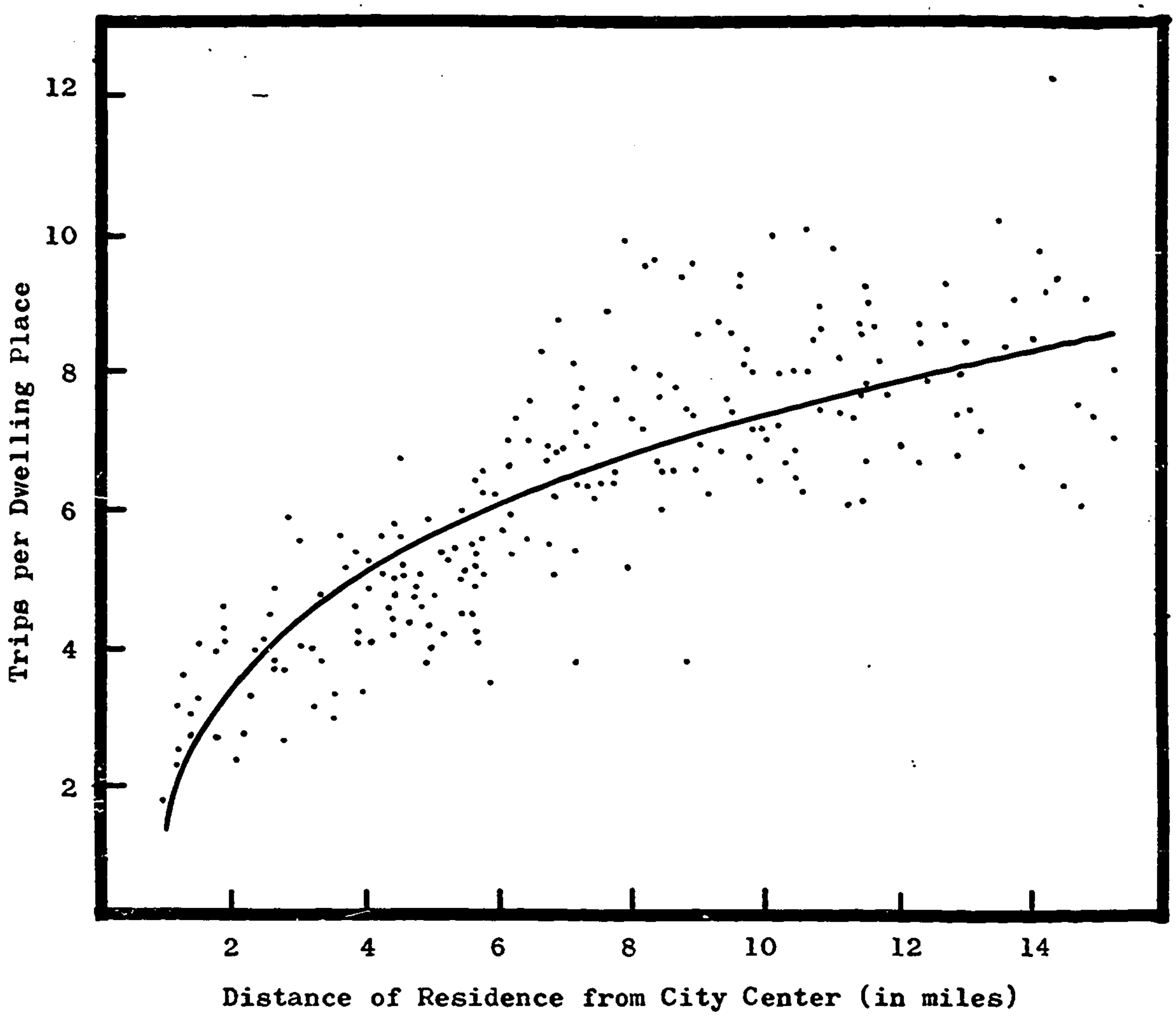

FIGURE 7

EFFECT OF DISTANCE OF RESIDENCE FROM CITY CENTER ON AVERAGE TRIP FREQUENCY PER DWELLING PLACE, DETROIT, MICHIGAN

Source: John R. Hamburg, "Some Social and Economic Factors Related to Intra-City Movement" (unpublished Master's thesis, Wayne State University, Detroit, 1957), p. 13.

the Division of Highway Transport Research of the Bureau of Public Roads.[7] Multiple regression analysis was again used to examine the associations between vehicular trips per dwelling unit, automobile ownership, population density, household income, and distance (presumably airline distance) from the central business district. Household characteristics were imputed from small area data in a manner similar to that employed in the Detroit study.

The distance and income factors did not prove to be statistically significant in this study, and population density was of doubtful value. The measure of the level of automobile ownership (automobiles per household) proved to be highly significant, and the authors concluded that this factor alone explained most of the observed variation in trip frequencies. Linear relationships were assumed throughout the study, although an examination of the scatter diagram strongly suggests the possibility of a nonlinear relationship in the distance factor (see Figure 8).

The three studies just reviewed have several shortcomings from the viewpoint of the present investigation:

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[7] William L. Mertz and Lamelle B. Hamner, "A Study of Factors Related to Urban Travel," Public Roads, 29: 208-212, April, 1957. Additional information on this study may be found in: Gordon B. Sharpe, Walter G. Hansen, and Lamelle B. Hamner, "Factors Affecting the Trip Generation of Residential Land-Use Areas," in Travel Characteristics in Urban Areas, op. cit.

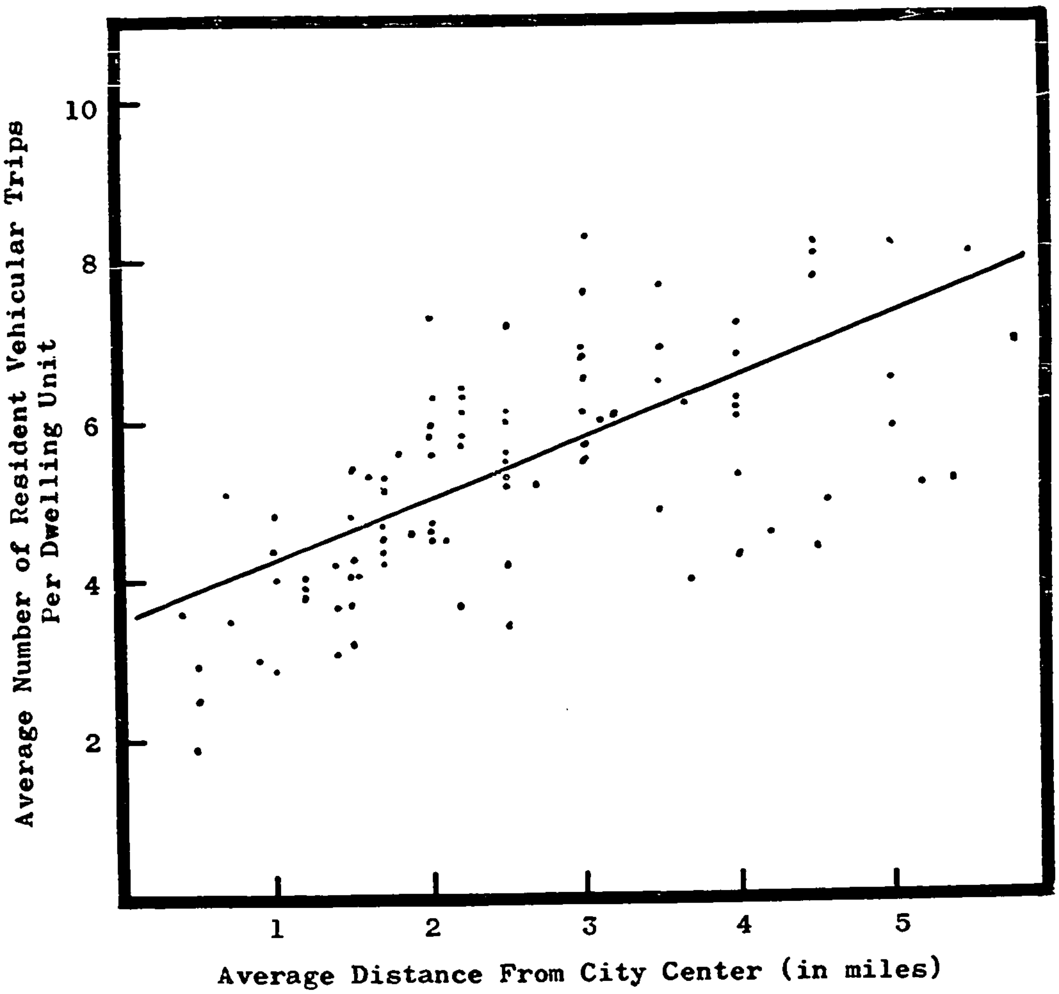

FIGURE 8

RELATION OF RESIDENT VEHICULAR TRIPS TO DISTANCE OF RESIDENCE FROM THE CENTRAL BUSINESS DISTRICT, WASHINGTON, D. C.

Source: William L. Mertz and Lamelle B. Hamner, "A Study of Factors Related to Urban Travel," Public Roads, XXIX (April, 1957), p. 171.

(1) all three studies utilized vehicular trips as a measure of traffic generation, (2) none of the studies utilized actual household data (household values in the last two studies were averages imputed from small area data), and (3) the only measure of residential location used was airline distance from the central business district. While some of the results reported by these studies are quite suggestive, none of the studies, as formulated, provides an adequate basis for testing current theory.

Socio-Economic Forces and Travel

The earlier review of available theory pointed out some possible relationships between individual travel patterns and non-spatial factors (e.g., Isard's space preference concept). Several empirical studies have examined the relationship of certain socio-economic factors to household travel, and their results indicate that these factors are of some importance in the analysis of transport inputs to the household.

The Virginia Studies

In 1951 the University of Virginia, in cooperation with the Virginia Department of Highways and the U. S. Bureau of Public Roads, undertook an examination of the relationships existing between certain socio-economic characteristics and the travel patterns of households in Charlotte County, Virginia.[8] Six factors were selected for analysis. These were: (1) family income, (2) socio-economic status of the family, (3) value of wheeled motor equipment, (4) cycle status of the head of the family, (5) type of farming by major source of income, and (6) economic land class of the farm on which the household resided.

On the basis of the investigations conducted in Charlotte County, it was concluded that (1) both trip frequency and total weekly mileage were related to family income level in a non-linear fashion (see Figures 9 and 10), (2) as the socio-economic status of the household increases the average number of trips per day and the average daily mileage rises, and (3) the amount of travel seems to be directly related to the composition of the family group.

These results would seem to indicate that socio-economic factors do exert a significant influence upon household travel patterns. This conclusion is supported by the results of another recent study which examined the long distance movements of households for recreational purposes.[9]

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[8] University of Virginia, Bureau of Population and Economic Research, The Impact of a New Manufacturing Plant Upon the Socio-Economic Characteristics and Travel Habits of the People in Charlotte County, Virginia, preliminary edition (Charlottesville: University of Virginia, 1951).

[9] Richard E. O'Brien, Socio-Economic Forces and Family Pleasure Travel (Jefferson City: Missouri Division of Resources and Development, 1958).

