EFFECTIVE DISTANCE OF URBAN HIGHWAY TRAVEL FOR SUPERMARKET SHOPPING TRIPS

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To Alice, Kathy, and Roy, without whose encouragement this treatise would not have been possible.

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CHAPTER I

INTRODUCTION

The growth of our cities and the expansion of our urban highway system indicate that people prefer to live in built-up areas and to travel within these areas by private automobile. For this privilege, we are now spending billions of dollars for the construction of an urban highway system. Billions more have been earmarked for future construction. Additional millions have been spent to study the broad patterns of travel movement in major metropolitan areas throughout the United States. In spite of this willingness to pay for urban highways, we have not solved the problem of urban movement. Any comprehensive planning solution to urban transportation problems will require a more fundamental knowledge of individual travel behavior in relation to land use patterns and the highway network than is presently available. The field investigation which is a part of this study examines individual highway travel linkages between residential and one type of commercial land use. The investigation is a step in the direction in which future urban travel research should move.

Summary of Field Investigation

The problem investigated is an individual travel behavior study that deals with the manner in which the automobile driver uses the urban highway network between his home and a retail store in order to satisfy a demand which cannot be fulfilled within his own household. Given a demand for shopping at a particular supermarket, the investigation made measurements of the driver responses to the highway route that the shopper chose when driving to the supermarket, and determined the effective distance, expressed in units of driver actions and vehicle motion, which spatially separated the supermarket from the shopper's home.

Using units of effective distance, the study shows that an increase in effective distance from the store results in a decrease in customer contacts at the supermarket, and that this relationship is mathematically functional. The investigation also indicates that sections of urban arterial streets can be characterized in units of effective distance, and suggests a methodology for calculating the effective distance between any two points.

The Nature of Urban Highway Facilities

The urban highway system is functionally related to the urban land use pattern. Cities consist of a bundle of specialized activities which have varying land requirements. This results in the spatial separation of these activities into differential land uses. These specialized activities must have interconnections through communications or the physical movement of people and goods. The highway and motor vehicle is one methodof linking land uses by means of actual movement. Improving the quality of highways and increasing the comfort and operating characteristics of motor vehicles result in improved communication between activities geographically disjointed but functionally interwoven. The magnitude of this effort to communicate and interact in urban areas is displayed by the size, cost, and complexity of the highway facilities which we have constructed and the enormity of the travel effort expended in operation over these facilities.

The Urban Highway System: Size and Travel Thereon

The streets and roads which comprise the urban highway system are composed of a relatively few miles of high service value arterial highways on which are accumulated nearly one-fourth of all United States vehicle-miles in both urban and rural areas. The remainder of the urban system, which is a major portion of the total, is functionally oriented in some degree toward providing local access.

Table 1 shows that municipal highway mileage comprises only 12% of the total in the United States. A gross measure of the functional

TABLE 1

RURAL AND MUNICIPAL HIGHWAY MILEAGE IN THE UNITED STATES-1960 [1,2]

	Rural	Municipal	Total
Miles	3,120,000	430,000	3,550,000
Percent of Total	88	12	100

importance of these 430,000 municipal miles can be obtained by examing the type of pavement surface. The higher the type of surface provided, the more important is the travel movement function. Table 2 below indicates that over 91% of all municipal highways have at least a minimum wearing surface. The medium type surface classification would normally be adequate for low density residential subdivisions, while the high

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[1]U. S., Department of Commerce, Bureau of Public Roads, Highway Statistics: 1960 (1962), p. 164.

[2]Ibid., p. 144. A municipality is defined as a population center including cities, boroughs, villages, and towns (Except New England).

type surfaces would be reserved for the routes which are the more important carriers of traffic.

TABLE 2

MUNICIPAL HIGHWAY MILEAGE IN UNITED STATES-1960[1]

Classified by Type of Surface					
	Nonsurfaced	Surfaced			Total
		Low Type	Med Type	High Type	
Miles	38,000	80,000	133,000	178,000	430,000
Percent of Total	8.5	19	31	41.5	100

The municipal extensions of the principal inter-county and intra-county highway routes total nearly 50,000 miles, with 35,000 of these miles being included as a part of the Federal-Aid System. The inescapable conclusion is that the major arterial linkages in municipal areas form but a small part of the urban system and a negligible part of the total United States highway system. Despite this small mileage in urban areas, the level of usage of the urban system causes it to accumulate almost one-half of vehicle-miles in the United States as shown in Table 3. Empirical studies have indicated that at least one-half of these vehicle-miles in urban areas will be amassed on arterial highways comprising less than 12% of the entire urban system. Thus 1.4% of the total United States highway mileage carries nearly 25% of the total United States vehicle-miles.

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[1] Ibid., p. 165.

TABLE 3

RURAL AND URBAN VEHICLE-MILES IN THE UNITED STATES-1960 [1,2]
(Million Vehicle-Miles)

	Rural	Urban	Total
Vehicle-Miles	387,000	332,000	719,000
Percent of Total	54	46	100

Considering the magnitude of vehicle-miles by urban movement alone, a properly balanced highway research program should include study of the characteristics of urban travel behavior.

The Urban Highway System: Planning, Financing, and Public Policy

The provision of highway service is a joint function of the state and federal governments. Thus planning, determination of spatial location, financing, and expenditure of funds for highway development become matters of public policy. Governmental agencies responsible for highways have been spending increasingly larger sums of money each year in order to supply additional or improved highway service. These increased expenditures have been in direct response to a growing public demand for private travel movement. This intensified demand for highway travel is a consequence of a nationwide population growth, an increased desire by people to live in cities, and an increased per capita use of motor vehicles.

The estimated current rate of highway expenditures for all units of governments- federal, state, and local- is slightly over twelve billion

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1 Ibid., p. 80.

2 Ibid., p. 144. An urban area is defined as an area including and adjacent to a municipality or other urban place having a population of 5,000 or more with boundaries fixed by the State highway department and approved by the Bureau of Public Roads.

dollars per year, or about seven per cent of all government expenditures. Since present highway financing is on a pay-as-you-go basis, total highway revenue will be approximately equal to expenditures. The twelve billion dollars of highway revenue is also about seven per cent of total governmental revenue.[1] In 1960, 10.74 billion dollars were expended on highways by all levels of government. This amount of money was larger than the sums spent by goverment on postal service, public welfare, hospitals, health, police, local fire protection, sanitation, natural resources, parks and recreation, housing and community development, or veterans' services. The 10.74 billion dollars was exceeded only by the 47.5 billion spent for foreign aid and national defense, and the 19.4 billion spent for education.[2]

The current rate of spending for highways in urban areas is estimated to be about 3.0 billion dollars. Of this amount 2.2 billion is allocated for capital improvements and the rest for maintenance. The money for capital outlays includes funds for 6,000 miles of urban extensions of the Interstate System and additional funds for the 29,000 miles of the Federal-Aid Primary and Secondary Systems. If the Interstate System is completed in 1971 as originally planned- and there is considerable doubt that it will be- about one half of the estimated cost of 40.0 billion dollars will have been spent in urban areas. Federal-Aid Acts already enacted have also authorized the expenditure of 5.4 billion dollars for

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[1] U.S., Department of Commerce, Bureau of Public Roads Tables: November, 1961 quoted in Automobile Manufacturers Association, Automobile Facts and Figures: 1962 (Detroit: Automobile Manufacturers Association, 1962), p.57.

[2] U.S., Department of Commerce, Bureau of Census, Summary of Governmental Finances: 1960, G-GF60-No. 1 (1961), p.14.

upgrading the municipal extensions of the Federal-Aid Systems. This money is to be spent at the rate of 0.45 billion per year from 1961-72.

Planning studies made by the Bureau of Public Roads indicate that the Interstate System will be adequate for the estimated traffic volumes until 1974. The Federal-Aid Systems will be adequate for the estimated traffic of 1972, the same year that the modernization program is completed. In additional planning studies of highway needs through 1984, the Bureau estimates that another 52.5 billion dollars will be required in urban areas over the period from 1965-84.[1]

The immensity of the sums of money presently being spent or planned for future expenditure for highways in urban areas staggers the imagination. On the basis of an expressed public demand, we as a nation, through governmental policy decisions, are allocating billions of dollars from our national income to the construction of urban highway facilities whose pattern will change and mold the configuration of our cities for the foreseeable future, and whose effects on the city are not too well known. The magnitude of these expenditures alone would seem to justify spending at least a small part of this money in research on urban travel behavior so that the effects of these urban highways on our cities could be more accurately predicted.

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[1] U.S., Bureau of Public Roads, Needs of Highway Systems, 1955-84 (1955), pp. 14, 18 and 19.

The Urban Highway System: Movement Problems

Transportation problems in our larger cities are horrendous, complicated, and are likely to grow worse in the future. Moreover, the traffic congestion alters the mobility of movement along the linkages interconnecting various land uses. This has the effect of altering the competitive position of many urban activities.

The statement that a movement problem exists in our cities is supported by an extensive list of studies and observations made by students of the urban scene. Owen's documented report on metropolitan traffic problems maintains that the "inability to overcome congestion and to remove obstacles to mobility threaten to make the city an economic liability rather than an asset.[1] Owen also noted that the overtaxing of transport facilities is tending to have dire repercussions on the city which these self-same transport facilities made possible. In another publication, Owen commented that there was no doubt about the overwhelming desire of people to live in cities and to travel by private automobile but it is this very choice that is "destroying both the benefits of cities and the advantages of the private car."[2] Tunnard and Reed, commenting on traffic and parking problems in regional cities, observed that in spite of the fact that modern, high-speed highways were a major innovation of

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1 Wilfred Owen, The Metropolitan Transportation Problem (Washington: The Brookings Institution, 1956), p. 1. Reproduced by permission of the publisher.

2 Wilfred Owen, Cities in the Motor Age (New York: The Viking Press, 1959), p.3. Reproduced by permission of the publisher.

the present era, they "have often created as many new problems as those they were built to solve."[1] Public officials in Los Angeles, the city which is presumed to have solved the highway movement problem, have suggested that the saturation point in the use and operation of private automobiles has been reached in their city and that business is being driven away from the area due to serious traffic congestion.[2] With the widespread attention being given to urban movement problems today, further documentation that a problem exists seems unnecessary.

The problems of urban movement noted above are likely to grow worse. Total United States population is increasing and the major portion of this increase is settling in the peripheral sections of our cities. In 1960, nearly 70% of the total population of 179 million resided in urban places.[3] By 1980, it is conservatively estimated that three out of four persons of the nation's total of 245 million will be living in cities and built-up areas.[4] Not only are total motor vehicle registrations increasing, but so are vehicle registrations per capita. In 1960 there were

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1 Christopher Tunnard and Henry Hope Reed, American Skyline: The Growth and Form of Our Cities and Towns (New York: American Library of World Literature, 1956), p. 186.

2 Axel Olson, "The Problem of Decentralization in Metropolitan Areas," Proceedings, 1st Annual University of California Conference on City and Regional Planning (Berkeley: The Conference, 1953), p. 17.

3 U.S., Bureau of the Census, Statistical Abstract of U.S.: 1962, Table 13, p. 21.

4 Wilbur Smith and Associates, Future Highways and Urban Growth (New Haven: Wilbur Smith and Associates, 1961), p. iii.

a total of 73.8 million motor vehicle registrations, or one vehicle for every two and one-half persons.[1] By 1980 it is estimated that there will be a total of 120 million vehicles registered bringing the per capita ratio to one vehicle for every two persons.[2] These predicted increases in people and motor vehicles in urban areas will produce an increase in the volume and intensity of traffic along the highway routes interconnecting the city. There is agreement that urban traffic congestion will be of greater magnitude in the future than it is at the present.

The structure of urban movement is extremely complex. For example, changes in highway capacity have produced measurable effects on land use, the market value of land, agricultural production, tax revenues, traffic patterns, industrial location, retail business activity, and community growth.[3] All of these effects are related to changes in movement caused by altering the friction of travel between land uses. At the present time we have insufficient knowledge to permit us to make estimates of the changes in the factors listed above due to assumed variations in highway capacity. The intricacy of the interrelationships that exist in the total movement system lead to the conclusion that a more minute examination of particular parts of the total system is necessary. Numerous studies of aggregate travel movement have been made in cities throughout the U.S. These studies now need to be supplemented with behavioristic

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1 Statistical Abstract of U.S.: 1962, p. 561.