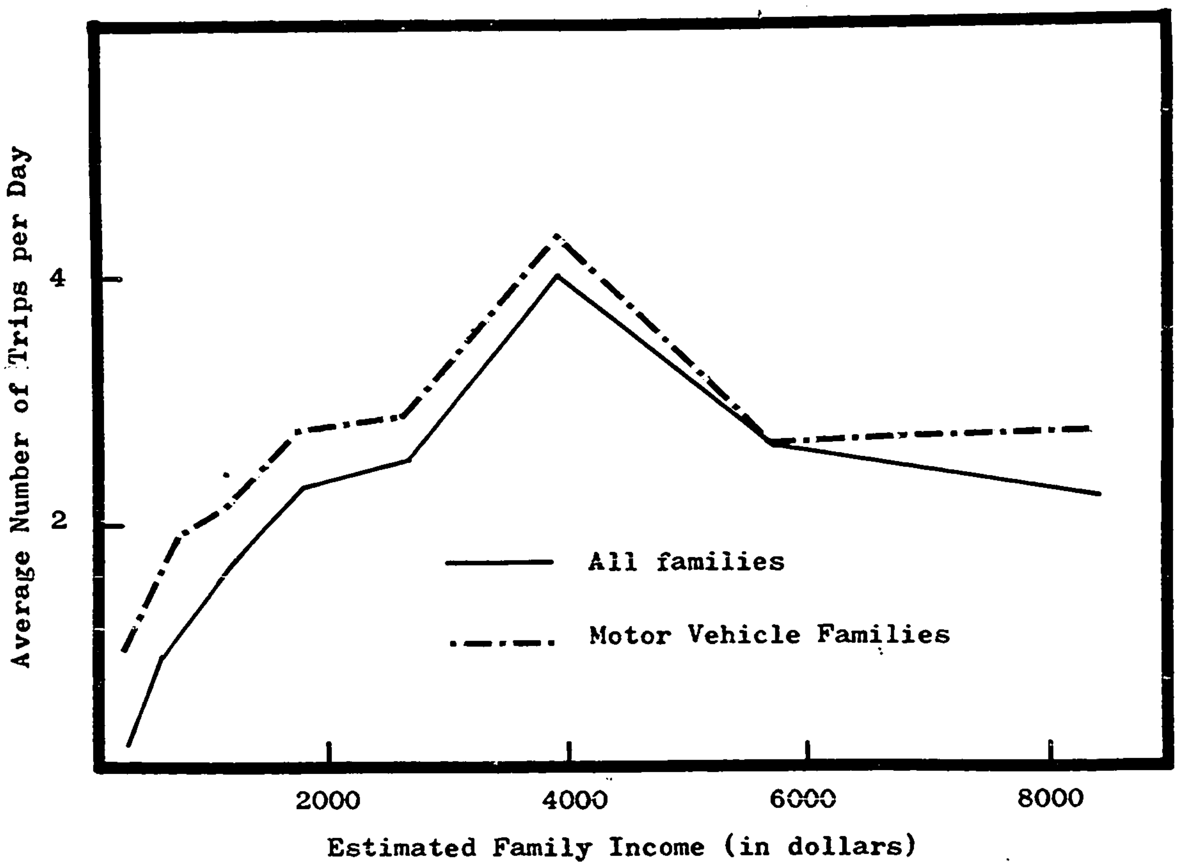

FIGURE 9

AVERAGE NUMBER OF TRIPS PER DAY FOR HOUSEHOLDS CLASSIFIED BY ESTIMATED FAMILY INCOME, CHARLOTTE COUNTY, VIRGINIA

Source: University of Virginia, Bureau of Population and Economic Research, The Impact of a New Manufacturing Plant Upon the Socio-Economic Characteristics and Travel Habits of the People in Charlotte County, Virginia, (Charlottesville: University of Virginia, 1951), p. 22.

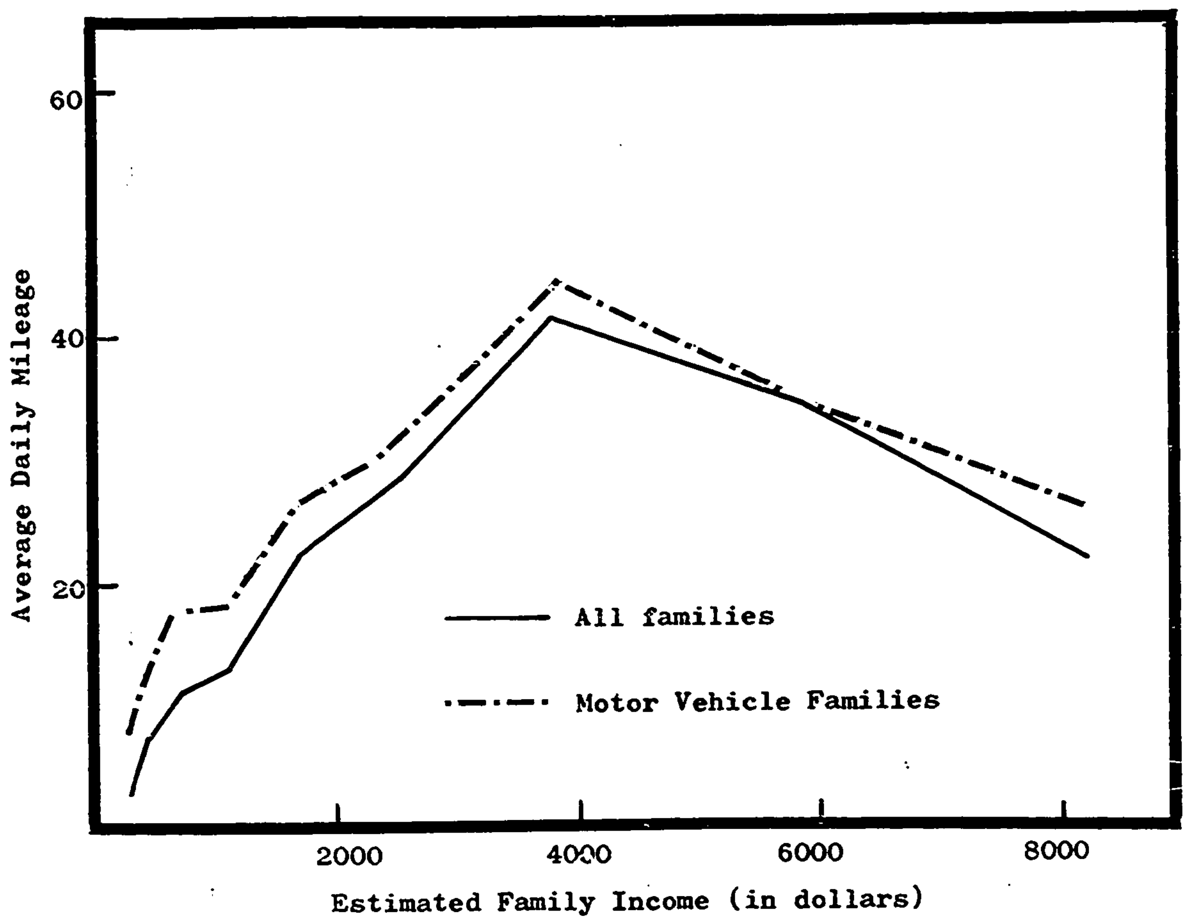

FIGURE 10

AVERAGE DAILY MILEAGE FOR HOUSEHOLDS CLASSIFIED BY ESTIMATED FAMILY INCOME, CHARLOTTE COUNTY, VIRGINIA

Source: University of Virginia, Bureau of Population and Economic Research, The Impact of a New Manufacturing Plant Upon the Socio-Economic Characteristics and Travel Habits of the People in Charlotte County, Virginia, (Charlottesville: University of Virginia, 1951), p. 22.

Jonassen's Study of Shopping Satisfaction

In a series of studies conducted in Columbus, Ohio; Seattle, Washington; and Houston, Texas, Jonassen examined the relationships between selected socio-economic factors and degree of shopping satisfaction for a sample of households.[10] Such factors as age, sex, duration of residence, occupation, and an overall socio-economic status score were examined in their relation to shopping behavior of the sample households.

While much of the study is of little interest in the present context, the author did conclude that persons differing as to such items as education, income, occupation, urban-rural background, etc., differ also in their use of and their attitudes toward the CBD and suburban shopping centers.

The results of these studies would seem to indicate that variations in the socio-economic structure of the household are associated with concomitant variations in the transport inputs to the households. This supports certain of the theoretical arguments reviewed in the previous chapter.

Consumer Behavior in Space

The empirical studies reviewed thus far have examined only in passing, if at all, the influence of consumer location

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[10] C. T. Jonassen, The Shopping Center Versus Downtown (Columbus: Ohio State University, Bureau of Business Research, 1955).

with reference to the general spatial system upon patterns of consumer behavior in space. The two urban travel prediction studies which utilized residential location as a variable related the location of the household to only one sector of the urban space-economy--the central business district. One series of studies, conducted in rural areas of Washington State, utilizes a wider framework, and provides some interesting insights on the relation of trip frequency to residential location.

The Washington State Studies

In 1954-55 Garrison conducted a study which examined the relationship of household travel patterns to the value of parcels of rural property in three Washington counties.[11] During the course of this study the associations between road-location and trip frequency of the sample households were examined.[12]

Using travel data collected from the sample households, trip frequency was compared with the length of trip through

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[11]William L. Garrison, The Benefits of Rural Roads to Rural Property (Seattle: Washington State Council for Highway Research, 1956).

[12]This arose out of the need to justify the use of a single equation model in the land value studies. A more extensive discussion of this problem may be found in the following chapter, and in: William L. Garrison, Brian J. L. Berry, Duane F. Marble, John D. Nystuen, and Richard L. Morrill, Studies of Highway Development and Geographic Change (Seattle: University of Washington Press, forthcoming).

the use of multiple regression analysis. Differences in road type were introduced into the model through the use of a separate term in the regression for each type of road. The measurement model had the general form:

$$\log F = \alpha + \sum \beta_i (\log x_i + 1)$$

where: F = trip frequency (trips per week)

α = a constant term

x_1 = distance via paved roads to the usual terminus of a trip type (distance in miles)

x_2 = distance via gravel surfaced roads

x_3 = distance via dirt roads

and the β's are the parameters to be estimated.

The postulated relationship between trip frequency, length of trip, and road type was examined in 18 cases. Each case was defined by one of the five types of trip, and each trip type was defined by two or more study areas. The results of the computations are displayed in Table II. An examination of these results indicates that the analysis failed to find significant relationships between: (1) trip frequency and distance to trip termini, and (2) trip frequency and the type of road over which the trip is taken.

Garrison concluded that the propensity to travel, at any given time, is distributed among households without any apparent relationship to the type of road service locally available, and that the frequency of shopping is independent

TABLE II

RELATIONSHIPS BETWEEN LENGTH OF TRIP, TYPE OF ROAD USED, AND TRIP FREQUENCY

County	Estimate of β_1			Power of the Model[a]
	b_1	b_2	b_3	
Usual Household Shopping				
Snohomish				
farmers	-.120	-.037	n.c.[b]	3.8
non-farmers	-.446	-.012	n.c.	26.3
Chelan				
farmers	-.141	-.093	n.c.	5.7
non-farmers	-.112	.042	n.c.	0.8
Douglas				
farmers	.012	.000	.001	6.2
Shopping Goods Shopping				
Snohomish				
farmers	-.070	.023	n.c.	0.9
non-farmers	-.038	.052	n.c.	1.1
Chelan				
farmers	-.071	-.061	n.c.	2.1
non-farmers	.032	-.198	n.c.	6.5
Douglas				
farmers	.456**	.068	.066	65.6
Amenity Travel				
Snohomish				
farmers	-.222*	-.116	n.c.	11.4
non-farmers	-.186	-.088	n.c.	6.0
Chelan				
non-farmers	-.095	-.038	n.c.	3.6

Source: Adapted from William L. Garrison, <u>The Benefits of Rural Roads to Rural Property</u>, <u>op. cit.</u>, p. 80.