2 Smith and Associates, p. 29.

3 National Research Council. Highway Research Board, Economic Impact of Highway Improvement, A Report of Conference Proceedings of March 10-19, 1957 (Washington: 1957), (Its Special Report 28), pp. 1-88.

investigations that will indicate the motivation for travel while at the same time specifying in detail land uses and movement characteristics. A comprehensive understanding of parts of the total system may be the key to an understanding of the movement system in its entirety.

Function of Individual Travel Behavior Studies In Urban Highway Research

Urban highway research should attempt to develop information about the organization of urban activities and the position of the highway in supporting these activities. The key to this relationship is the travel movement pattern of the highway users. The role of the behavioristic travel study is to relate the urban structure, in terms of land use activities, to travel purpose and travel movement. Using survey procedures, detailed information is obtained which defines the functional relation between travel purpose, land use, and the highway travel linking each of these land uses. Thus the survey data must specify the sequential pattern of movement, type of urban establishments visited, and the trip purposes associated with each stop. All modes of travel must be recorded as well as precise routes. The terminal problems at the beginning and end of the movement must be determined as well as any mid-trip locations where there is a change in mode of travel. This detailed information is necessary in a first approach to the problem.

The analysis of the data collected proceeds on the basis that the trip purpose information will help to define the motivation for the travel. The land use activities visited during travel movement are the complement of the trip purpose. But in addition, the land use activities at the establishments where travel stops are made are also indicative of the utility of that stop. Collectively, the functions of the establishments represent the total trip utility. The particularized data on actual movement is needed to characterize the friction of travel between the establishments visited. In essence, the empirical data collected represents the gross utility of the trip and the disutility of movement. The analyst can now proceed to identify and classify types of travel movement, make measurements, establish quantitative functional relationships, and draw conclusions. Finally, he can develop empirical abstractions concerning the urban structure and the movement system which can be compared with existing movement theory.

The field investigation which is a part of this thesis in an individual travel behavior study that concerns itself primarily with the disutility of travel between urban establishments. This disutility has sometimes been expressed in geometric units of distance measured along the highway route linking the establishments, or sometimes as the airline distance connecting the two activities. It has been recognized that units of land distance often do not adequately characterize either the friction or disutility of travel. The term friction of travel includes the numerous factors which tend to oppose or discourage movement. The effect of these friction factors is to require the expenditure of energy for movement. The contribution of this study is to show that actual units of highway distance can be physically expressed in units of automobile driver actions. This driver action distance is also shown to be functionally related to customer contacts for a supermarket.

Related Travel Studies

The bulk of the information available today on urban travel patterns has been derived from data collected in comprehensive origin-and-destination studies conducted in cities throughout the United States. These studies constitute the major research effort on urban travel patterns by highway and traffic engineers. The information has been summarized in numerous publications including that of Schmidt and Campbell.[1] These studies have contributed much to our present knowledge of the characteristics of urban travel. But at the same time we must realize that this type of empirical investigation has four inherent limitations: (1) the functional interrelationships between trip purpose, land use, and travel routes are not made clear because of deficiencies in the data collected; (2) the information gathered is attempting to portray the entire movement system and at best, only aggregate observations can be made concerning large groups of people; (3) the O-and-D study in point of time always applys to a past situation and therefore can best be used to describe travel at the time the study was made; and (4), the empirical information collected is representative of the particular spatial arrangement of functions within the city studied.

The difficulties noted in (1) and (2) above are problems involving survey procedure. Precise locations for origins and destinations are often not given, even with recourse to the original data. Thus specific

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[1] Robert E. Schmidt and M. Earl Campbell, Highway Traffic Estimation (Saugatuck, Connecticut: Eno Foundation for Highway Traffic Control, 1956), pp 8-170.

land uses cannot be identified. The eight classifications for trip purposes are often too gross to identify the trip motivation.[1] Moreover, there are no provisions for recording multiple-purpose trips. It is also difficult to evaluate the friction of travel since the precise route followed is not recorded nor are terminal problems investigated. The latter includes parking maneuvers, parking charges, and walking. Since walking trips are excluded from the survey, travel either entirely or partially by this means is not recorded. The problems noted in this paragraph could have been overcome by conducting a few detailed studies to accompany the broader objective of the basic O-and-D study.

Two more recent pieces of research in this field are worth noting. In a Chicago study, some sixty land use classifications at the origin and destination of each trip were recorded. The classifications were sufficiently detailed that in the case of retail shopping trips, basic store types could be differentiated.[2] In a San Diego study, the travel characteristics of two subdivisions were analyzed in detail.[3] Both of these works are steps in the direction toward a more complete understanding of the basic movement problem.

Other than the O-and-D studies and the investigations by Hall and Lynch, there is little travel behavior research reported in the

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[1] Bureau of Public Roads, Manual of Procedures for Home Interview Traffic Study: Revised Edition (October, 1954), p. 34.

[2] John T. Lynch, "Home Interview Surveys and Related Research Activities," National Research Council. Highway Research Board Bulletin, 224 (1959), p. 85.

[3] Edward M. Hall, "Travel Characteristics of Two San Diego Subdivision Developments," National Research Council. Highway Research Board Bulletin, 203 (1958). pp 1-19.

technical literature. The Highway Research Board, an agency of the Engineering Division of the National Research Council, acts as a national clearing house for the publication and dissemination of technical reports on highway research activities. Bibliographies published by this agency indicate that the bulk of the urban traffic research has been both empirical and facility-oriented. The highway impact studies published by the Highway Research Board and noted in this section on page 10 did take into account some of the spatial effects when a new highway was constructed, or an existing one was modernized. But there was no attempt to develop a structural basis which would explain these effects.

Important contributions to travel behavior notions have been made by other disciplines. Garrison and Marts investigated business establishments both before and after changes were made in the highway system serving these establishments. Observations were then made concerning modifications in the business location structure subsequent to the highway changes.[1] A theoretical presentation by Mitchell and Rapkin portrayed traffic as a function of land use and developed several means of obtaining information on urban travel behavior.[2] Troxel's theory on the demands for the movement of people suggests that individuals attempt to maximize the returns from travel over the period of time spent in accomplishing the purposes of the travel.[3]

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1 William L. Garrison and Marion E. Marts, Geographic Impact of Highway Improvement, ed. William L. Garrison and Others, Studies of Highway Development and Geographic Change (Seattle: University of Washington Press, 1959), pp. 101-14.

2 Robert B. Mitchell and Chester Rapkin, Urban Traffic: A function of Land Use (New York: Columbia University Press, 1954), p. 76.

3 Emery Troxel, Economics of Transport (New York: Holt, Rinehart and Winston, 1955), pp. 151-55.

The citations noted in this section are the major research efforts on urban travel behavior where the topic investigated deals specifically with transportation. The paucity of information and research in this area indicates the need for further investigative work.

Conclusion

As a nation, we may be committing some tragic mistakes. We are spending, and are prepared to spend in the future, billions of dollars for urban highway facilities with the expectation of relieving traffic congestion. But in planning these facilities, we are not able to estimate their effects on the urban structure because of lack of detailed information on the manner in which people move. With extensive construction and modernization programs for urban highways already under way, we are most certainly changing the present configuration of our cities and establishing patterns for the future. But what this pattern will be we cannot state. There is no apparent lack of willingness by people to pay for these facilities-only a lack of allocation of funds to the needed research. The predicted growth of cities and the projected increase in the use of motor vehicles in urban places makes the need for this research much more urgent.

CHAPTER II

ACCESSIBILITY AND URBAN MOVEMENT NOTIONS

The previous chapter examined the important position of individual travel behavior studies in furthering our empirical knowledge of the relation between the highway system and the specialized activities on urban land. This chapter continues by introducing some terminology and then relating a behaviorial study to accessibility concepts. Since the latter term has a variety of meanings, some standard definitions are adopted. Next, it is shown that the ability to measure the effective distance between two points is a structural assumption of all urban movement theory. Finally, the technical factors influencing effective highway distance are considered.

General Nomenclature

Accessibility and movement structure involve additional terminology which should be made clear. An urban area consists of a group of specialized activities. These activities, normal and appropriate to cities, are the actions, operations, and processes which produce goods and services. A good is any item of real or personal property which human beings desire and a service is an accomodation demanded by the public. These goods and services have the quality of satisfying human needs and thus possess utility. The specialized activities are functionally divided into broad groups. One is a firm and is usually thought of as a business designation. The other is a household and is a residence or home. The functions of firms and households are conducted at specific locations called establishments. The desire by people in cities to have contacts and interaction at establishments spatially separated from them is the source of a travel demand. A trip purpose is defined by the functions carried on at the establishment visited and the satisfaction obtained therein is the trip utility of that stop. The actual movement to other establishments creates linkages between the various specialized activities. The spatial arrangement of these activities determines the functional land use pattern. Physical movement between establishments cannot be accomplished without the expenditure of energy which is alternately termed travel effort, travel cost, or the disutility of displacement. Factors causing this expenditure of energy are collectively labeled as the friction of travel. The term distance will for the moment be construed as encompassing all possible measures and units describing the spatial separation between two points. Given a firm occupying a particular establishment, the various distances which people are willing to travel to the establishment for the utility located there marks out a contributory area, the radial extent of which is called the range of the good or service produced by the firm. The outermost limit of this radial distance from the establishment is denoted by the maximum range and is determined by the greatest distance which people are willing to travel. Beyond this maximum distance either the cost is too high because of the travel effort involved or there is a closer competing source for the utility provided by the particular good or service. The minimum range or threshold circumscribes an area around the establishment which includes the minimum number of customers necessary to insure the economic operation of the firm.

Relation of Individual Travel Behavior To Accessibility

The prior chapter indicated that a behavioristic investigation of travel movement elicits information from the individual which identifies the reason or motivation for a trip thus permitting the assignment of a particular purpose to it. The place where this purposive trip starts is a point source of demand for transportation. The terms trip purpose and trip demand are considered to be interchangeable on the assumption that the trip purpose defines the utility of the trip and that the trip demand indicates a willingness to pay for this utility in terms of the travel effort associated with the contemplated movement. Trip utility and travel effort are thus related in a schedule sense. Assuming that travel effort is directly related to travel distance, the implication of the demand schedule is that each trip purpose in the schedule presupposes a maximum aggregate travel distance or maximum range of movement. Thus a trip purpose or a trip demand always has associated with it a particular utility and a maximum range of movement. The relationship between trip purpose and travel distance has been verified by studies made of comprehensive origin-destination data collected in major cities throughout the United States.[1]

In conclusion it should be noted that an actual travel demand is a function of an individual's evaluation of the existing opportunities

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[1] For example see Detroit Metropolitan Area Traffic Study, Part I (Lansing: Speaker, Hines and Thomas, 1955), Table 42, p. 125.

for movement that are included within the spatial boundaries established by the maximum range for this travel demand. The notions involved in opportunity for movement revolve around concepts of accessibility. Hence individual travel behavior and ideas pertaining to accessibility are inseparably linked.

Accessibility, Travel Behavior, And Urban Land Use Patterns

The literature on urban studies is replete with definitions and descriptions of accessibility as it relates to travel movement and land use. Many of these descriptions have special meanings to the authors within the context of their studies. Running through these varied notions of accessibility however are several consistent themes. Because of the growing importance of understanding the urban structure and its transportation system, an increasing number of scholars have felt the necessity of identifying these central ideas in the accessibility concepts in order to provide some uniformity to an otherwise confused situation.[1,2] Since accessibility, travel behavior, and land use are interrelated, the three topics should be discussed together. However, the material is organized around concepts of accessibility.

Accessibility Notions

Accessibility is similar to a coin with each face conveying a different picture. Yet the two faces are complementary in forming a

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[1] John D. Nystuen, "A Theory and Simulation of Intraurban Travel," Paper Prepared for Symposium on Quantitative Methods in Geography, National Academy of Sciences-National Research Council, Chicago, May 5-6, 1960.

[2] W. R. Tobler, "Studies in the Geometry of Transportation," Paper prepared for a Transportation Georgrphy Study, Transportation Center, Northwester University, Oct. 31, 1962.

single entity. One side of the accessibility coin is thought of as the opportunity or potential for movement. This movement is within specified limits provided by a designated mode or modes of transportation between a given point and all other places. Since the emphasis in this study is on urban areas and traffic problems, the "displacement opportunity provided" is limited to people, physical goods, and services that are transportable by any of the usual modes of travel found in urban places.[1] The specified limit may be an arbitrary one such as a political or geographic boundary; or it may be a behavioristic limit similar to the maximum range of travel associated with the contributory area around an urban function.

The other side of the accessibility coin is the movement face. Here the emphasis is on the assumed or actual displacement that results from the potential on the other coin face. Displacement is expressed as the friction of travel or as the magnitude of travel effort. Since many travel demands tend to be repetitive with time, it may be more meaningful to express the travel effort over an appropriate time period, and relate it to the relevant displacement opportunity for a similar period.

Within the general framework of these concepts of accessibility there are several special meanings. These are discussed in the paragraphs which follow.

Locational Accessibility

Given a reference point and a specific mode of travel, locational accessibility defines the lineal extent or spatial expanse from

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[1] Ibid., p. 30. Tobler quantifies this concept of accessibility by cumulatively adding the relevant items for which a displacement opportunity is provided.

this reference point for interlocational travel opportunities. The idea presented here is somewhat analogous to the concept of outright physical access. This special meaning has no associated travel purpose and hence no limitation on the range of movement other than the transportation facility itself, or some arbitrary limit established by the individual using the term. For example it is possible for people to travel by subway from the Battery in New York City to 212th St. With respect to the Battery, 212th St. is locationally accessible by subway. On the other hand one might be interested in the opportunities for movement by streets and highways from every point within the New York Metropolitan Area to the intersection of Lexington Avenue and 42nd St. The emphasis in locational accessibility as indicated by the examples, is most often on the land served by a particular transportation facility.

Aggregate Accessibility

Given a specific point within a city, the aggregate accessibility at the given point is the sum total of all opportunities for travel by all modes of transportation from (to) every point within the city to (from) the given point. This type of accessibility can also be expressed as the potential for movement within the city from all other points to a given point. Since the publication of Haig's theory of urban organization,[1] it has been accepted that if a city encompasses an area approximating a circle, the greatest aggregate accessibility is at

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[1] Robert M. Haig, Major Factors in Metropolitan Growth and Arrangement: Regional Survey of New York and Its Environs, Vol. I (New York: The Regional Survey Commission, 1927), p. 38.

the center of the city and the accessibility of any other point away from the center is a lesser value. Accessibility is presumed to be directly related to site rent and inversely related to aggregate travel costs. In moving away from the center of the city, there is a decrease in accessibility, a decrease in site rent, and an increase in aggregate city-wide travel costs. The urban activities which occupy land at the center of the city will have to pay the highest site rents in the city but the total travel costs for the city to that same point will be a minimum. Conversely, site rents at the periphery of the city will be the lowest, accessibility the least, and total travel costs the highest.

This notion of accessibility is used to explain the pattern of land use that develops within a city. Urban activities are viewed as competing with each other for the relative spatial positions they occupy on the basis of their efficiency in extracting economic utility from any given site. This latter efficiency then determines the rent-paying ability of that activity. The efficiency of an activity to extract economic utility from a site depends in part on the internal operating characteristics of the activity and the intensity with which it can use the site. For example, a jewelry store can make much more intense use of the land it occupies than a furniture store can. The efficiency also depends on the extent to which any given activity can utilize the aggregate accessibility of a site when measured against the travel requirements implied from the other urban activities interconnected with the given function at the site. Land uses occupying highly accessible sites- and able to pay high site rents- are doing so because of the savings in transportation costs which the site provides. The outcome of this economic competition among alternate land uses is a spatially organized pattern of urban activities.

Functional Accessibility

This classification of accessibility is a measure of the opportunities for movement to (from) a particular urban function from (to) other urban activities that are spatially interconnected with the given function. The boundary on the opportunities for travel is in this case the maximum range of travel to (from) the establishment for the given function, or the maximum range of travel for the given function in combination with one or more of the other spatially linked functions. The movement aspect of functional accessibility is either the friction or effort of the travel pattern which links the given function to the other activities. As an example of this type of accessibility, consider a supermarket. It has strong linkages to the households which it serves. From empirical observations made in the field investigation which is a part of this study, it is known that a supermarket has other linkages of lesser importance to banks, to other food stores, to wholesale food suppliers and to households other than those furnishing a shopper at the supermarket. The area encompassed by the opportunities for movement includes the maximum range for some combination of the above functions. The travel pattern interconnecting these activities generates a cumulative travel effort which is also a measure of the functional accessibility.

It is clear that the framework of reference for the above definition is the group of functions connected. But it is also clear that it is the movement pattern that establishes the linkages between the various land use activities. Travel behavior notions start with an individual having a demand for travel. This demand may include a collection of travel purposes. Each purpose has a maximum range of travel. These purposes may be grouped together to form a new maximum range of travel. It is then assumed that the individual considers all of the locations where the trip utility may be obtained and the various opportunities for movement to the different establishments. As a result of this procedure, he arranges a sequence of movement that will maximize the difference, on a time basis, between total trip utility and aggregate travel effort.

Discounted Accessibility

This concept is used to account for the observed decrease in the intensity of travel to (from) an activity as the distance from the activity increases. The total displacement opportunities provided for people, goods, or services within some specified limit is diminished by a weighting factor which decreases with increasing distance from the establishment. At the maximum range the weighting factor is zero.

When the displacement opportunities are calculated for a functional accessibility situation, it is understood that not all of the people, goods, or services will either move or be moved. The discounted accessibility notion measures the extent to which the potential is used at various radial distances from the establishment.

Accessibility and Effective Distance

The general notion of accessibility as discussed in the prior paragraphs has been built around the concept of the opportunities for movement provided for people, goods, or services in urban areas. The evaluation of these opportunities undoubtedly involves a number of quality of movement considerations which can broadly be characterized as the time, comfort, and convenience factors. Discounted accessibility is probably the result of discounting for both distance and quality of movement.[1] In the field of highway transportation, relative differences in the quality of travel may make one road far more attractive for movement than any other even with no difference in total overall length. In order to compare the quality of two different highways, units of measure and distinguishing terms are required in addition to ground distance. From henceforth in the text, the term effective distance is assumed to encompass all possible measures and units for describing the spatial separation of two points including friction and effort factors and units of land measure. The term distance will from now on refer to land measure exclusively. In this context, distance is only one of many possible measures of effective distance.

Role of Effective Distance In Movement-Location Theory

Two of the major structural assumptions in almost all of the theories of travel movement pertaining to land utilization are that

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[1] If elapsed time and distance are combined into a speed of travel notion, the entire process can conceptually be one of quality discounting.

transportation costs are proportional to distance and that the quality of movement is everywhere the same. This abstraction is necessary to simplify the variables and reduce their number. Moreover, there has been no satisfactory technique to relate either the friction or effort of travel to distance, or to compare the relative qualities of movement between different routes. The role of effective distance in several location-movement theories is briefly sketched below.

Urban Land Rent

R. M. Haig laid down the principles of the urban land rent theory which were discussed under the topic of aggregate accessibility on p. 22. In brief, the theory holds that there is an order to the land use patterns which develop within urban areas. The utilization of urban land is dictated by the relative efficiency which each of the competing uses can make of a given site. One of the measures of this efficiency is the extent to which the competing land uses can utilize the aggregate accessibility of a given site when measured against the functional accessibility requirements for each of these competing uses. Since notions of accessibility suggest quality of movement considerations and aggregate travel costs, effective distance as a measure of the interval spatially separating two or more points thus becomes one of the major factors shaping the resulting pattern of land utilization in Haig's theory.

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1 Haig, pp. 21-38.

Another author, R. U. Ratcliff, has written extensively on the urban land rent theory but his work has consisted chiefly of an amplification of Haig's basic principles.[1]

Location Theory

The land rent theory discussed above stops with the identification of the forces tending to shape land utilization. Location theory accepts the forces identified in the land rent concept, but goes further by attempting to explain the emergent pattern of land use. Location theory is constructed around the premise that the spatial position of an economic activity can be explained in terms of orderly and measurable processes. The part played by transportation in the location procedure is made more specific by explicit recognition of travel costs, or by acknowledging their indirect effect in establishing boundaries for producers or distributors of goods or services within an economic region. Von Thünen assumed transportation costs to be directly proportional to distance in describing the concentric ring distribution of agricultural production around a single, isolated market with radial distance from the city dependent on the rent-paying ability of each crop.[2] In his "Central Place Theory," Christaller set forth the complementary relationship between the number of functions in a central place and the magnitude of its

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1 For example see Richard U. Ratcliff, Urban Land Economics (New York: McGraw-Hill, 1949), p. 387. Ratcliff adds details to Haig's notion of the city center being the most accessible location.

2 Johann N. von Thünen, Der Isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie (Jena: Gustav Fischer, 1930) and discussed in Richard T. Ely and George S. Wehrwein, Land Economics (New York: Macmillan, 1940), pp. 66-70.

rural market area. Boundaries between central places of the same size are determined on the basis of the maximum range of consumer movement from the rural areas to the central place for the function located there. Christaller's conclusions that a group of overlapping hexagonal market areas develop, and that central places with the same number of functions have equal market areas depend on the assumption that transportation cost for the consumer is directly proportional to distance.[1] Lösch postulated an economic region which is dissected into a net of hexagonal market areas for each commodity. The entire net is grouped around a central production point on the basis of least transportation [distance] effort.[2] Isard's notion of a regional economy proposes to express some of the complex economic relationships in terms of a transport input. The latter is defined as the movement of a unit of weight over a unit of distance.[3]

Movement patterns in the foregoing theories are based upon complete knowledge of the market, no mistakes in travel choices, single purpose trips, and minimization of travel to fulfil the travel demand. Troxel has suggested another approach to travel inducement and movement patterns by individual consumers. He outlines a process in which travel

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[1] Walter Christaller, Die zentralen Orte in Süddeutschland (Jena: Gustav Fischer Verlag, 1933), and analyzed by William L. Garrison and Others, Studies of Highway Development and Geographic Change (Seattle: University of Washington Press, 1959), p. 51.

[2] August Lösch, The Economics of Location, 2d ed., trans. William H. Woglom assisted by Wolfgang F. Stolper (New Haven: Yale University Press, 1954), p. 111.

[3] Walter Isard, Location and Space Economy (Cambridge: Technological Press of Massachusetts Institute of Technology, 1956), p. 79.

motivation by a home based consumer is predicated upon the individual maximizing the net return for a trip per unit of elapsed trip time. The gross travel returns are the utilities obtained from the establishments visited. The deductions from gross travel returns include loss of home utility and travel costs for a given movement pattern. The gross trip utility less the cost of being away from home and the movement costs is the net travel return for the trip.[1]

Conclusion

It is clear from the contributions made by various authors to urban land rent notions and to location theory that a major underlying assumption by all of these scholars is the direct relationship between distance and all possible measures of effective distance. The latter also implies an ubiquitous quality of movement. These theories and notions are of obvious interest to us today as we attempt to gain a better understanding of the urban structure. However, the abstraction that travel effort or travel friction is proportional to distance is not realistic when applied to an urban environment. The theory may still be valid though if appropriate units of effective distance are substituted for distance. Thus any attempt to empirically verify these existing theories as they relate to our urban areas depends upon the development of a practical technique for relating distance and effective distance.

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[1] Troxel, pp. 151-55.