* Significant at the 5 percent level.

** Significant at the 1 percent level.

a $R^2 \cdot 100$, where R^2 is the multiple correlation coefficient.

b Where b_3 was not computed, values of X_3 were combined with X_2: $(X_2+X_3=X_2)$.

of the distance from the shopping center, although the place visited is a function of the distance traveled.

Summary

The lack of articulation of these studies renders any attempt to relate their findings to current theory extremely difficult. Of the theoretical and empirical studies reviewed here, only one makes any mention of the others. These studies have suggested three measures of transport inputs to the household: (1) trips per time period, (2) time spent away from home during a given time period, and (3) the total distance traveled during a given time period. This threefold classification will be used to organize the reported results of the empirical studies discussed in the present chapter.

Trip Frequency

One of the main concerns of the empirical studies reviewed here has been the explanation of household-to-household variations in trip frequencies. Most of the studies have dealt with vehicular trips exclusively and, because of this emphasis, it is difficult to extend their conclusions to cover the total trip structure. The study by Garrison represents the one exception since the nature of the study area as well as the particular structuring of trips by purpose serves to minimize the importance of non-vehicular trips.

Residential location. The attempts of these studies to relate variations in trip frequencies to variations in the location of the residence differ only in their level of complexity. Two of the three studies which considered residential location used a single term which related residential location to the CBD while the other, conducted in a rural area, related residential location (by trip purpose) to the trip terminus most frequently visited. The reported results are somewhat conflicting, but tend toward a general conclusion that trip frequency shows no significant variation with variations in residential location.

Isard's space preference concept (discussed in Chapter II) was defined as the individual's desired level of social contact. It is possible to view this desired level of contact as expressed in terms of a given contact frequency. If this were so, we would expect variations in trip frequency to be associated with variations in non-spatial factors. These studies offer some support to this view through their failure to find significant associations between variations in trip frequency and variations in residential location.

Socio-economic factors. It is unfortunate that those empirical studies which examined the effects of residential location did not also examine the effects of various socio-economic factors, and vice versa. However, sufficient evidence seems to be at hand to indicate that variations in certain socio-economic factors are associated with variations in trip frequency, although the nature of the association is far from clear.

Trip Duration

No analysis of trip duration was included in any of the empirical studies reviewed here, and no study has come to the attention of the author which contains any such analysis.

Total Distance Traveled

None of the studies reviewed examined the relationship of residential location to the quantity of passenger-mile inputs to the household, and the author knows of no study which deals with this relationship. While one study did examine the relationship of socio-economic structure to household trip mileage the results reported were indeterminant.

CHAPTER IV

EMPIRICAL STUDIES IN CEDAR RAPIDS, IOWA

This chapter reports upon a series of empirical studies designed to examine existing associations between alternate measures of transport inputs to households, and three factors which theory holds to be important in determining the level of these transport inputs.

The resources available for this study did not permit the extensive field work necessary to obtain detailed information upon household behavior patterns in space, and as a result, it became necessary to use data which were already in existence. Only two sets of data were known to exist which would be suitable for the purposes of the present study. One study, conducted in 1946, examined the travel patterns of 1,300 households in Fort Wayne and Allan County, Indiana, for one day. The second study, conducted in 1949, examined the travel patterns of 256 households in Cedar Rapids and Linn County, Iowa, over a thirty day period. Both studies were conducted by a private research organization engaged in studying the impact of outdoor poster advertising.[1]

Through the generous cooperation of the Traffic Audit Bureau, Inc., and the Outdoor Advertising Association of America, Inc., both sets of data were made available for analysis. The Cedar Rapids data were selected for primary analysis since they provided information over a thirty day time period, and it was thus possible to derive estimates of transport inputs with a greater degree of precision.

The Study Area

Cedar Rapids is located in Linn County, Iowa, in the east-central portion of the state (see Figure 11). At the time of the travel study (1949) the population within the corporate city limits was about 72,000; representing some 69 percent of the total SMA population. With the exception of Iowa City, twenty-six miles to the south (population about 27,000), there is no other large or medium sized town for seventy to a hundred miles in any direction. The city serves as the central market point for a productive agricultural region; however, manufacturing is an important part of the city's economic structure with some 200 firms employing a total

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[1]The results of these studies which pertain to the impact of outdoor advertising are reported in: Traffic Audit Bureau, Methods for the Evaluation of Outdoor Advertising (New York: Traffic Audit Bureau, 1947); and Traffic Audit Bureau, Coverage, Repetition and Impact Provided by Poster Showings (New York: Traffic Audit Bureau, 1950).

FIGURE 11

LOCATION OF THE STUDY AREA

of nearly 21,000 persons. The manufacturing is fairly diverse, with food processing, manufacture of electrical equipment, and the production of heavy farm and construction equipment representing the more important sectors.

The city exhibits a fairly simple land use pattern (see Figure 12) which is complicated only by the passage of several major railroads through the city. The distribution of population (as indicated by the distribution of dwelling units in Figure 13) shows a fairly regular clustering about the central portion of the city, with only a sparse distribution in the outlying areas. In some ways, these patterns may be too simple and too regular. A larger urban area, exhibiting a more highly integrated spatial structure, might have been more suitable for the purposes of the present study. Since travel information is not available for other cities, this comment is really more pertinent to future studies than the present one.

Survey Methods in Cedar Rapids and Linn County[2]

Two schedules were used in the collection of information from the sample households (see Appendix A). The first dealt

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[2]Information contained in this section is largely drawn from unpublished records of the Traffic Audit Bureau, Inc. This information was made available to the author through the generous cooperation of Mr. Victor Pelz, director of TAB.

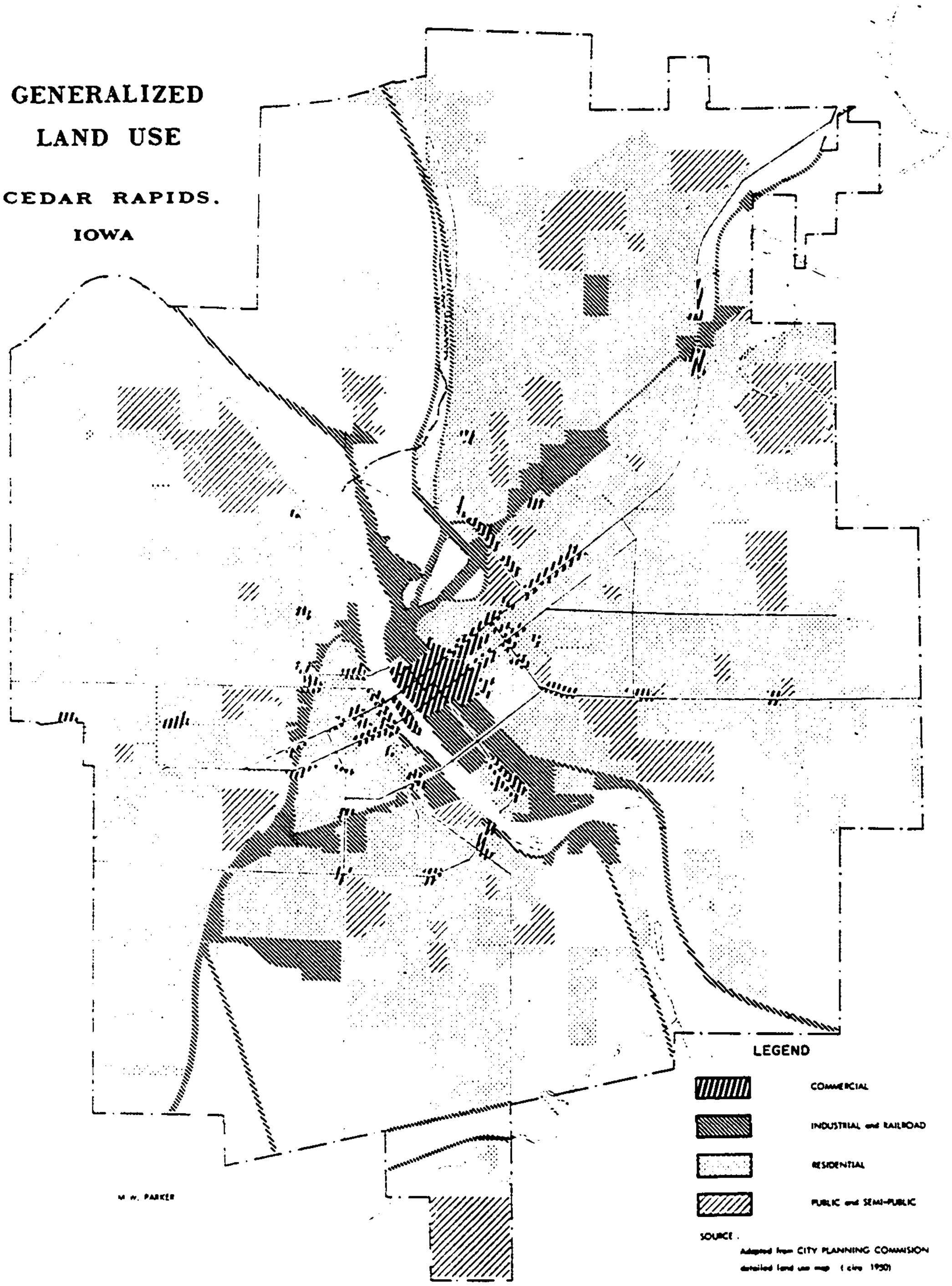
GENERALIZED
LAND USE
CEDAR RAPIDS,
IOWA
LEGEND
COMMERCIAL
INDUSTRIAL and RAILROAD
RESIDENTIAL
PUBLIC and SEMI-PUBLIC
SOURCE.
Adapted from CITY PLANNING COMMISION
detailed land use map (circa 1950)
M. W. PARKER