Technical Concepts For Evaluating The Effective Distance Of Highway Travel

Effective distance has been characterized as a measure of the interval spatially separating two or more points. The term embraces a complementary cause-effect relationship. Effective distance can be expressed in friction of travel units to emphasize the factors that are tending to oppose an actual or contemplated movement. Examples of friction of highway travel units are the number of stoplights, the number of stopsigns, or the number of major intersections per mile of travel. The friction of travel requires the expenditure of units of disutility. Examples of these units are trip time, distance, trip fares, out-of-pocket costs, and physical effort. In this section friction factors for highway travel are examined but no attempt is made to quantify them due to the extensive number. Possible measures of travel disutility are indicated along with the one used in this investigation.

Factors Contributing To Highway Travel Friction

The frictional environment of the highway is determined by the collective effect of the fixed fixtures of the highway path, the individual driver characteristics, the nature of the vehicles being driven, the traffic stream operating on the highway, terminal problems, the nature of the land use abutting and adjacent to the highway, general atmospheric conditions, and the configuration of the urban area.

Highway Geometry

These features are often inclusively referred to as the fixed geometric design elements. Their importance lies in the fact that their combined effect conclusively determines the manner of vehicle operation. The highway designer considers the topography and land use through which the highway is planned. He estimates the hourly volume of vehicles which will move over the proposed highway. The latter volume is essentially the load which is being applied to the highway and is extremely important in determining the type of geometric features provided. A design speed is selected which will correlate the physical highway features with vehicle operation. Lastly, a capacity for the highway is selected with respect to uninterrupted flow, taking into account capacity restrictions of intersections at-grade, ramps, and weaving sections.

The previous design criteria are then translated into the basic elements of geometric design. These elements, all of which influence travel friction, include consideration of the items which follow:

1. The passing sight distance necessary for one vehicle to overtake, pass, and move ahead of another vehicle.

2. The maximum degree of horizontal curvature.

3. Horizontal easement curves to make the transition between tangent and circular sections of roadway.

4. Superelevation of the outer edges of the pavement surface on horizontal curves and transition sections.

5. Widening of the traffic lanes and shoulders on horizontal curves.

6. Sight distance on horizontal curves.

7. The maximum vertical gradient, and the critical length of highway at that gradient which will not seriously affect vehicle operation.

8. The rate of change of the slope to the vertical curve connecting two vertical gradients.

9. The facilities provided for the drainage of water from the pavement surface and adjacent right-of-way and the accompanying erosion control measures.

10. Landscape development of the highway right-of-way.
11. Highway lighting to increase the motorist's visibility.
12. The material used to construct the pavement surface.
13. The transverse slope of the traffic lanes.
14. The width and number of traffic lanes.
15. The control of access to abutting and adjacent land.
16. The number and complexity of at-grade intersections.
17. Actual and apparent lateral obstructions along the highway.

Traffic Friction

Highway traffic friction is determined by the interaction of the driver and vehicle characteristics, the geometry of the highway, the traffic regulations and control devices in effect, and the operating characteristics of the traffic stream.

Driver Characteristics.--In attempting to define the nature of individual road users, one finds that the pertinent elements are largely physical and psychological. The precise relationship between these factors and the manner in which the individual operates a motor vehicle has not been clearly defined except with respect to motor vehicle accidents. The bulk of the research in the past ten years pertaining to the individual road user has been in connection with accident proneness and the psychological traits of the individual which produce this type of driver. Investigators studying the general characteristics of the individual driver agree on the physical and psychological factors to consider, but the level of knowledge does not permit one to state the degree to which these factors influence the driver. The problem is further complicated by the fact that each driver contributes certain individual characteristics to the composite nature of the traffic stream. Yet the composite characteristics of all the individuals using the highway have a feed-back effect which can produce changes in any one driver. To avoid delving into this problem, one usually assumes that a temporary state of equilibrium is reached between the characteristics of the traffic stream and each road user. The variables listed on the following pages are important characteristics of the individual road user which may vary widely among individuals.

The ability of each driver to interpret changing highway and traffic situations and to comprehend the mechanical operation of the car appears to be somewhat related to the general level of intelligence. Matson notes that drivers having a higher mechanical comprehension tend to have fewer traffic accidents. But drivers with superior intelligence appear to be less attentive to the driving task.[1] Moffie also found that safe drivers made high scores on mechanical comprehension tests.[2] The ability of the driver to learn from previous highway and traffic situations will condition his response when these same or similar situations occur again. The familiarity of the driver with a particular route and

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[1] Theodore M. Matson and Others, Traffic Engineering (New York: McGraw-Hill, 1955), p. 12.

[2] D. J. Moffie and Others, "Relation Between Psychological Tests and Driver Performance," National Research Council. Highway Research Board Bulletin, 60 (1952), p. 22.

his years of driving experience are important characteristics of the individual. Visual acuity is another important variable between drivers. Every highway or traffic situation that requires some positive action by the driver involves an individual time response factor. This is the total time that elapses while the driver perceives and evaluates the road situation presented to him, decides on a course of action, and begins to set certain mechanical operations in motion. The physical and emotional well-being of the driver affects the manner in which he drives. Fatigue, alcohol, drugs, anxiety, and anger have well known effects on individuals. Disease and disability tend to produce more complex and less well known effects. The age and sex of the driver may also be important factors. In connection with age though, some authors point out that functional age is much more important than chronogical age.[1]

Varying weather conditions are known to produce drastic changes in vehicle operation. But Matson notes that the generalized climate of an area also evokes different psychological responses in the individual. Severe weather conditions produce apprehension. Unusually high temperatures produce nervous irritability.[2] Unusually low temperatures tend to slow down physical activity and responses. Strong winds may cause the driver to adopt a more cautious driving behavior. Precipitation, cloudiness, and fog reduce the driver's visibility. Depending on the humidity and temperature, any of these three items may add to or subtract from the

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1 Ross A. McFarland, "Human Factors in Highway Transport Safety," National Research Council. Highway Research Board Bulletin, 60 (1952), p. 41.

2 Matson and Others, Traffic Engineering, p. 23.

individual's level of comfort. Bright sunshine often makes people feel more expansive while dull, cloudy days cause them to be more withdrawn. The generalized weather conditions undoubtedly produce complex reactions in individuals but little appears to be known concerning its precise effect.

The trip purpose is presumed to have an effect on the manner in which the vehicle is operated and on the highway selected. But it undoubtedly produces an effect on the driver, irrespective of the two preceding manifestations. Trips of an emergency nature produce apprehension and anxiety. The driver is probably more relaxed on a social-recreational trip than he is on a work trip. The length of time available for a particular trip is important.

Lastly, one's degree of social maturity seems to be related to one's driving behavior. Fear, anger, self-protection and competition are not uncommon responses produced in the driver. Control of these emotions requires a mature individual. Brody found a high correlation between accident repeaters, traffic violators, and the emotional make-up of the individual. The violators and repeaters were aggressive, intolerant of others, resented authority, had exaggerated opinions of themselves, and acted impulsively.[1] McFarland stated it quite succinctly when he said that a man drove a car in the same manner that he lived. If he were maladjusted in his personal life, then he was apt to be an accident prone driver.[2]

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[1] Leon Brody, "Personal Characteristics of Chronic Violators and Accident Repeaters," National Research Council. Highway Research Board Bulletin, 152 (1957), p. 2.

[2] Ross A. McFarland, Highway Research Board Bulletin, 60 (1952), p. 41.

Vehicle Characteristics.-- The motor vehicle contributes to highway friction in a number of complex ways. The dimensions, performance, operating ease, state of repair, and physical comfort influence the extent of its use and the manner of its operation. When the vehicle is moving on the highway, it can be considered as a discrete particle in a traffic stream. In this context, each vehicle produces an effect on the drivers of other cars coming within its zone of influence as well as an effect on the individual operating the car.

Physical dimensions of an automobile produce reactions on the driver. The drivers of small foreign and compact cars cite their increased highway maneuverability. Some owners of the physically smaller imports will not drive on freeways during rush hours due to the lower and narrower silhouette, and smaller horsepower. The larger width, and longer length and overhang of the standard American car is a disadvantage in congested traffic or where parking maneuvers are restricted.

The operating ease and physical comfort of a vehicle are best described by its general road behavior.[1] Included within this classification would be the behavior of the braking system; the ability of the car to prevent or reduce uncomfortable motion for its passengers when moving over rough or uneven road surfaces (generally characterized by the single word ride); the noise level inside the car due to the motor and power train system, body rattles and looseness, and tire, pavement, and wind noise; the seating comfort provided by the seat contour, the height

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[1] For an excellent discussion of the term, see "Road Behavior," Consumer Reports, XXVI, No. 4 (April, 1961), p. 183.

above the floor, the upholstery of the seat surface, the firmness of the springs, and the insulation and padding over the springs; steering as measured by the degree of close agreement between changes in the car's direction in relation to the amount of turning of the steering wheel; and lastly, the visibility afforded to the driver so that he will receive all visible information related to the safe operation of his car.

For a large cross-section of vehicles, the state of repair is related to the age. Here again the variability is great. Some drivers purchase new automobiles and spend the absolute minimum on maintenance since they plan to trade every two years. Other drivers will not operate a vehicle of any age unless it is in a satisfactory state of repair.

Traffic Regulations.--Traffic regulations and motor vehicle codes promulgated at the state and local level are unquestionably involved with the driver's evaluation of highway friction. Of all regulations, probably speed controls are the most important, since they establish the maximum speed at which the motorist may legally travel. In urban areas, pedestrian rules, bicycle regulations, and their level of enforcement establish the degree and extent to which the motorist must share the highway with individuals who are not motor vehicle operators. The presence of numerous bicycles and pedestrians in the street gives the motorist a sense of uneasiness and he may drastically reduce his speed. The establishment of one-way streets can improve the ease of movement on these streets. But they can increase the actual driving time and distance if the destination happens to be inconveniently situated with respect to the one-way street system. Curb parking regulations are related to the terminal problem. The time duration of curb parking permitted tends to control the turnover of parking space, and thus the availability. The permitting of curb parking and its time-duration is important to those facilities within the maximum limit of the distance which a motorist will walk.

Traffic Control Devices.--Traffic control devices are physical appurtenances which are placed along the highway at specific locations to advise the motorists of any requirements or conditions influencing his use of the highway. In order to be effective, control devices must be viewed and understood by the motorist. The time rate with which the driver encounters these devices, their visibility, the clarity of meaning, and the complexity of any driver maneuvers required by these devices, are important to the driver's ease, safety, and comfort of movement.

Traffic signs are placed along the roadway for a number of purposes. Traffic regulations relating to roadway use must be conveyed to the motorist. No parking signs and speed control signs are typical of this group. Signs are also used to warn the motorist of an impending danger. Advisory speed signs for sharp curves, underpasses with restricted vertical clearances, and railroad crossings fit into this category. Signs can also be used to direct the motorist such as one that tells him the name of the next town and its distance.

Traffic markings are the lines, words, or symbols that are usually affixed to the pavement or curb. A traffic marking may be regulatory, as it is when the speed limit is painted on the pavement, or the curb is painted yellow to signify a "No Parking" zone. It may be advisory when the words "School Ahead" are painted on the pavement, or it may be guiding when left turning lanes, through traffic lanes, and right-turning lanes are appropriately marked on the pavement.

The last traffic control device is the traffic signal. This control device is used at intersections where the volumes of vehicles approach the capacity of the intersection, and it is necessary to assign priority of movement to each of the different approaching legs. The individual motorist's evaluation of highway friction is partially dependent on his ability to keep his car moving. The length of delay for a driver at any signal depends on the time apportionment between the diverse highway routes and the number of cars ahead of him waiting to move through the intersection after the light changes to green.

<u>Operating Characteristics Of The Traffic Stream</u>.--An indirect indication of the motorist's evaluation of the travel friction of a particular highway can be obtained by measuring the operating characteristics of all the traffic. If this discussion is restricted to the urban area where usually there are a number of choices of routes available, then one can assume that the driver has considered the nature of the other drivers on the road, their vehicles, the type of highway design, and the operating traffic characteristics which are known or are likely to exist. Given this information and the trip purpose, the motorist makes his selection of a particular route.

In characterizing traffic stream friction, one needs to know the various components making up the total-private cars, commercial vehicles, bicycles, and pedestrians. Speed is another variable which can be described in a number of different fashions. The running speed is the average speed maintained while the vehicle is in motion. Over-all speed is the average between the origin and destination. Cruising speed is the nominal speed of the vehicle when it is not obstructed. Maximum and minimum speeds are self-explanatory. And lastly, the feature of the traffic stream may be noted by measuring traffic volumes and their distribution by time: hourly, daily, and weekly; their distribution by particular routes; and, their distribution longitudinally along the highway to obtain a density measurement.

Terminal Problems

A trip made via private automobile and highway from an origin to a particular destination usually involves the temporary storage of the vehicle at or near the destination. Parking and storage is in reality a part of the total highway movement problem. The proximity of parking facilities may strongly influence the driver's choice of destination, when a choice exists.

For a motor vehicle trip which terminates in an on-street parking space, terminal friction is determined by the following considerations: the municipal parking regulations in effect at that location; whether parking meters are present, and if so, the parking charge per time period; whether cars are parked parallel to the curb or at an angle; the lineal dimensions of the curb parking space in relation to the size of the motorist's car; the adequacy of definition of individual curb parking spaces by means of painted lines and curbs; and lastly, the extent of traffic interference to curb parking maneuvers caused by vehicles moving past the curb parking space.

For vehicle trips terminating in an off-street parking space, terminal friction is evaluated by the following considerations: the ease and safety of movement over the road connecting the street or highway and the off-street parking area; whether the off-street parking provided is a lot or a garage; if a garage, whether parking of vehicles is done by motorists or attendants; if parking in a garage is by attendant, the time delays in delivery and pick-up of the motorist's car; if parking in the garage or lot is by the individual motorist, the ease of interior circulation within the lot or garage as measured by the sharpness of turns, steepness of grades (if any), width of aisles, angle of parking, lineal dimensions of individual stalls, spacing between stalls, clarity of delineation of parking spaces, interference from other vehicles, type of pavement surface and adequacy of drainage, and safety and distance of pedestrian movement from car through parking area; and lastly, for all off-street facilities, the parking charges, if any, and whether collected by meter or attendant.

Control Of Access And Land Use

Comprehensive community planning is physically expressed in the master plan for the urban area. A transportation plan for the community, evolving from the master plan, can materially minimize future traffic problems, since the transportation plan provides for congruity in the development of land and transportation facilities. The major tool for implementing the master plan and all its elements, is the zoning ordinance. Zoning regulations control the location and density of traffic generators and thus can effectively limit traffic congestion. The

National Committee on Urban Transportation has noted that "to a greater extent than in the past, zoning ordinances today embody special provisions dealing specifically with traffic problems and land-use development."[1] The Committee stated that these special provisions include requirements for off-street parking and off-street loading and unloading when new buildings are constructed or when major building revisions take place, the screening of parking areas from adjacent residential developments, and for the location of terminal facilities in relation to major street systems.

But the implementation of the land-use plan and the balancing of land uses and transportation facilities are not the only objectives of a zoning program. As Stanhagen pointed out, a zoning program can be effective in the preservation of the traffic-carrying ability of existing or newly developed transportation routes and in the proper utilization of existing transport routes.[2] The effect of zoning controls on highway movement is largely indirect by providing a faster, safer, and a more free moving manner of vehicle operation. This in turn tends to reduce the friction of travel.

Climatic Conditions

The generalized weather conditions are presumed to be an important factor in the evaluation of highway friction. However, there are

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[1] National Committee on Urban Transportation, Better Transportation for Your City (Chicago: Public Administration Service, 1958), p. 87.

[2] W. H. Stanhagen, Highway Transportation Criteria In Zoning Law (Washington: U.S. Government Printing Office, 1960), p. 6.

no studies available to evaluate the precise and complex influence of weather. A previous section has indicated that climate produces a psychological reaction on the individual highway user, separate and distinct from his role as a vehicle operator. Climate also strongly affects the speed and safety of vehicle operation. Snow, rain, fog, and reduced visibility under general storm conditions make driving less safe. Undoubtedly the highway user takes these factors into account when contemplating a motor trip. Operators of retail businesses have noted that customer volumes fall off with inclement weather of any kind, including a light rain shower.

Shape Of Land Use Development

The spatial arrangement of urban land activities is influenced by the collective effect of individual travel behavior patterns. But such behavioristic influence in causing the rearrangement or development of urban functions is always subject to the limitations of availability and suitability of land for the intended use. These limitations include topography, climate, soil characteristics, physical barriers both natural and man-made, existing land uses, and zoning restrictions. The effect of travel behavior subject to these limitations can produce a spatial distribution of urban functions irregular in shape. For highway users residing and traveling within these areas, the irregular shape influences travel distances and establishes the lower limit for individual and collective minimization of travel effort.

Conclusions

The individual factors contributing to travel friction are multitudinous and varied. In a broad sense the friction results from the interaction of physical and behaviorial elements. But the precise way the driver, the vehicle, and the highway environment are interrelated is not known due to the paucity of research. The behaviorial implications of the problem and the relation of the friction of highway travel to land use activities suggest that the total problem is one involving both the physical and social sciences.

Examination of the highway environment has resulted in the identification of over two hundred factors involved in the evaluation of highway friction. Yet there is no assurance that this list is an exhaustive citation. The causative factors influencing highway friction are endless, many are variable with time, and are interdependent with other variables, all of which must be measured at the same time. The difficulty of identification of highway friction factors, let alone any attempt at quantification, suggests that measures of travel disutility may be a more productive approach to the problem.

Measures Of Disutility For Highway Travel

Time And Distance

A review of highway research literature leaves little doubt that time, distance, or some combination of the two are the most widely used units for measures of travel disutility. Voorhees used auto travel time in place of distance in calculating travel patterns to shopping centers.[1] In assigning automobile trips to major arterial streets and expressways, the California Division of Highways has developed a family of curves for the per cent diversion of traffic to arterials and expressways from other surface streets. The per cent diversion is based on the time and distance saved on the expressway or arterial when compared with other surface streets.[2] Essentially the same technique was used in the Detroit Metropolitan Area Study.[3] An improvement on the time and distance technique for traffic assignment is the development of discounting factors for trip assignment based on travel time in minutes and four categories of trip purposes.[4]

The effectiveness of time and distance as a measure of travel disutility has been studied by a number of different authors. The general conclusion is that time and distance over competing routes are important factors in the decision process of the motorist, but these two factors alone do not explain all the choices of highways which motorists actually make. Speaking with respect to this problem Rothrock and Campbell noted that "more studies of driver preference are needed in order to give engineers a clearer picture of traffic diversion" [to freeways][5]. Trueblood,

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1 Alan M. Voorhees and Others, "Shopping Habits and Travel Patterns," National Research Council. Highway Research Board Special Report, 11-B (1955), p. 16.

2 National Committee on Urban Transportation, Better Transportation for Your City (Chicago: Public Administration Service, 1958), p. 64.

3 Detroit Metropolitan Area Traffic Study, Part II (Lansing: Speaker-Hines and Thomas, 1955), p. 83.

4 Alan M. Voorhees and Robert Morris, "Estimating and Forecasting Travel for Baltimore by Use of Mathematical Model," National Research Council. Highway Research Board Bulletin, 224 (1959), p. 108.

5 National Research Council. Highway Research Board, Traffic Assignment (Washington, D.C., 1952), p. 7. (Its Bulletin 61).

in studying freeway usage on the Shirley Memorial Highway in Arlington and Fairfax Counties, Virginia, concluded: "that motorists are also influenced by factors other than distance and travel time is evidenced by the fact that nineteen per cent of the motorists studied lost both time and distance" [on their choice of route when compared with other alternatives available].[1]

Travel Cost

A few studies have attempted to evaluate the total cost of vehicle travel in monetary terms.[2] When dealing with vehicle costs the analysis is straightforward. But controversy arises when the authors attempt to attach a money value to the trip time. Problems of compatibility of units arise when the trip is partly by motor vehicle and partly by walking. For these reasons little support is found for a cost approach to travel disutility.

Driver Actions And Vehicle Maneuvers

This chapter has indicated that a multitude of factors can be involved in the motorist's concept of highway friction. Furthermore, since many of these factors are variables, they will be changing with time. To attempt to measure all of the highway friction factors and their variation with time in a single field experiment becomes impossible. One solution to this problem is to place a test vehicle and a driver in the

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[1] _Ibid._, p. 18.

[2] Bruce D. Greenshields, "Quality of Traffic Flow," _Quality and Theory of Traffic Flow_ (New Haven: Bureau of Highway Traffic, Yale University, 1961), p. 29.

highway environment and to quantitatively record the manner in which he drives over different routes. This technique assumes that differences in driving behavior on the part of a single driver over the various sections of the urban highway net are due to differences in the highway environment.

Dr. Bruce D. Greenshields, Assistant Director, University of Michigan Transportation Institute, in collaboration with Mr. Fletcher N. Platt, Director of Highway Safety, Ford Motor Company, have developed a piece of equipment, which they call a Driveometer, to measure driver actions and vehicle maneuvers while traveling over the highway. Greenshields makes the following observations with respect to this work:

> The equipment [in the test car] furnishes an entire record of the motions of the car, the actions of the driver, and the traffic and highway events. This data makes it possible to evaluate the driving behavior patterns of various drivers and correlate them with the characteristics of the traffic environment ....The results of 300 driving tests over a selected route show that driving patterns can be measured and highway environment characterized [numerically].[1]

Greenshields and Platt indicate that the traffic and highway events are significant observations or happenings occuring with the zone of sight of the driver which have the potential to require the driver to make some adjustment in his operation of the vehicle.

Dr. Greenshields has permitted the author to use the Driveometer for investigating highway travel for supermarket shopping trips.

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[1] Bruce D. Greenshields and Fletcher N. Platt, "A Technique for Investigating the Relationship of Traffic and Highway Events to Driver Actions," Ann Arbor, Michigan, 1961. (Mimeographed)

The driver actions (and the resulting vehicle maneuvers) as measured by the Driveometer are the physical acts of the driver to control the vehicle in response to the existing highway environment. This control requires the driver to exert physical effort in order to turn the steering wheel, and to depress the accelerator and brake. Thus the quantitative values for driver actions are measurements of the physical effort resulting from the friction of the highway environment. In addition, these driver actions are objective manifestations of the driver's evaluation of the highway geometry and traffic characteristics at the time of the trip.

It is recognized that there is also a mental effort involved in driving an automobile, but it was not considered in this investigation. Michaels has reported that the emotional tension of driving on urban streets is directly related to traffic volumes, land use activities abutting on the highway, and the complexity of the highway geometry.[1,2] Other than these studies, little work has been done in this area.

The particular operating controls for which a manipulation record is made are as follows: reversals of the steering wheel and the number of brake and accelerator pedal applications. In addition to these driver actions, the following variables pertaining to the vehicle are recorded: elapsed time, distance, time in motion, and cumulative change of speed and compass direction.

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[1] Richard M. Michaels, "Effect of Expressway Design on Driver Tension Responses," National Research Council. Highway Research Board Bulletin, 330 (1962), p. 23.

[2] Richard M. Michaels, "Tension Responses of Drivers Generated on Urban Streets," National Research Council. Highway Research Board Bulletin, 271 (1960), pp. 29-44.

In Greenshields' work, the highway route was fixed so that different drivers maneuvered the test vehicle over the same route. Thus the individual driver was a variable along with the traffic characteristics and climatic conditions. However, if the same driver is used in the test vehicle, and the highway route becomes the variable, the test vehicle can be used to measure the friction of the highway environment for different streets and highways, thus permitting relative comparisons of the physical effort of travel.