FIGURE 12

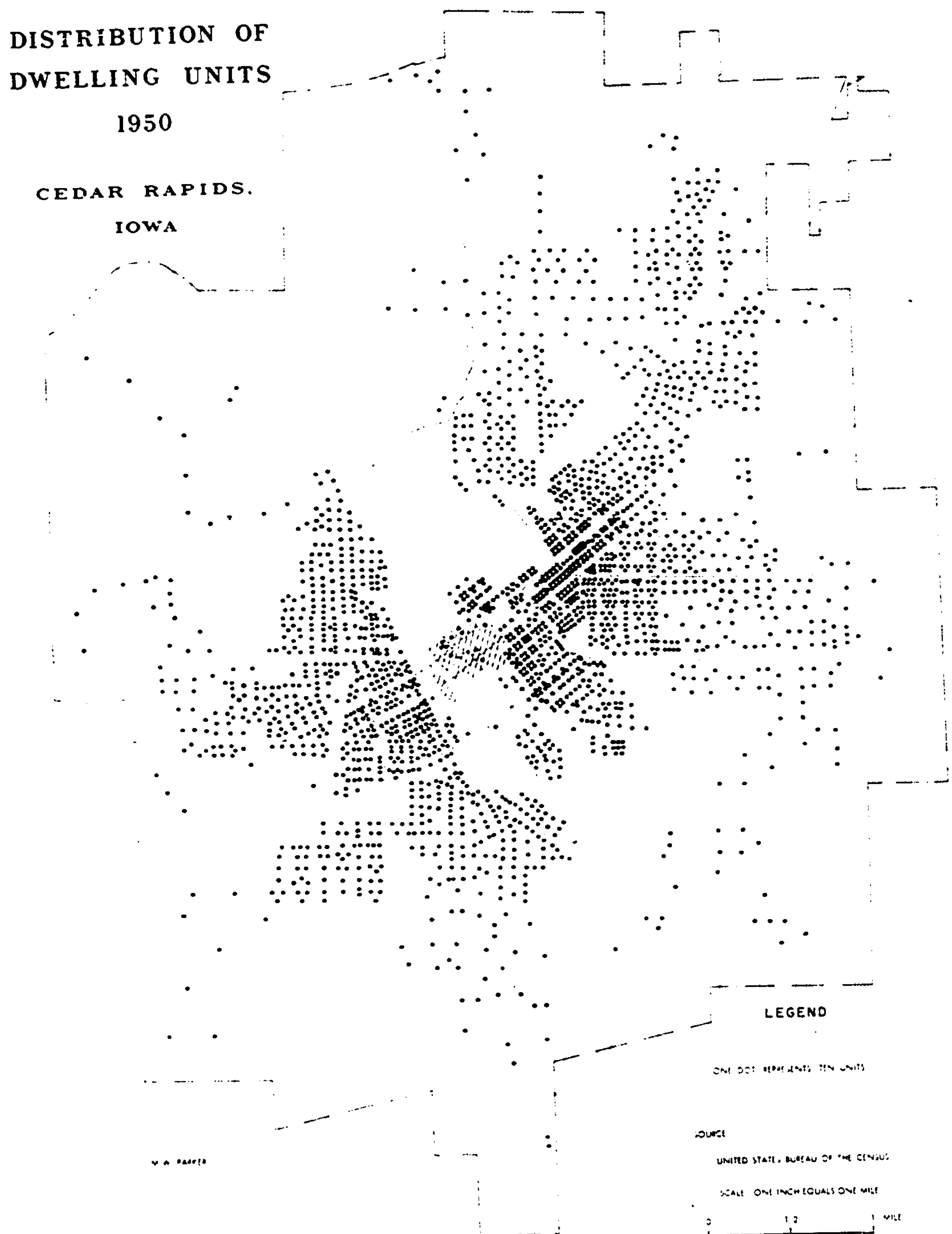
DISTRIBUTION OF
DWELLING UNITS
1950
CEDAR RAPIDS,
IOWA
LEGEND
SCALE ONE INCH EQUALS ONE MILE
0
1/2
1 MILE
0
2000
4000
FEET

FIGURE 13

with the socio-economic characteristics of the sample household and included such items as family composition, educational levels, automobile ownership, and family income. The second was designed to report upon the characteristics of a single trip, and such items as time of origin and return, trip purposes, mode of travel, route followed, and addresses of all stops were included. All persons ten years of age or older in the sample households filled out one of the second schedules for every trip they made during the thirty day study period. All field work was carried out by staff members of the firm of Alderson and Sessions.

Sample Design

A minimum sample of 256 households was established for the study on the basis of this figure being close to one percent of the estimated number of households in Linn County in 1949. This minimum total of 256 households was then allocated to Cedar Rapids proper, rural farm, and rural nonfarm (including the town of Marion) on the basis of the estimated number of dwelling units. The sample was based on the R. L. Polk Co. *City Directory for Cedar Rapids*, dated 1947. This information was updated with additional information provided by the city engineer to include new dwellings constructed up to April 1, 1949.

Since this survey required informants (including every member of the household ten years of age and over) to keep records of all travel (by all modes, including trips on foot) for 30 consecutive days, it was necessary to provide for a sizable shrinkage caused by families who would start to keep records but who would drop out before the 30 days were over. This problem was met by starting with a sample of 308 instead of 256. It was also recognized that many families would refuse to even start a 30 day consecutive record. This problem was met by drawing two samples of 308 each and pairing on a map each family in the first sample with the nearest family in the second sample. A refusing family in the first sample was replaced by the paired family in the second sample. The rate of refusals in the first sample was approximately 16.6 percent, but in no case did the second family of a pair refuse. Actually there were 262 households in which all members completed the full 30 day record. Since the total of 262 households was not distributed properly in the three categories (Cedar Rapids, rural farm, and rural nonfarm), six families were selected at random to be dropped from the final sample.

In selecting dwelling units to be included in the sample, every dwelling unit was given an equal chance of coming into the sample. The household selected from the list of addresses was chosen by taking every _n_ th address after a starting point had been selected from a table of random numbers. The same procedure was followed for selecting dwelling units in the areas of new construction. In both cases the address was used as the sampling unit even though the city directory furnished a name as well as the address. Similar methods were used to select dwelling units located outside the corporate city limits of Cedar Rapids.

Interviewing

Street addresses of households for the interviews in Cedar Rapids were assigned to each interviewer. In the event that the household from the first sample refused to participate, the interviewer then approached paired households from the second sample. Interviewers were instructed to make whatever call-backs were necessary to contact the households in the first sample before approaching the second sample household.

The purpose of the survey was explained as one designed to secure information over a consecutive thirty day period as to where people travel. Interviewers were instructed to answer questions of respondents fully and freely. While the fact that the survey was being done on behalf of outdoor advertising was not volunteered by the interviewers, this explanation was freely made if needed to satisfy respondents.

Responsibility for seeing that daily travel diaries were made out properly was placed either on each individual respondent or upon some one person in the family, depending on which method seemed to the interviewer most likely to be effective.

Each household was paid a maximum of fifteen dollars for acceptable completion of thirty day diaries from each member of the household, ten years of age and over. The total interviewing period covered five weeks. A payment of two dollars and a half was made for each of the four weeks, plus a premium of five dollars to those families who completed the full thirty days. Families dropping out before the end of the thirty days were paid for the time for which they actually completed diaries.

After the initial interview, the interviewer returned to the home to check up on diaries made out by those not at home at the time of the initial interview and to inspect diaries for the preceding day. If all respondents in the home then seemed to understand the making out of the diaries, they were accepted; otherwise further instructions were given. From then on the interviewer called at each home every other day to review diaries and to pick them up and bring them into the office. This every-other-day contact was continued throughout the thirty days.

Completed diaries brought in by interviewers were checked day by day against a record kept for each individual. Each day's diaries were reviewed and, if not clear or satisfactory, were referred back to the interviewer to be taken up with the respondent on the next visit.

Modification of the Sample

Because of time limitations it was impossible to utilize in the current studies all the information made available by TAB and OAAA. The empirical discussions which follow in this chapter are based upon a subsample of 100 households whose residences were located within the corporate city limits of Cedar Rapids (see Figure 14). Detailed tabulations were undertaken on the movements of these households during the second and third week of the sample period. This two week period constitutes the basic time period to which subsequent counts of trip frequencies, etc., are referred.

The travel diaries gave a block-by-block description of the route of each of the trips made by respondents during this time period. This route description was translated into miles traveled, by mode of travel, in the course of each trip by tracing out the route on a map of the city and following the trip with a map measurer which recorded the distance traveled. It was this operation that imposed the limit upon the number of households which could be considered in the present series of studies.

Design of the Empirical Studies

The studies reviewed earlier suggested three measures of transport inputs to the household: (1) trips per time period, (2) time spent away from home during a given time period,

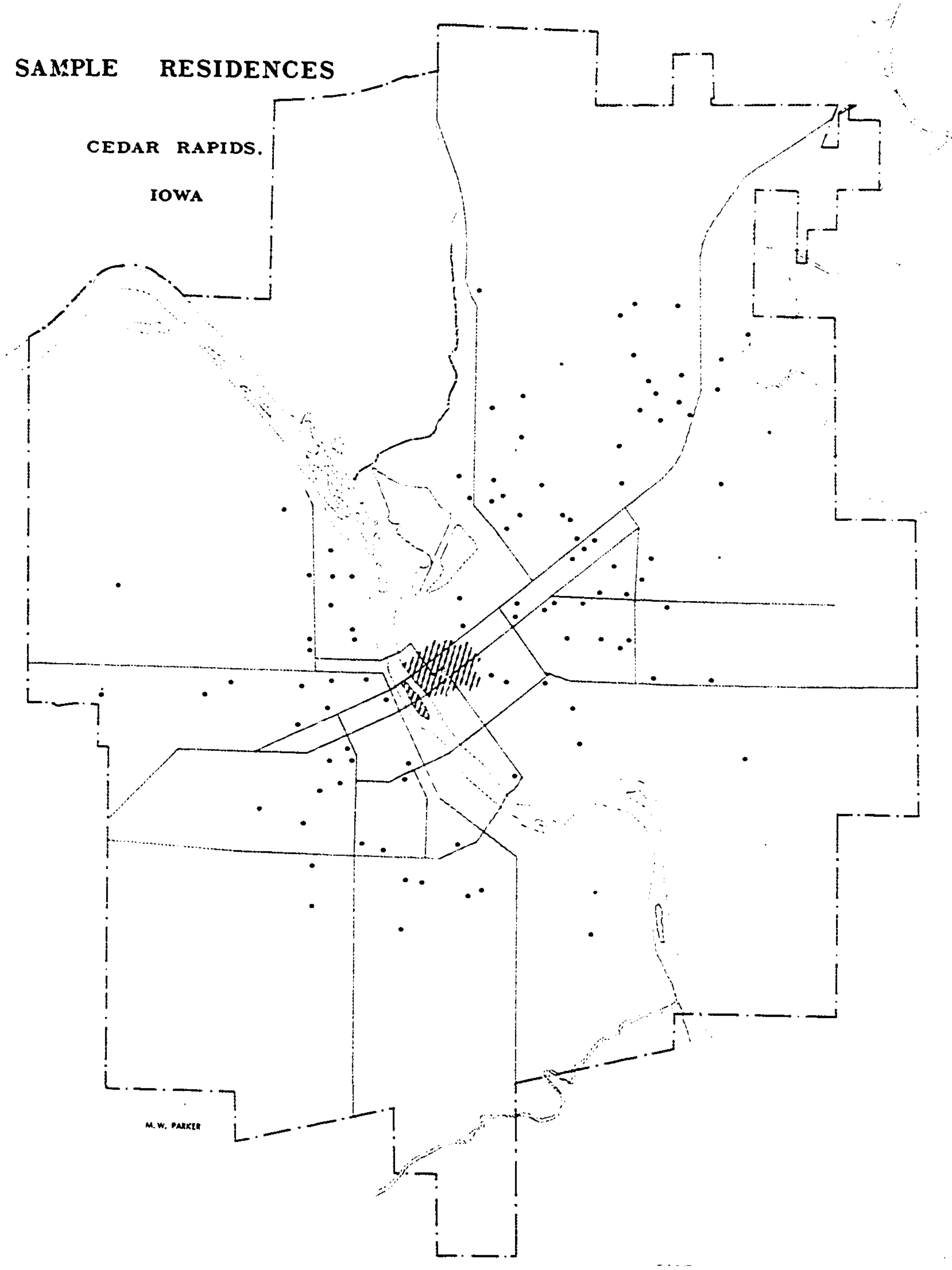

FIGURE 14

and (3) the total distance traveled during a given time period. The theoretical structures which are currently available suggest three factors as being of importance in determining the level of transport inputs to a household. These three factors are: (1) the socio-economic structure of the household, (2) the availability of transportation, and (3) the location of the household's residential site relative to the other elements of the spatial system. Techniques of multiple regression analysis provide a tool for examining the associations which exist, on an empirical level, between these factors and the level of transport inputs.[3] The following empirical studies, utilizing multiple regression as applied to the Cedar Rapids travel data, represent a first attempt at testing the validity of these associations.