CHAPTER III

MEASURING THE EFFECTIVE DISTANCE OF TRAVEL FOR SUPERMARKET SHOPPING TRIPS

Statement Of The Problem

Concepts Of Shopping Trip Travel Behavior

The integration of the theory and notions of urban movement presented in Chapter II give us the following composite picture of urban residents as they plan and execute shopping trips:

> Not all of the needs and desires of the family can be satisfied within the establishment housing the family unit. The members of the household must move to the establishments producing and dispensing the goods and services needed by the family. Thus urban travel becomes the means by which the household acquires the utility of particular goods and services.
>
> Every utility in the urban area is assumed to have a set of defining coordinates which specifies the spatial separation of the utility from the home base of the household. For each and every spatial separation from the home base there is also associated a total travel effort caused by the friction of travel.
>
> As time progresses, members of the household accumulate shopping needs which can only be satisfied by leaving the home base and moving to the location of the utilities. The theory and notions imply that the household member considers the accumulated shopping needs in relation to the various spatial locations where these utilities can be obtained. He evaluates the gross shopping utility to be obtained from a particular retail establishment, subtracts from this gross utility the loss of utility occasioned by the travel costs and the loss of utility which results from leaving the comfort and convenience of his home base. The result is the net utility obtained from the shopping trip. If the shopper has incomplete knowledge of the retail market, he attaches a probability of success factor to his stop at an establishment. He combines stops in a sequence that will maximize his net utility per unit of elapsed time.

This description applies to a possible procedure whereby the household member arrives at a decision to leave his home base. Obviously such a decision is predicated on the net utility being greater than zero. But as the trip progresses there may be a revaluation of the trip. This can be due to a failure to obtain the shopping utility. Thus the path sequence may be altered. The theory also assumes that loss of home satisfaction increases with elapsed time, while travel costs are approximately proportional to distance. Thus failure at an establishment results in a decrease of gross utility. Several failures can result in a negative gross trip utility and cause the shopper to return home.

The above presentation explains how and why urban residents are motivated to make shopping trip expeditions, and the manner in which they determine their path sequence. The procedure is valid for one or more shopping needs. It explains the success of the large integrated shopping centers, for here a multi-purpose trip can be combined into one stop with a minimum expenditure of time and travel effort.

Field Investigation

Objectives And Limitations

A field study based upon the shopping trip procedure described above would be divided into five parts. These are: (1) obtaining by means of a shopper interview a record of the precise block-by-block street movement; (2) the recording of street addresses of all establishments visited, precise locations where the automobile was parked, movement paths as a pedestrian, and the street address of the home base; (3) evaluating the quality of travel on the streets and highways used; (4) improvising a manner to cumulatively add the gross utility for multi-purpose shopping trips; and (5) devising an overall measure of travel disutility which integrates movement on the highway, walking, and the friction at terminals.

The magnitude of an investigation of this scope that would be statistically significant is not justified at the present time. Almost no work has been done relating shopping trip utility to the disutility of highway travel. Any research contemplated in this area should be a pilot study to establish the feasibility of a broader investigation. From a research point of view, it would be desirable to devise a measure of travel disutility in one investigation and a means of adding multi-purpose trip utility in a second investigation. While the situation described is applicable, the pilot study was reduced to include only single purpose automobile shopping trips, beginning and ending at home, and made to a food supermarket. These limitations avoid the difficulty of adding multi-purpose trip utility. A food supermarket tends to have uniform potential utility for many people. In most large chain supermarkets, the food items stocked and the depth of selection tends to be similar. Therefore, it was assumed that the selection of a supermarket by a shopper was made for reasons of travel friction rather than store contents.

Based upon the above limitations, the field investigation was oriented toward answering five specific questions: (1) Can the environment of urban highways be characterized by driver actions and vehicle motions measured with Greenshields' Driveometer; (2) Can these measurements be represented by an index number; (3) Can this index be used to compare different highways classified according to design and use; (4) For households within the maximum range of the supermarket, are the number of household contacts at the store related to the index and thus to effective distance; and (5) Can indexes, once developed for urban streets, be used to synthesize urban shopping trips.

Resume

At one of ten similar supermarkets in the city of Ann Arbor, Michigan, a random sample of all shoopers was interviewed for a period of one week to obtain a collection of single purpose automobile trips originating at the shopper's household. The interview recorded the shopper's home address, the precise highway route traveled to the store, the contemplated route home, and the parking location of the car in an adjacent lot. Using a test car equipped with Greenshields' Driveometer, the routes and parking maneuvers recorded in the interview were redriven and data recorded. The major arterial highways providing access to the supermarket were also driven with the test car.

Assumptions

The major assumptions in this investigation are as follows: (1) that the utility of a shopping trip can be adequately characterized in terms of the function of the establishment; (2) that the travel disutility consists of the driver actions and vehicle maneuvers for the terminal and for the highway, and that these values can be added to obtain a single value for the trip; (3) that the bulk of the urban shoppers attempt to maximize net shopping utility by maximizing the difference between the gross trip utility and the travel disutility per unit of elapsed time; (4) that the omission of data for loss of home utility, walking distances at home and at the store, and unparking and parking maneuvers at the home base, will not seriously affect the results; (5) that for each extra-home utility desired by the urban shopper there is some maximum range of travel; (6) that the highway environment can be measured by using a test vehicle that records driver actions, vehicle motions, elapsed trip time, trip running time, and trip distance; (7) that the test vehicle will encounter approximately the same highway environment by redriving the shopper's route to the store at the same hour of the day and on the same day of the week since traffic tends to be periodic; (8) that in the aggregate, the selection of a supermarket by shoppers is predicated upon the minimization of travel effort rather than store contents; and (9) that the use of a single driver in a test vehicle equipped with the Driveometer results in a uniform driving behavior pattern so that relative differences in driver behavior can be assumed to be caused by differences in the highway environment.

Models Of Supermarket Shopping Trip Travel Behavior

A general model encompassing a shopping trip can be framed in terms of trip utility:

$$U_{net} \text{ per unit of elapsed trip time} = \frac{U_{gross} - TE_{total} - E_{he}}{\text{Elapsed trip time}} \qquad (1)$$

This model states that the net utility per unit of shopping trip time is equal to the gross utility less the total terminal effort and less the effort of movement within the highway environment, divided by the elapsed trip time.

The total terminal effort for single-purpose home-to-store-to-home shopping trips consists of the effort at the home base plus the effort at the store:

$$TE_{total} = te_{home\ base} + te_{store}. \qquad (2)$$

The terminal friction of the home base includes walking from the place of residence to the location where the car is garaged or parked, the unparking maneuvers, and the accelerating and entering into the traffic stream. The reverse procedure occurs on returning home. The terminal effort at the store includes the effort of leaving the arterial and the traffic stream, driving in the parking lot, vehicle parking maneuvers, and walking from the car to the entrance to the store. The reverse sequence occurs when leaving the store to return to the home base.

The effort of travel within the highway environment equals the sum of the effort of movement on the arterials, the collector streets, and the residential streets. In symbolic terms:

$$E_{he} = EM_{arterial} + EM_{collector} + EM_{residential}. \quad (3)$$

The effort of movement on an arterial expressed as a quantitative value is believed to be a function of three other quantities: effective distance traveled on the arterial, the time of the day, and the day of the week, or:

$$EM_{arterial} = f\text{ (effective arterial distance, time of the day, and day of the week)}. \quad (4)$$

Research Methods

Selection Of Supermarket

Within the city of Ann Arbor, Michigan (population 71,000) there are ten supermarkets offering similar food and household maintenance items within the same price range. These ten stores are spatially distributed throughout the city as shown on the map in Figure 20, rear pocket. The customer patronage is almost exclusively by the automobile transported shopper. Of these ten supermarkets, the selection was narrowed to four stores belonging to one chain. These four are similar in size, items stocked, and the availability of parking facilities. The four stores are indicated on the maps in Figures 18, 19, and 20, rear pocket. Figure 18 shows the urban highway net serving the stores. Figures 19 and 20 show the population distribution and the generalized land use for the areas which the stores serve.

Store one is located on Packard Road near the city limits in southeastern Ann Arbor. Access to the store is provided by two major arterial highways. The first- Packard Road- leads northwesterly to the central business district and southeasterly to the urban fringe. The second- Stadium Boulevard- is an outer circumferential arterial which passes around the south and west sides of the city. Between store one and the Packard- Stadium intersection to the northwest the business development is as shown in Figure 1. There is little pedestrian traffic between business establishments. Store two is situated in a forty-five unit regional shopping center in eastern Ann Arbor. The shopping center is immediately northwest of the separated intersection of an intercounty north-south limited access freeway and a major intracounty east-west arterial. See the map in Figure 2 for the location of store two. Store three is located in a fifteen unit community shopping center in the western part of Ann Arbor. Interstate Route 94, Stadium Boulevard, and West Huron Street provide access to the store as shown on the map in Figure 3. Store four is situated in north central Ann Arbor north of the

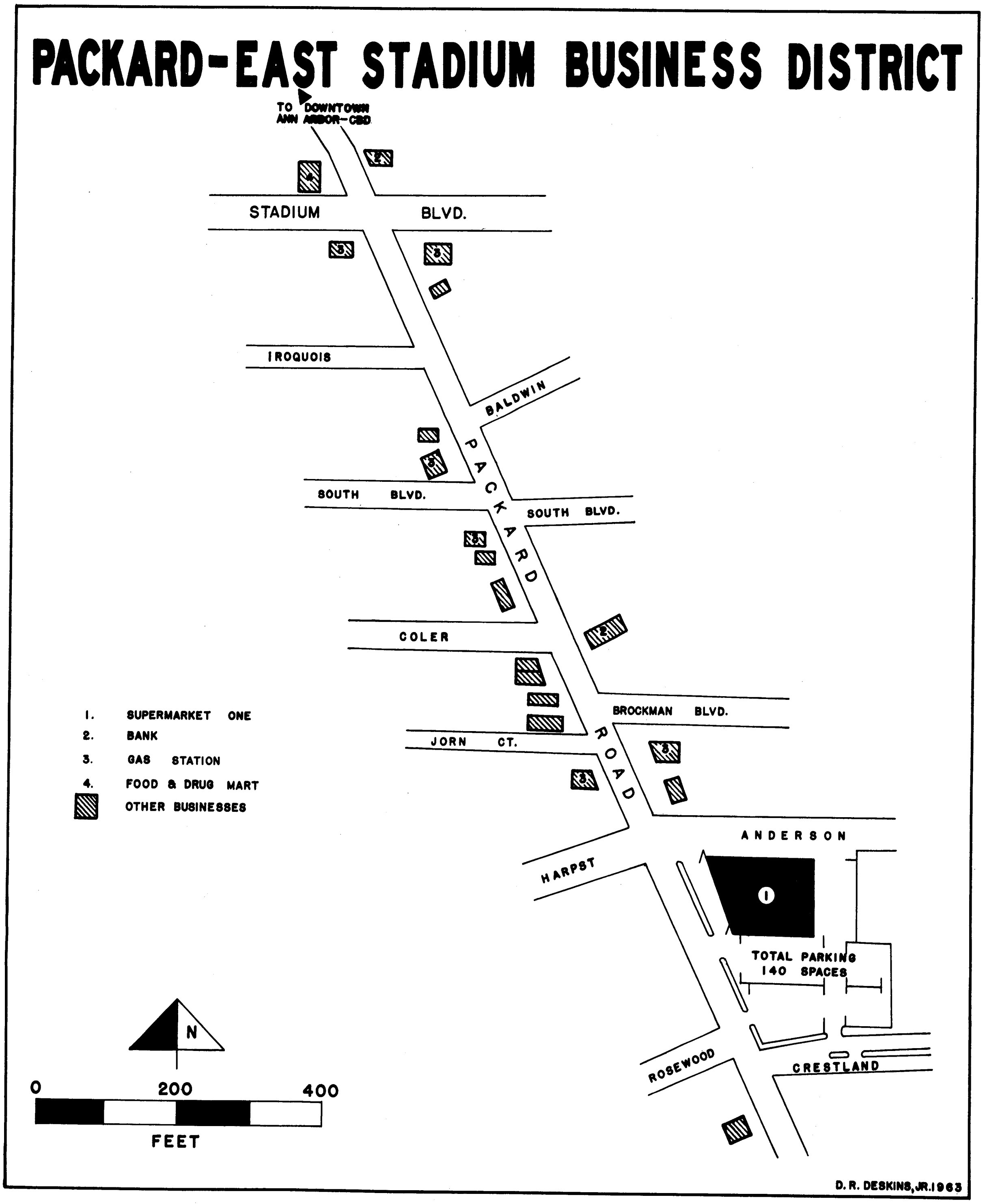

Figure 1. Location of Supermarket One in Packard Road- East Stadium Blvd. Business District, Ann Arbor, Michigan.

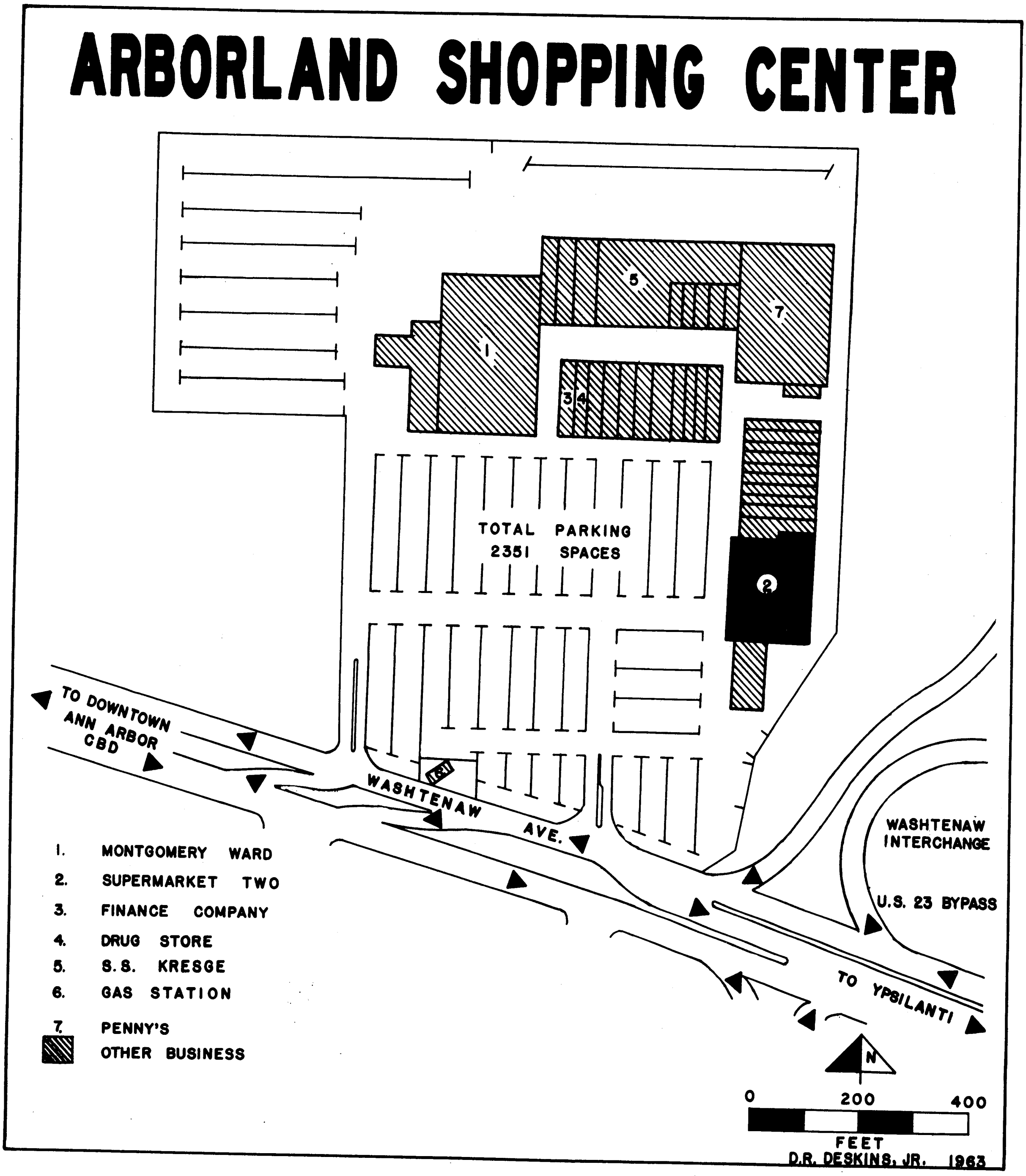

Figure 2. Location of Supermarket Two in Regional Shopping Center, Ann Arbor, Michigan.

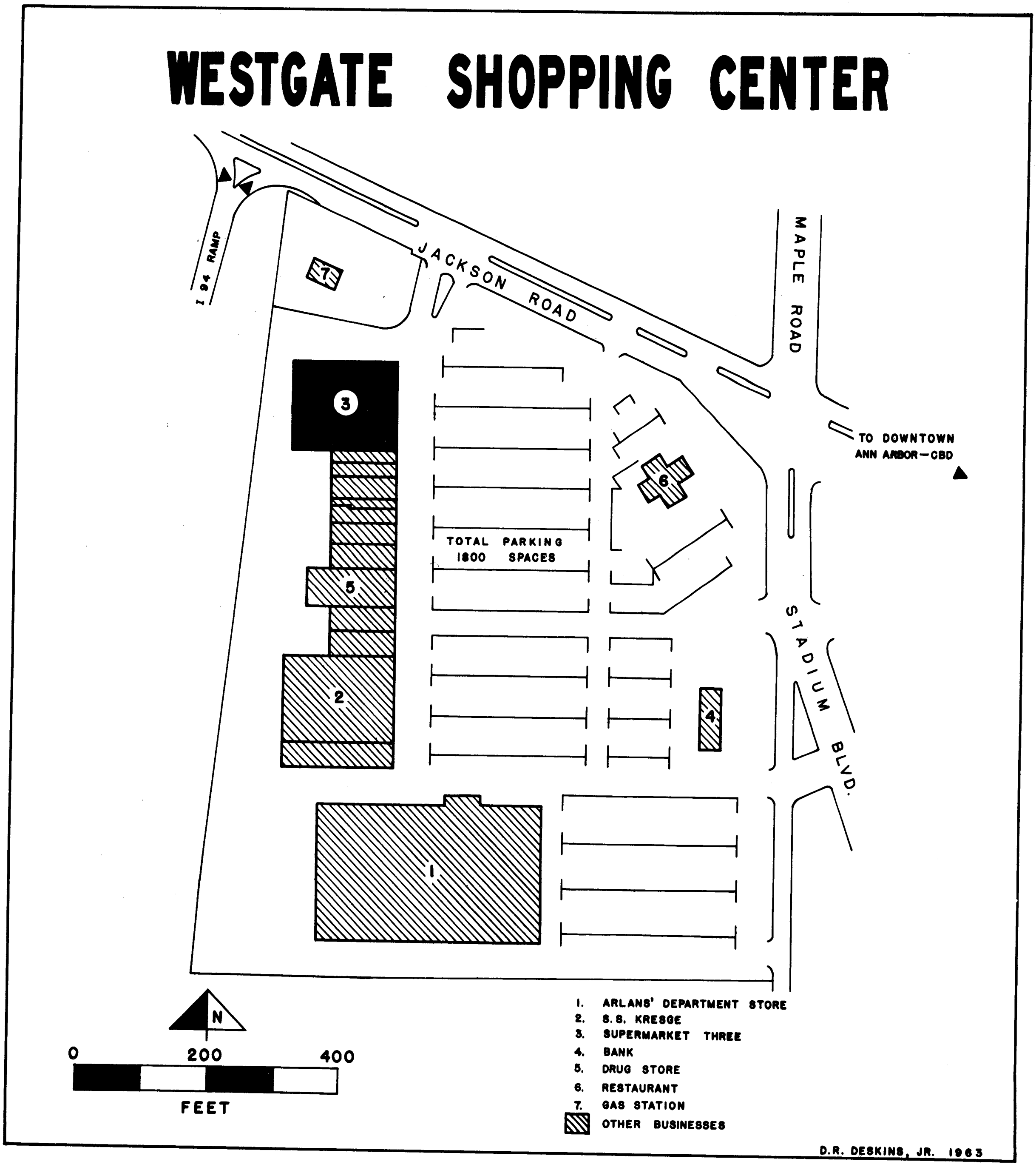

Figure 3. Location of Supermarket Three in Community Shopping Center, Ann Arbor, Michigan.

Huron River near the intersection of two major highways leading to the northeast to urban fringe and rural areas. See Figure 4 for location map of this supermarket.

Because of the emphasis in this investigation on single purpose trips, stores two and three were not considered. Store four was also eliminated because of its physical separation from the city to the south. Store one was the supermarket selected for this study.

Supermarket Interviewing

To obtain information concerning the shopper's home address, the highway route used, and the purpose of the trip, shopper's were interviewed at store one. The interviews were conducted from 9:00 AM to 9:00 PM, Thursday, July 5, through Wednesday, July 11, 1962. The store was closed on Sunday, July 8. The interviewing station was located inside the supermarket near the sole customer exit and was staffed by two young women, one of whom interviewed customers after completion of their purchases. The other maintained an hourly count of the household units[1,2] represented by customers passing through the check-out stations. The average number of interviews per hour was nine, ranging from a high of

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1 The significance of the housing unit is that it is the population unit which normally satisfies the collective grocery and household maintenance shopping needs for individual members of that housing unit.

2 A housing unit is one of the methods of characterizing the intensity of usage of urban residential land. The U. S. Bureau of Census defines a housing unit as a "group of rooms or a single room occupied or intended for occupany as separate living quarters." It does not include "group quarters" defined "as living arrangements for institutional inmates, or groups containing five or more persons unrelated to the person in charge whose quarters are not divided into housing units."

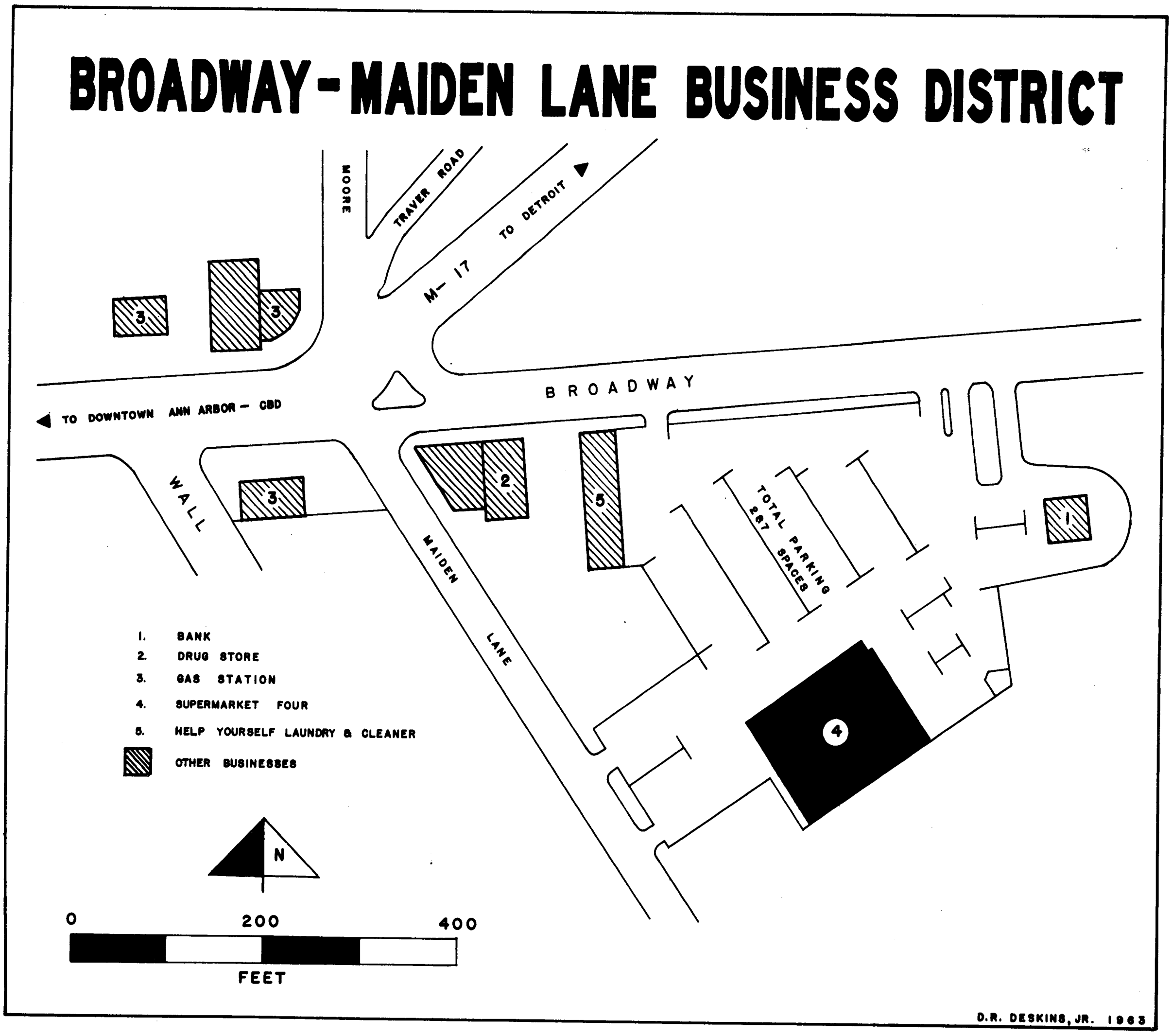

Figure 4. Location of Supermarket Four in Broadway- Maiden Lane Business District, Ann Arbor, Michigan.