Operational Definitions

Before proceeding further with the analysis, it is necessary to operationally define the measures to be used. The measures of transport inputs which have been proposed are explicit enough to permit their use without further discussion. However, the three factors believed to influence the level of transport inputs (socio-economic status of the household,

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[3]For a discussion of multiple regression analysis the reader is referred to: George W. Snedecor, Statistical Methods (Ames: Iowa State College Press, 1956).

availability of transportation, and the location of the household's residential site relative to the other elements of the spatial system) must be defined in a more explicit fashion before they can be used. Since the present study did not involve the original collection of data, these definitions must be limited to the extent that they can be used with the data currently available.

It is unfortunate that the structure of the Cedar Rapids household data made it impossible to utilize any of the various scales available for the measurement of the socio-economic status of the household. The present studies attempt this measurement through the use of a series of variables which include: size of the household, income level, age and educational level of the head of the household, and the presence or absence of school children and employed persons. It is freely admitted that these factors do not present an ideal picture of the socio-economic structure of the household, but they do represent the best approximation that could be constructed with the information available.

Three types of transport (movement by foot, private automobile, and public transit) were assumed to be available in some degree to each household. While every household obviously has the ability to make trips on foot, the ability to make trips by private automobile or public transit varies from household to household. The ability to make trips by automobile is crudely measured in the present studies by the inclusion of a dichotomous variable relating to the ownership of one or more motor vehicles by the household. The availability of public transit to households in the study area appears to be related only to the distance of the residence from the nearest facility since there appears to be no significant difference in scheduled frequencies between transit routes.

Measurement of residential location poses the most difficult problem. The spatial structure of the modern urban region is exceedingly complex, and any attempt to define the relative location of a point within this complex (e.g. a residential location) by means of a single simple measure is likely to prove highly misleading. As an example of the complexity of the urban region, let us examine just one sector: retail business. Recent theoretical and empirical studies have extended the traditional concepts of central place theory to include the structure of intra-urban business, and have shown that a hierarchy of retail business centers exists within the city.[4] Because of the highly interdependent structure of the urban region the household is compelled to interact with the various members of this retail hierarchy in order to maintain its existence. How then are we to define the location of the household relative to this complex spatial structure? Interaction

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[4]William L. Garrison, _et al_, _op_. _cit_.

takes place with all levels of the hierarchy and it would seem that, as a minimum, there should be as many reference measurements as there are levels in the hierarchy. The same argument holds in a more general way when the numerous contacts of the household for purposes of work, schooling, recreation, etc., are examined.

Empirical studies reported upon elsewhere have identified four levels (including the CBD) in the retail hierarchy of Cedar Rapids[5] (see Figure 15). For the purposes of the present series of studies, the location of each household is given by a series of four measurements of over-the-road distances to the nearest member of each level of the observed retail hierarchy. It is recognized that other demand points within the city may well be of major importance, but it is felt that this series of variables represented as great a degree of complexity as it was practical to introduce.

The General Form of the Model

The factors, as explicitly defined above, were entered into a general linear model which was applied to each of the three measures of transport inputs. The model has the general form:

$$Y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + u$$

where u is a random disturbance term, α and the β's are the

[5] *Ibid.*

RETAIL BUSINESS CENTERS

CEDAR RAPIDS, IOWA

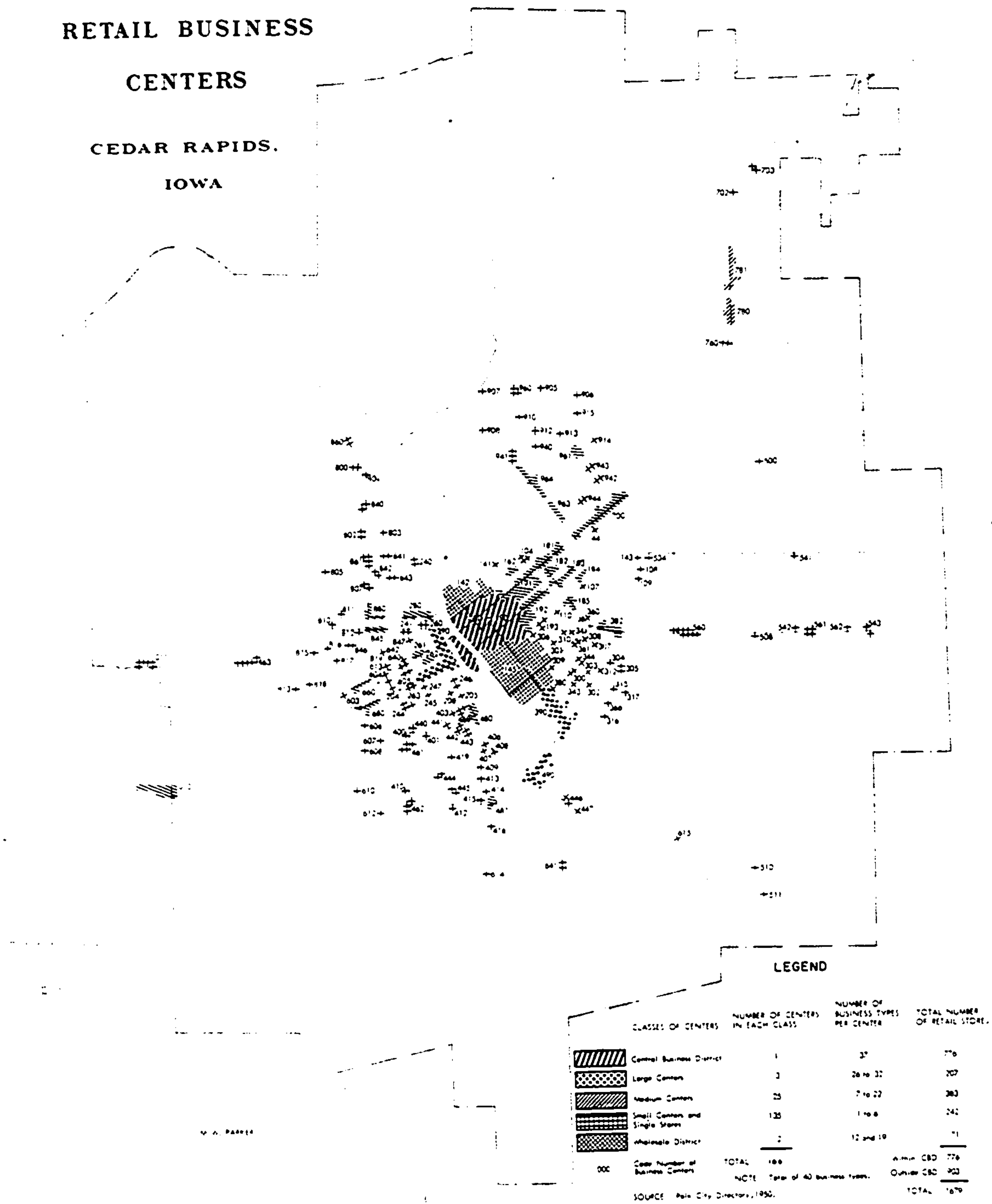

FIGURE 15

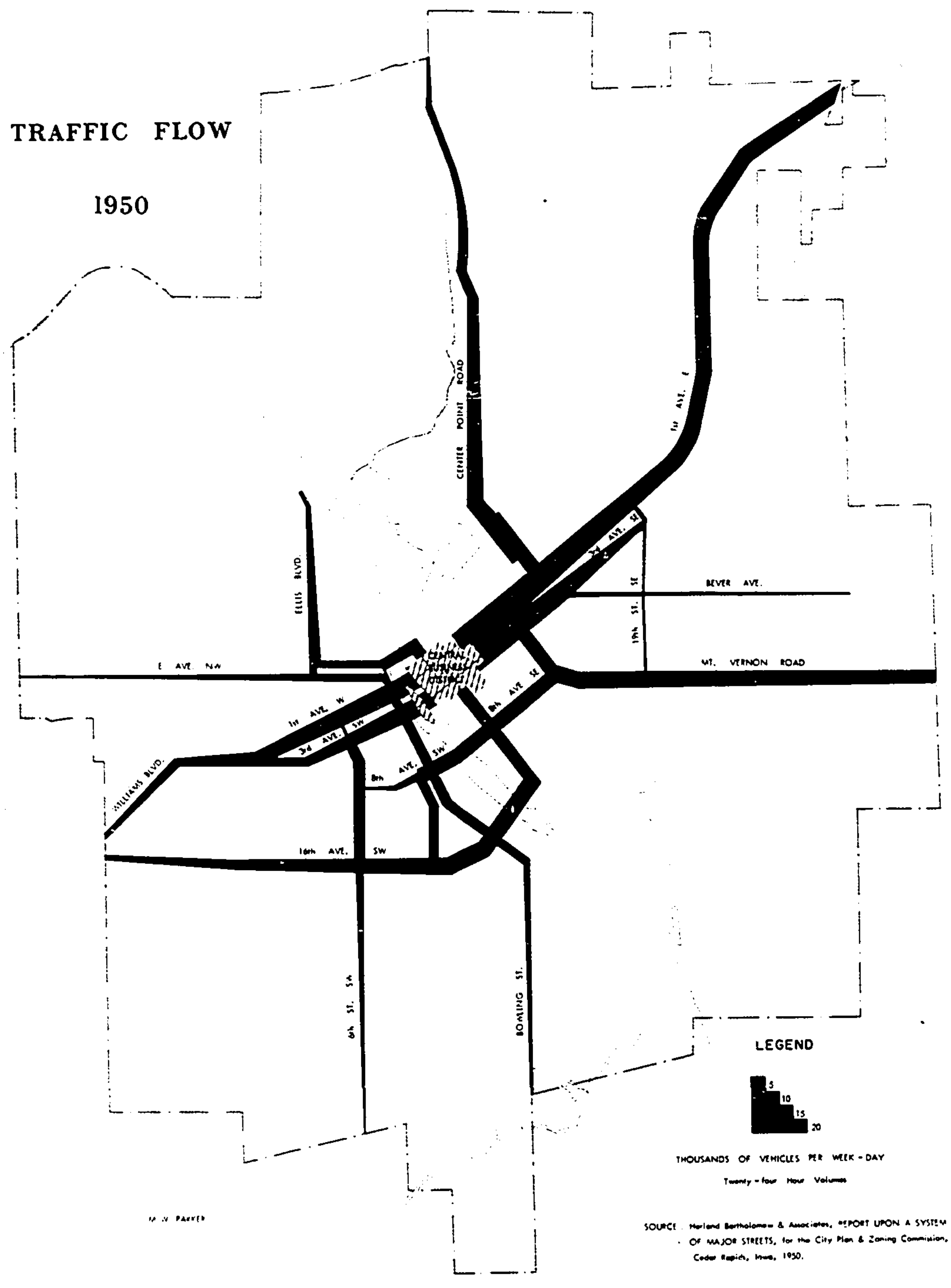
TRAFFIC FLOW
1950
CENTER POINT ROAD
1st AVE. E
3d AVE. SE
BEVER AVE.
19th ST. SE
MT. VERNON ROAD
ELLIS BLVD.
E AVE. NW
1st AVE. W
3d AVE. SW
8th AVE. SE
8th AVE. SW
WILLIAMS BLVD.
16th AVE. SW
6th ST. SW
BOWLING ST.
LEGEND
5
10
15
20
THOUSANDS OF VEHICLES PER WEEK - DAY
Twenty - four Hour Volumes
SOURCE . Harland Bartholomew & Associates, REPORT UPON A SYSTEM OF MAJOR STREETS, for the City Plan & Zoning Commission, Cedar Rapids, Iowa, 1950.

FIGURE 16

parameters to be estimated from the sample data. The variables are:

Y_f = total number of trips made by all members of the household during the study period

Y_t = total time (in hours) spent away from home by all members of the household during the study period

Y_d = total distance traveled (in miles) by all members of the household during the study period

Measures of socio-economic factors:

x_1 = size of the family

x_2 = age of the head of the household in years

x_3 = has the head of the household received any education beyond the high school level? (1 = yes and 0 = no)

x_4 = is the household in the low income (below $3000 per year) group? (1 = yes and 0 = no)

x_5 = is the household in the medium income ($3000 to $5000 per year) group? (1 = yes and 0 = no)

x_6 = is the household in the high income (over $5000 per year) group? (1 = yes and 0 = no)

x_7 = are there one or more full-time workers in the household? (0 = yes and 1 = no)

x_8 = are there one or more school children in the household? (1 = yes and 0 = no)

Measures of transport availability:

x_9 = does the family own one or more automobiles? (1 = yes and 0 = no)

x_{10} = road distance in miles from the residence to the nearest transit line

Measures of residence location:

x_{11} = road distance in miles from the residence to the central business district

x_{12} = road distance in miles from the residence to the nearest high order retail center

x_{13} = road distance in miles from the residence to the nearest medium order retail center

x_{14} = road distance in miles from the residence to the nearest low order retail center.

Data Processing

Computations for the three runs of the general model were carried out using the facilities of the University of Washington's Research Computer Laboratory. The computer used was a standard IBM 650, and the regression program was one supplied by the Research Division of the Shell Oil Company. Total running time was approximately two hours.

Transport Inputs to Households in Cedar Rapids

Tabulation of the movement data collected in Cedar Rapids revealed a very complex pattern of movement. This complexity is especially evident when attempts are made to structure the movement of persons by the purpose of the movements. In many traffic studies movement purposes are classified under several simple headings (e.g., those used in Table I). It proved to be impossible to use these simple structurings to classify the person movements in Cedar Rapids. For instance, during the study period some 144 stops were made at supermarkets by individuals in the travel sample. While 21 percent of these stops did not involve other movement purposes (single purpose trips), 34 percent involved one or more other stops for shopping purposes, 19 percent involved stops at the place of work, and 15 percent involved stops for such purposes as visiting friends. The current studies will not deal further with this complex, but in the following discussions it should be clearly realized that such terms as total trips tend to conceal a complex pattern of movements.

Of the 100 households in the original travel sample, 13 were dropped for various reasons, and the results of the following studies are based upon a final sample of 87 households. Summary measures of household characteristics are given in Table III, and some simple measures of association are shown in

TABLE III

AVERAGE CHARACTERISTICS OF THE SAMPLE HOUSEHOLDS

	Mean
Size of Family	3.1 persons
Age of Head of Household	44.6 years
Road Distance to the CBD	1.50 miles
Road Distance to the Nearest High Order Retail Center	1.31 miles
Road Distance to the Nearest Medium Order Retail Center	0.41 miles
Road Distance to the Nearest Low Order Retail Center	0.16 miles
Road Distance to the Nearest Transit Line	0.12 miles
Time Away from Home*	164.1 hours
Number of Trips*	35.7
Distance Traveled*	94.9 miles

* During two week study period.

Table IV.

The Elapsed Time Study

Troxel has suggested the use of the amount of time spent away from home as a measure of the demand for movement at residential sites.[6] The Cedar Rapids travel diaries contained information on the time at which each trip began and ended. The duration of each trip was obtained from these entries and the information on individual trips aggregated by households.

Preliminary computations disclosed that members of the average household spent about 164 hours away from home during the two week study period. This amounted to some 28 hours per week per person. An examination of the zero order correlations (see Table IV) disclosed significant associations with only two items: size of family and total number of trips.

Fitting the general linear model to the household data produced the following estimating equation:

$$Y_t = 66.8 + 19.2\ x_1 + 0.9\ x_2 - 57.4\ x_3 + 0.4\ x_4 + 20.4\ x_5 + 25.5\ x_6 - 132.2\ x_7 + 83.9\ x_8 - 24.1\ x_9 - 39.1\ x_{10} + 33.9\ x_{11} - 34.4\ x_{12} + 10.7\ x_{13} + 23.1\ x_{14}$$

where Y_t is the estimate of the number of hours spent away from home during the study period. Interpretation of the estimating

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[6]Troxel, op. cit.

TABLE IV

ZERO ORDER CORRELATION MATRIX

	1	2	3	4	5	6	7	8	9	10
1	1.00	-.26	.03	.05	.02	.00	.00	.46	.52	.31
2		1.00	-.05	-.18	.00	-.11	-.08	-.11	-.10	-.15
3			1.00	.45	.91	.56	.56	.06	.13	.40
4				1.00	.31	.53	.58	.00	.00	.27
5					1.00	.47	.48	-.01	.02	.35
6						1.00	.53	.10	.12	.44
7							1.00	.16	.08	.29
8								1.00	.81	.66
9									1.00	.64
10										1.00

Variable:

1 = Size of family
2 = Age of head of household
3 = Road distance from CBD
4 = Road distance from nearest transit line
5 = Road distance from nearest high order retail center
6 = Road distance from nearest medium order retail center
7 = Road distance from nearest low order retail center
8 = Total number of trips during the study period
9 = Total time spent away from home during the study period
10 = Total distance traveled during the study period

Note: Values falling between +0.20 and -0.20 are not statistically significant at the five percent level.

equation is quite simple. For instance, for every unit increase in the size of the family (x_1) we observe an increase of 19.2 hours in the time spent away from home by the household.

Four of the variables, family size (x_1), educational level of the head of the household (x_3), the presence of one or more workers in the household (x_7), and the presence of one or more school children in the household (x_8), proved to be highly significant (1 percent level). The variables contained in this model were able to account for 60 percent of the observed household-to-household variation in the amount of time spent away from home during the study period (Y_t). It is interesting to note that only variables in the socio-economic category proved to be statistically significant, and that none of the spatial variables were significant even at very low confidence levels.

The Trip Frequency Study

The average Cedar Rapids household made just under 36 trips during the two week study period, excluding movements made purely for the purpose of visiting friends or pleasure driving. Application of the general regression model produced the following estimating equation:

$$Y_f = 19.9 + 1.7\,x_1 + 0.2\,x_2 - 1.7\,x_3 - 1.9\,x_4 + 1.7\,x_5 + 7.7\,x_6 - 23.9\,x_7 + 23.2\,x_8 + 5.6\,x_9 - 3.0\,x_{10} - 3.7\,x_{11} - 1.3\,x_{12} - 2.4\,x_{13} + 23.1\,x_{14}$$

where Y_f is the estimate of the total number of trips made during the study period.

Two variables, the presence of one or more workers in the household (x_7) and the presence of one or more school children (x_8), were statistically significant at the 1 percent confidence level. The variables contained in the model were able to account for 49 percent of the observed household-to-household variation in the total number of trips made during the two week study period. The two variables which proved to be highly significant in this study were of a dichotomous nature, and once again fell into the socio-economic category.

The Total Distance Study

The information on total miles traveled, again excluding movements to visit friends or for pleasure driving, was tabulated for the households in the Cedar Rapids travel sample and following estimating equation obtained:

$$Y_d = 189.3 + 5.1\,x_1 - 1.0\,x_2 - 49.8\,x_3 - 96.6\,x_4 - 39.8\,x_5 - 79.8\,x_6 - 26.8\,x_7 + 46.5\,x_8 + 24.2\,x_9 + 240.1\,x_{10} - 74.8\,x_{11} + 99.8\,x_{12} - 6.0\,x_{13} - 223.9\,x_{14}$$

where Y_d is the estimate of the total distance traveled by the household during the study period.

The general model was in this case able to explain only 14 percent of the observed household-to-household variation in total distance traveled. None of the variables were statistically significant except at very low levels (20 percent). At the 20 percent level three variables, distance to the nearest transit line (x_{10}), distance to the nearest high order retail center (x_{12}), and distance to the nearest low order retail center (x_{14}) were significant. Although locational variables were the only ones to show any degree of significance, the low degree of confidence which must be attached to them, together with the overall poor performance of the model in this case, leaves much to be desired.

Summary

From the standpoint of current theory, it appears that if an individual's space preference (his desired level of social contact) is thought of as being expressed in terms of either a desired number of contacts or as a desired total contact duration, then it would be reasonable to expect gross trip frequencies and the amount of time spent away from home to be largely determined by social and psychological factors outside of the general spatial system.[7] Total distance traveled, on the other hand, would be expected to be especially

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[7]Problems which may arise if trip frequencies are influenced by the location of the residence relative to the rest of the spatial system are discussed in: Duane F. Marble, "Transport Inputs at Urban Residential Sites," Papers and Proceedings of the Regional Science Association, Volume 5 (1959), forthcoming.

sensitive to variations in the location of the residence (or home base) relative to the rest of the spatial system.

The results of the empirical studies conducted in Cedar Rapids, when viewed in this framework, appear to be somewhat contradictory. Both trip frequencies and time spent away from home showed very strong associations with the variables in the socio-economic sector of the model, and very weak associations with the variables in the spatial sector. These results, together with the somewhat negative evidence presented by other empirical studies, tend to support quite strongly the contention that trip frequencies and the amount of time spent away from home are determined by forces exogenous to the spatial system.

On the other hand, the poor showing of the model in attempting to explain household-to-household variations in total distance traveled is quite puzzling in light of the other results. While some of the variables in the spatial sector of the model were significant at very low confidence levels, this result cannot be regarded as anything more than mildly suggestive.

The following chapter discusses some of the theoretical implications of these results, and proposes a tentative extension of theory to cover problems of individual decision-making in a spatial context.

CHAPTER V

A PROPOSED RESTATEMENT OF THEORY

The review portion of this study indicated that current theoretical structures which deal with the behavior of individuals or household units in a spatial context suffer from several serious deficiencies. The empirical studies conducted in Cedar Rapids pointed out certain of these weaknesses and contradictions in an explicit manner. The problems examined in the Cedar Rapids studies were of a very general nature, and the lack of development of current theory becomes even more evident when attention is directed to more specific questions.

During the past ten years a new battery of analytic tools has become available to the research worker studying decision situations. The decisions which an individual makes regarding his movements in space are not simple. He is confronted with a complex spatial system and a wide range of possible destinations, modes of travel, etc., and from this large group of possible actions he must select those which will satisfy his demands in some efficient manner. The following sections outline a new approach to the study of individual behavior in space through the use of one of these new analytic tools--game theory.

Game Theory and Individual Behavior in Space

The new tools which have become available for the analysis of complex decision situations fall into two classes. The first, typified by linear programming, deals with situations involving decision-making under conditions of certain knowledge regarding the possible outcomes.[1] The second, which includes the several forms of game theory, deals with situations involving risk or uncertainty with regard to the possible outcomes.

It has been argued elsewhere that a movement situation may be regarded as a two-person game played against nature under conditions of incomplete information.[2] Within this game theory framework, the movements of the individual in space are regarded as physical analogs of his movements among the

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[1]For an example of the application of linear programming to a problem of decision-making within a spatial contex, see William L. Garrison and Duane F. Marble, "The Analysis of Highway Networks: A Linear Programming Formulation," Proceedings, Highway Research Board, NAS-NRC, 37: 1-17 (1958).

[2]Duane F. Marble, "Transport Inputs at Urban Residential Sites," Papers and Proceedings, Regional Science Association (1959), forthcoming.

branches of a game tree.[3]

A Simple Model

What would be the general form of a game-theoretic model of individual behavior in space? For purposes of discussion assume a greatly simplified spatial structure consisting of a residence and n points (stores). All locations are spatially separated, and each store supplies an identical commodity. An individual, whose home base is the residence, desires to obtain a supply of this commodity, and he may do so only by visiting one of the stores which supplies it. To simplify the situation even further, assume also that the individual must select only one destination, and if that destination fails to supply the commodity (e.g., the store may not be open), then the individual returns to his home base rather than going on to another destination. This situation is admittedly unrealistic, but it will serve to illustrate some of the general concepts which must be grasped before entering into a more complex situation.

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[3]For obvious reasons it is not possible to review here the many portions of the theory of games which will be called upon in the following discussion. The reader who is unfamiliar with the terms and concepts encountered here is referred to the recent work by R. Duncan Luce and Howard Raiffa, Games and Decisions: Introduction and Critical Survey (New York: John Wiley & Sons, 1957), which provides an excellent survey of the field.

The elements of the decision situation are displayed in Table V. The decision matrix consists of n rows, with each row corresponding to a trip to one of the n possible destinations; and m columns, each corresponding to one of the m possible states of nature (or conditions of the system) which may prevail. A payoff (or utility), designated by u_{ij}, is assigned by the player to each destination-state of nature combination. Thus if the individual chooses to go to destination i and state of nature j prevails, then he will receive a payoff of u_{ij}. This payoff may be either positive or negative in nature.

Since the situation is one of decision-making under conditions of risk, the player does not know with certainty which state of nature will prevail at any given time. However, he may be presumed to have, possibly from past experience, a fairly good knowledge of just how likely the occurrence of each one is. This level of information is referred to as having an _a priori_ probability distribution over the possible states of nature. Thus while the player does not know if the j^{th} state will occur at a given instant, he does know the probability (p_j) of its occurrence.

Having explicitly defined the elements of the decision situation, the question then is which trip should the player undertake? Game theory takes the position that there is a definite way in which rational people should behave, if they

TABLE V

A SIMPLE DECISION MATRIX

Destinations	States of Nature												
	S_1	S_2	.	.	.	S_j	.	.	.	.	.	.	S_m
D_1	u_{11}	u_{12}	.	.	.	u_{1j}	.	.	.	.	.	.	u_{1m}
D_2	u_{21}	u_{22}	.	.	.	u_{2j}	.	.	.	.	.	.	u_{2m}
.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.
D_i	u_{i1}	u_{i2}	.	.	.	u_{ij}	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.
D_n	u_{n1}	u_{n2}	.	.	.	u_{nj}	.	.	.	.	.	.	u_{nm}

believe in the game matrix. Williams elaborates upon this point in an interesting fashion:

> The notion that there is some way people ought to behave does not refer to an obligation based on law or ethics. Rather it refers to a kind of mathematical morality, or at least frugality, which claims that the sensible object of the player is to gain as much from the game as he can, safely, in the face of a skillful opponent who is pursuing an antithetical goal. This is our model of rational behavior. As with all models, the shoe has to be tried on each time an application comes along to see whether the fit is tolerable; but it is well known in the Military Establishment, for instance, that a lot of ground can be covered in shoes that do not fit perfectly.[4]

The answer to the question, given the above definition of rational behavior, is fairly simple in the present case. The player has attached a probability, $p_j \geq 0$, to the occurrence of each state of nature. The expected value of the i^{th} trip is then equal to $\sum_j p_j u_{ij}$, where $\sum_j p_j = 1$. To find the trip which will maximize his payoff the player computes the expected value for each trip, and then determines the maximum by inspection. Alternatively, if the player is not willing to assign probability levels to the various states of nature, a max-min procedure may be employed in which each row is scanned and the lowest u_{ij} identified. The row containing the maximum of these minimums then defines the least risk trip.

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[4]J. D. Williams, The Compleat Strategyst (New York: McGraw-Hill Book Co., 1954), p. 23.

The real world is much more complex than the simple situation outlined here for purposes of demonstration. It is possible to extend the simple model to include such things as multiple purpose trips, the existence of more than one commodity in the system, alternate methods of travel, etc. The complete model necessary to handle all these factors will not be presented here, but many of its characteristics may be demonstrated through a minor modification of the previous model.

A More Complex Model

Assume the same simplified spatial situation as before, but with one modification. In the present formulation the player has a desired payoff which he wishes to obtain, and no one supply point is able to satisfy this demand. Thus the player, in his search for the desired payoff level, may generate a multi-stop trip where he is concerned with the payoff level of the total system of stops, rather than that of any individual stop. The model in this case becomes one of a class of dynamic supergames which consist of sequential compounding of simple games, with the component games--in the present case--corresponding to the links of the multi-stop trip. One other difference in this case is that the player's strategies control not only the expected payoff at each stage, but also the transition probabilities which govern the continuance of the game to the next stage. A game in which these transition probabilities exist, and they exist in the present model to insure that the trip will come to an end, is called a stochastic game.

At any given stage (the γ^{th} stage, for instance) of the game, the payoffs are denoted by w_{ij}^{γ}. This payoff consists of two components, u_{ij}^{γ}, which has the same interpretation as in the simple model; and $\left[p_{ij}^{\gamma}(S)\right]$, which denotes the probability of stopping the game at stage γ. At all stages the probability of stopping is greater than zero. The payoff at any given stage is then interpreted as follows: the player receives a payoff of value u_{ij}^{γ} and then engages in a lottery, with probabilities p_{ij}^{γ} of stopping and $(1 - p_{ij}^{\gamma})$ of continuing. Each outcome of each component game now has associated with it a real-valued payoff, as well as a non-zero probability of stopping the play at that stage.

The player then, under the definition of rational behavior, wishes to maximize his return, not for any one component game, but over the entire supergame system. Given the characteristics of the system, it is difficult but not impossible to solve for the required optimal strategy.[5] If the distribution of the p_j's is such that one and only one of the many possible states of nature is nearly certain to occur (e.g.,

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[5]Luce and Raiffa, op. cit., pp. 459-461.

as $p_j \rightarrow 1$), then the complex supergame system becomes degenerate and the decision situation may then be handled as a dynamic programming problem.[6]

Generalization of the Complex Model

Generalization of the supergame system to include such factors as the existence of more than one commodity in the system, as well as the existence of a specified bundle of commodities at each destination is not difficult. In the former case it is sufficient to adopt the assumption that utilities of different commodities can be compared, and in the latter to recognize links (or rows in the decision matrix) whose selection does not involve spatial movement.

Empirical Operation of the Model

Consideration of the previous examples leads to the conclusion that a game-theoretic formulation of the problem of individual behavior in space will be capable of dealing with many factors and operations which present theoretical structures are incapable of handling. In addition, the methods of solution of the game matrix which are available provide a

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[6] L. S. Shapley, "Stochastic Games," Proceedings of the National Academy of Sciences, U.S.A., 39: 1095-1100 (1953). For a detailed discussion of dynamic programming see the recent book by Richard Bellman, Dynamic Programming (Princeton: Princeton University Press, 1957).

means of finding specific optimal solutions to spatial movement problems.

However, models of this nature have been subject to certain criticisms in the past. These criticisms are recognized and commented upon in a statement by Davidson and Suppes:

> The most serious general criticism of . . . formalized theories of decision making among risky alternatives is that they are not empirically applicable. This criticism takes two quite different forms. (a) It is argued that people simply do not meet the conditions of rationality. . . . (b) The second criticism is that no satisfactory empirical interpretation of the theory has been given, and therefore it is impossible even to test the theory.
>
> Obviously the second criticism is the more fundamental, and unless it can be met the first is captious. Further, if the second criticism can be met, the first criticism is, in effect, an a priori decision concerning a testable matter of fact. If the facts are worth arguing, they are worth testing, while if they _cannot_ be tested, it is not clear what there is to argue about. Finally, and perhaps most important, even if a theory of rational decision has little general descriptive value, it still may have great interest as a normative theory. Even if no one, or hardly anyone, acts in accord with some such theory over a period of time, we may be willing to grant that it is worth asking . . . whether a given pattern of decisions, or of preferences and expectations, is rational in the sense of the theory.[7]

No argument is put forth here for the interpretation of this class of spatial decision models as anything other than a normative form. However, as Davidson and Suppes point

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[7]Donald Davidson and Patrick Suppes, _Decision Making: An Experimental Approach_ (Stanford: Stanford University Press, 1957), p. 3.

out, before they can be useful even in this context, it is necessary to have a workable empirical interpretation of the theory. It is not possible at the present time to state if the analytic system proposed here is empirically applicable or not, but it is possible to briefly point out certain problem areas and to make crude estimates of the difficulties involved in their empirical solution.

Estimation of the Payoffs

While the enumeration of possible destinations and states of nature presents little difficulty, aside from the sheer size of the operations involved, the estimation of the payoffs (the u_{ij}^{γ}'s) is a different matter.

The measurability of utility has been a topic of heated debate in economics since before the turn of the century.[8] Recent developments in that field, with some assistance from psychology, now hold forth definite promise of being able to produce good experimental estimates of utilities. The first experimental attempt at estimation was undertaken only nine years ago, and was rather crude.[9] The field has attracted a

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[8] A review of this debate is given in: Richard E. Quandt, "A Probabilistic Theory of Consumer Behavior," Quarterly Journal of Economics, 60: 507-536 (1956).

[9] F. Mosteller and P. Nogee, "An Experimental Measurement of Utility," Journal of Political Economy, 59: 371-404 (1951).

great deal of attention since that time, and recent developments have significantly raised the level of operations.[10]

On the basis of results currently in hand, it would appear that the measurement of the payoff elements in the spatial decision matrix is a definite empirical possibility.

Estimation of the Transition Probabilities

Transition probabilities are inserted into the payoffs of each stage to insure that the play (trip) will come to an end in some reasonable length of time. Presumably the probability of stopping becomes greater as the length of play (elapsed time away from home) increases. That is, $p_{ij}^{\gamma-1} < p_{ij}^{\gamma}$. How rapidly does the probability of stopping increase? Examination of the Cedar Rapids travel data shows that few trips involve more than six stops and/or a duration of more than twelve hours. On the basis of this information, we would expect the probability of stopping to increase rapidly with increases in elapsed time away from home. Estimation of the p_{ij} 's could be undertaken with the data now available.

When estimates of the payoffs and transition probabilities are available, solution of the supergame system is limited only by the ability of the researcher to process the large

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[10]See, for instance, the work by Davidson and Suppes, op. cit.

volumes of data involved. With the assistance of large electronic computers the research worker is presently able to manipulate vast quantities of information, and innovations in computer technology are constantly expanding this ability.

Conclusions

The game-theoretic formulation presented here is one of a general class of complex decision models. It has the advantage of containing and extending present levels of knowledge in an explicit fashion, as well as being amenable to explicit and exact solution in specific cases. Theoretical structures of this nature will provide normative structures from which individual behavior patterns in the real world may be studied. As a by-product, this formulation also permits the inclusion of spatial behavior parameters in computer simulation systems such as Orcutt's SUSSEX (Simulation of the United States Social Economic System), which are potentially of great value in such fields as traffic and urban planning.[11]

The empirical application of this class of models appears to be currently possible, and research in the fields of economics and psychology is likely to increase the ease with

[11]Guy H. Orcutt, "A New Type of Socio-Economic System," The Review of Economics and Statistics, 39: 116-123 (1957).

which the transition from the real world to the game matrix may be made. It is felt that this method of analysis, if energetically developed, will lead to a significant extension of knowledge of individual behavior in space, and the transport inputs which these movements generate.

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APPENDIX A: SAMPLE INTERVIEW SCHEDULES

Individual Classification Sheet

Respondent Number ____________

Sub Area Number ____________

Name ______________________ Male ( ) Female ( )

Address ____________________

____________________ Telephone Number __________

In Cedar Rapids ( ) Respondent's Age __________

Rural Non-Farm ( ) ( ) Married ( ) Single

Farm ( ) ( ) Widowed ( ) Divorced

Last grade respondent completed in school ____________

If still in school, what grade ____________

What type school (if not public school) ____________

Respondent's occupation ____________

Where respondent works ____________

Is there at least one car or truck in the family? ( ) Yes ( ) No

Please list the license numbers of all cars and trucks owned by any members of the family.

______________________ ______________________

______________________ ______________________

______________________ ______________________

Please look at this card and tell me in which group the TOTAL FAMILY INCOME falls: ______________________.

Sex	Age	In-Out	Inc.	Car	Occup.

TRIP TRAVEL DIARY

Name____________________ Day of week____________

Address__________________ Date:________________

I left home at ______ o'clock and on this trip I returned home at ______ o'clock

Segment #	Method of Travel	Along (Name of Street)	To (Name of Street)	Exact Addresses of Stops	Why I Stopped

APPENDIX B

CEDAR RAPIDS SAMPLE HOUSEHOLDS: BASIC DATA

Column	Contents
1	Household number.
2	Family size.
3	Family income level. (L = below $3000/year; M = $3000 to $5000/year; H = $5000/year)
4	Does the family own one or more automobiles? (X = yes)
5	Age of the head of the household in years.
6	Has the head of the household received any education beyond the high school level? (X = yes)
7	Does the household contain one or more full-time workers? (X = yes)
8	Does the household contain one or more school children over ten years of age? (X = yes)
9	Road distance, in miles, from the residence to the nearest transit line.
10	Road distance, in miles, from the residence to the CBD.
11	Road distance, in miles, from the residence to the nearest high order retail center.
12	Road distance, in miles from the residence to the nearest medium order retail center.

Column	Contents
13	Road distance, in miles, from the residence to the nearest low order retail center.
14	Total number of trips made during the study period.
15	Total number of hours away from home during the study period.
16	Total miles traveled during the study period.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
01	3	L	X	24		X		0.19	1.86	1.68	1.06	0.14	18	104.1	65.2
02	7	L	X	33		X		0.00	1.05	0.73	0.03	0.03	20	114.7	50.8
03	2	L	X	25		X		0.23	0.94	0.72	0.20	0.14	38	156.4	121.3
04	3	M	X	58		X		0.06	1.58	1.33	0.61	0.22	41	261.1	123.4
05	6	L	X	30		X		0.25	0.86	0.62	0.17	0.17	38	139.9	148.4
06	3	L		63		X	X	0.06	1.22	0.97	0.39	0.02	19	141.5	77.7
07	3	M		30	X	X		0.25	0.89	0.66	0.14	0.14	27	117.0	37.5
08	5	L	X	57		X		0.00	1.16	0.89	0.08	0.08	57	355.7	65.8
09	4	L	X	23		X		0.25	1.47	1.31	0.58	0.19	30	161.6	96.8
10	4	L	X	28	X	X	X	0.06	1.08	0.80	0.11	0.11	56	174.2	109.0
11	3	M	X	27		X		0.03	1.08	0.80	0.25	0.03	19	112.4	73.8
12	3	L		56		X		0.12	1.31	1.20	0.44	0.05	54	290.0	196.0
13	2	M	X	34		X		0.00	0.80	0.56	0.16	0.03	35	127.7	71.1
14	4	M	X	32	X	X		0.00	0.65	0.44	0.09	0.03	57	159.5	93.4
15	3	L	X	34		X		1.00	2.47	2.23	1.61	1.03	48	148.1	239.2
16	2	M		43		X		0.00	1.70	1.42	0.78	0.05	46	271.8	189.2
17	2	L	X	58		X		0.59	2.41	2.17	1.47	0.02	27	122.2	174.6
18	3	M	X	26		X		0.36	3.27	3.27	0.41	0.41	12	98.4	30.2
19	3	H		30		X		0.11	2.59	2.59	0.34	0.12	31	227.8	221.5
20	2	M	X	55	X	X		0.14	1.36	1.36	0.23	0.03	27	70.8	69.2
21	6	M	X	39	X	X	X	0.00	2.14	2.14	0.64	0.16	38	123.0	157.2
22	2	L		37		X		0.00	1.19	1.19	0.02	0.02	34	131.3	72.2
23	2	L		47			X	0.12	0.52	0.52	0.22	0.08	11	66.5	12.6
24	3	L	X	34		X		0.00	1.56	1.56	0.02	0.02	59	143.4	142.4
25	2	M	X	59		X		0.20	1.48	1.48	0.22	0.12	35	103.8	74.1
26	3	M	X	58		X	X	0.06	2.61	2.61	1.42	0.56	47	211.8	241.3

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
27	2	L		55		X		0.12	1.31	1.31	0.16	0.16	21	162.6	35.9
28	4	M	X	29		X		0.22	1.50	1.50	0.26	0.03	25	184.6	159.6
29	5	M	X	41		X		0.11	1.39	1.39	0.19	0.19	21	34.8	46.6
30	3	L	X	26	X	X		0.00	1.41	1.41	0.17	0.02	23	109.2	61.7
31	1	L		69				0.16	3.00	3.00	0.14	0.14	4	13.2	22.0
32	2	M	X	33		X		0.00	1.95	1.95	0.73	0.14	23	195.0	71.9
33	5	L		37		X	X	0.53	3.42	3.42	0.56	0.56	51	350.2	172.1
34	4	M	X	38		X	X	0.12	2.59	2.59	0.56	0.36	67	238.7	186.9
35	2	M	X	47		X		0.09	1.94	1.94	0.39	0.20	27	215.7	175.1
36	5	M	X	43		X	X	0.00	2.34	2.34	0.69	0.48	115	392.8	148.3
37	2	L		60	X		X	0.05	2.36	2.36	0.41	0.23	26	114.0	79.1
38	3	M	X	46	X	X	X	0.11	1.95	1.95	0.61	0.52	83	224.7	133.0
39	2	L		39	X	X	X	0.03	1.36	1.36	0.30	0.06	40	161.9	54.1
40	4	M	X	28		X		0.00	0.26	0.26	0.09	0.09	38	150.7	48.1
41	4	L	X	24		X		0.00	1.17	1.17	0.14	0.14	27	155.5	72.3
42	4	H	X	32	X	X		0.38	2.78	2.78	0.37	0.37	15	87.6	73.6
43	4	L	X	61		X	X	0.05	2.48	2.48	0.53	0.34	52	229.9	200.1
44	10	L	X	48		X	X	0.25	1.20	1.20	0.50	0.05	61	364.1	85.3
45	4	M	X	59		X	X	0.06	1.14	1.14	0.34	0.06	67	317.3	146.5
46	1	L		79				0.00	0.83	0.70	0.22	0.08	9	11.0	8.3
47	4	L	X	58		X		0.00	0.44	0.44	0.44	0.02	41	234.2	131.9
48	3	M	X	40		X		0.06	1.55	1.02	0.48	0.28	16	119.5	66.6
49	2	M	X	26		X		0.00	1.36	1.36	0.61	0.20	34	154.7	83.4
50	5	H	X	35		X		0.00	1.14	1.14	0.45	0.09	16	103.4	37.4
51	2	L	X	58	X	X		0.09	1.20	1.20	0.31	0.31	16	80.2	30.7
52	2	L		50	X	X		0.00	1.09	1.09	0.37	0.08	22	69.5	46.3

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
53	2	L	X	60		X		0.00	0.75	0.75	0.09	0.09	27	103.6	32.5
54	2	M		66		X		0.00	0.59	0.59	0.28	0.12	25	136.6	28.5
55	3	H	X	34	X	X		0.12	2.27	2.27	1.26	0.03	33	102.1	113.0
56	2	L		41		X		0.00	0.59	0.59	0.26	0.16	19	91.8	19.6
57	2	M	X	47		X		0.05	0.50	0.50	0.05	0.05	39	144.9	50.6
58	1	L	X	74				0.09	1.00	1.00	0.12	0.12	5	10.8	19.6
59	4	M	X	33		X		0.06	1.31	1.31	0.41	0.26	13	113.1	26.4
60	2	H	X	76				0.06	0.86	0.86	0.06	0.06	31	57.1	53.9
61	2	M		66		X		0.09	2.62	2.62	0.17	0.17	20	167.8	91.8
62	3	H	X	64		X		0.00	2.20	2.20	0.45	0.25	42	137.9	104.1
63	1	L		57	X			0.11	1.61	1.61	0.83	0.37	5	8.9	20.1
64	1	L		70				0.09	1.50	1.50	0.58	0.37	4	4.0	9.0
65	4	H	X	39	X	X	X	0.00	1.61	1.61	0.53	0.23	68	215.2	178.5
66	5	H	X	36	X	X		0.30	1.89	1.89	0.84	0.02	22	112.9	70.0
67	2	M	X	32		X		0.00	1.42	1.42	0.39	0.14	39	239.6	152.9
68	2	L	X	31		X		0.05	0.88	0.14	0.14	0.14	22	93.4	42.9
69	1	L		74				0.03	1.20	1.20	0.03	0.03	10	18.8	8.6
70	5	H	X	49		X		0.14	1.00	0.59	0.23	0.05	111	405.9	226.7
71	3	L		45		X	X	0.00	1.31	0.86	0.39	0.03	44	239.6	114.8
72	3	L	X	32		X		0.47	1.41	1.08	0.55	0.37	37	161.0	138.2
73	3	L		45		X	X	0.11	1.69	1.11	0.58	0.06	41	259.2	103.1
74	4	L	X	45		X	X	0.03	0.95	0.53	0.20	0.05	55	325.1	125.1
75	2	M	X	32		X		0.08	1.84	1.34	0.86	0.08	34	156.1	84.7
76	3	H	X	69				0.00	0.39	0.05	0.05	0.05	17	20.3	12.6
77	2	L	X	26	X	X		0.11	1.14	0.72	0.22	0.22	53	112.6	110.4
78	5	M	X	41		X	X	0.03	1.66	0.42	0.42	0.34	65	442.7	95.3

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
79	2	M	X	31		X		0.78	2.22	0.95	0.95	0.53	37	164.5	67.2
80	2	M	X	38		X		0.33	2.09	1.50	0.98	0.30	32	141.9	159.8
81	3	M	X	39		X	X	0.28	1.98	1.02	0.67	0.25	38	184.9	104.0
82	2	L	X	25		X		0.00	1.08	0.58	0.39	0.08	29	162.1	54.8
83	2	L		35		X		0.03	0.81	0.37	0.09	0.03	28	155.0	43.1
84	4	M	X	38		X	X	0.20	1.55	0.53	0.33	0.12	68	231.8	136.9
85	2	L	X	65		X		0.09	1.59	0.62	0.26	0.19	19	26.1	42.9
86	5	M	X	67		X	X	0.09	1.25	0.80	0.33	0.11	85	501.3	202.1
87	3	H	X	57		X		0.23	1.69	0.73	0.39	0.17	28	217.6	80.9

VITA

Duane Francis Marble was born on December 10, 1931, in Seattle, Washington. His parents are Mr. and Mrs. Frank A. Marble of Everett, Washington. Mr. Marble is a graduate of Everett High School, and he received his B.A. in 1953 and his M.A. in 1956, both from the University of Washington. While at Washington, he held appointments as teaching assistant and acting instructor in the Department of Geography, and as research assistant and research instructor on several research projects.