fourteen to a low of three. Appendix A shows the Shopping Travel Inventory form used for the interview. Not included in Appendix A is the map of the street system of Ann Arbor on which the shopper, on an individual copy, traced his highway route to and from the store. The map omitted in Appendix A is similar to Figure 17. Prior to the investigation there was doubt whether the shopper could perform this task. Pilot interviews conducted prior to the investigation indicated that shoppers could complete this request with ease and enjoyment.

Weather

The presumed inportance of weather as it relates to shopping trips has been discussed previously. On the form shown in Appendix B is a weather chart. The weather matrix is an abbreviated form of the one used by the U. S. Department of Commerce Weather Bureau. During the six day store interview period, an hourly record of the weather was maintained. When the highway route used by the shopper was redriven with the test car, the weather conditions, using this matrix, were recorded for trip.

Street And Highway Classification

It is an established practice among traffic engineers to classify street systems on a functional basis (e.g., arterial,

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Under this concept, the conclusion is that one family homes, separate apartments in multiple dwellings and rooming houses with less than five roomers are considered to be housing units. As a practical matter, a housing unit will consist of living quarters of one or more rooms either having, or having direct access to, separate kitchen or cooking equipment. (Source: U.S. Census of Population: 1960, General Population Characteristics, Michigan Final Report PC (1) - 24B, p. ix and x.)

residential, collector, freeway). The proposition underlying this classification is that the quality of movement and traffic carrying ability of each of these classifications are fundamentally different. There are no uniform rules for the classification. It usually consists of a physical inventory of the geometric design features supplemented by field observations to observe the characteristics of road use.

Since one of the objectives of the field investigation is to evaluate the effort of highway movement on urban streets, it is necessary to first classify the streets into functional groups. The criteria used to do this is shown in Table 4. The application of these criteria to the Ann Arbor street system results in the functional classification indicated on the map in Figure 18, rear pocket.

Use Of Test Car And Driveometer

Instrumentation

A schematic layout of the Driveometer in an automobile is shown in Figure 5. Three types of data are collected: driver actions, car motions, and traffic events. Driver actions of the vehicle operator taken from the movements of the steering wheel, the brake, and the accelerator are recorded inside the data box on the back seat of the car. The car motions- cumulative change of speed and compass direction- are also recorded here. Traffic events are recorded manually by means of slide switches, controlled by an observer in either the front or rear seat. See Appendices C and D for the events measured and the layout of the recording keyboard. Traffic events were recorded but were not analyzed as a part of this investigation.

TABLE 4

CRITERIA FOR THE FUNCTIONAL CLASSIFICATION OF THE URBAN STREET SYSTEM

Criteria	Expressway-Freeway	Arterial	Collec-tor	Residential and Local Access
Control of access	Yes-full	Yes-partial	No	No
Designed to move traffice	100%	80%	50%	0%
Designed to provide local access	0%	20%	50%	100%
Operating speeds	35-50	25-35	20-25	-
No. of moving traffice lanes	4-8	4 min.	2 min.	1 min.
Parking permitted	No	Revocable privilege	Yes	Yes
No. of parking lanes	0	2 (option)	2	2
Street width	4-8 lanes[1]	44'-48'	40'-44'	30'
Max. grade	3%	6%	8%	12%
Urban spacing (miles)	1-3	1	1/2	-
VPH[2] Capacity	1500	350	150	-
Interconnects different parts of city	Yes	Yes	No	No
Interconnects different lands uses	Yes	Yes	Yes	No
Interconnects major routes entering city	Yes	Yes	No	No
Serves through traffic	Yes	Yes	No	No

1 @ 12'/lane

2 Vehicles per hour

The camera shown in Figure 5 is mounted on the deck behind the rear seat and takes time-lapse photographs. It is used for checking the visible traffic and highway conditions while the driver actions and vehicle motions are being recorded. Figure 8 shows a mirror on the rear of the front seat for reflecting the view of the road to the rear in the lower one-half of the photograph while the upper one-half shows the road ahead. In this study the camera was mounted directly behind the top center portion of the windshield taking photographs of the road ahead only.

Figures 6 and 7 indicate the instrumentation installed in the test car, a 1960 two-door Ford from the University of Michigan Motor Pool fleet, and equipped with a six cylinder motor and automatic transmission. The front seat passenger in Figure 6 is the observer and is holding the traffic event keyboard. A partial view of the data recording box is visible through the rear side window. Figure 8 shows the data box in position on a level platform.

Figure 9 shows a device mounted on the steering column that records reversals of the steering wheel. It also shows an attachment to the accelerator pedal. One number is added to the cumulative recording dials on the display panel whenever: (1) there is a steering wheel reversal greater than 0.258 radians (about 15 degrees); (2) the accelerator pedal is depressed and then allowed to raise one-fourth of an inch; and (3) the brake is applied so the stop light is actuated. The power supply for the data box is through the electric cable fastened in the cigarette lighter receptacle as shown in Figure 9.

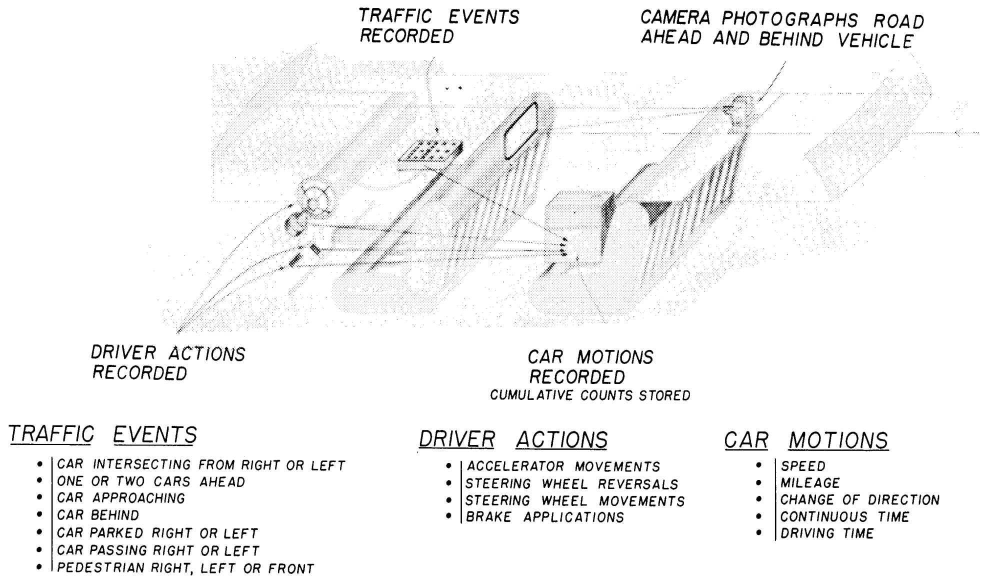

Figure 5. Schematic Representation of Greenshields' Driveometer Installed in an Automobile, and the Variables the Unit Measures.

Figure 6. Photograph of Driveometer Installed in the Test Car Used in the Collection of Field Data.

Figure 7. Photograph of Driveometer Installed in Test Car Showing Data Box on Back Seat Directly Behind the Driver.

Figure 8. Photograph of Interior of Test Car Showing Data Box Mounted on Rear Seat. Mirror Mounted on Rear of Front Seat Provides Reflected Image of Highway Behind Test Car for Camera Mounted on Deck Behind Rear Seat.

Figure 10 shows the inside of the data box with the sides and top removed. The four digit counter-register display panel is visible in the right center, while the traffic events keyboard is in the lower right hand corner. In the left center is a gyro compass which measures the change of vehicle direction. In the right background is an odometer and a speed registering unit which measures the distance and cumulative changes of speed.

Plate I, Figure 11 is a view of the data box showing the 16 mm camera in the upper left-hand part of the picture. By means of a reflecting mirror and artificial light supplied by bulbs over the display panel, the camera takes photographs of the dials while the unit is in operation. The shutter of the camera is connected to an odometer which automatically causes the camera to take a photograph every one-tenth of a mile. The camera can also be actuated by a hand control switch on the top of the box which is visible in the upper right-hand corner of Plate I, Figure 11.

Data Collection Procedure

Shopping Trip Routes.--Using supermarket interview data, single purpose home-to-store-to-home trips were sorted from all others and redriven with the test vehicle. Two college students were used. One was assigned as a permanent driver and the other as observer.

The trip started in the street in front of the shopper's residence. The route to the store was the same as the route recorded during the supermarket interview. Upon arrival at the supermarket parking lot, the car was brought to a halt at the parking location indicated during this interview. Data was read and recorded with the

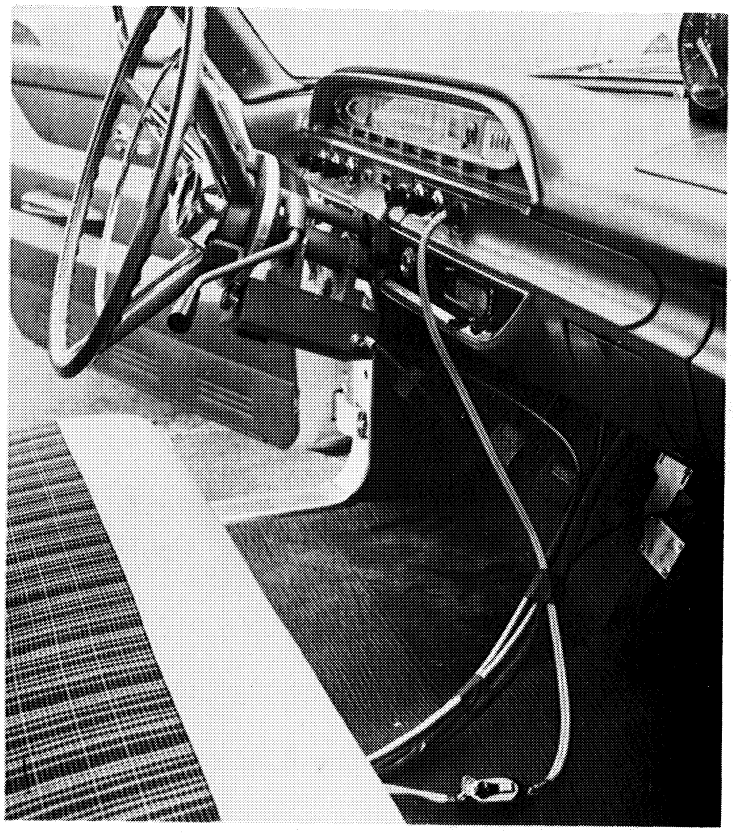

Figure 9. Photograph of the Steering Wheel and Dashboard of the Test Vehicle.

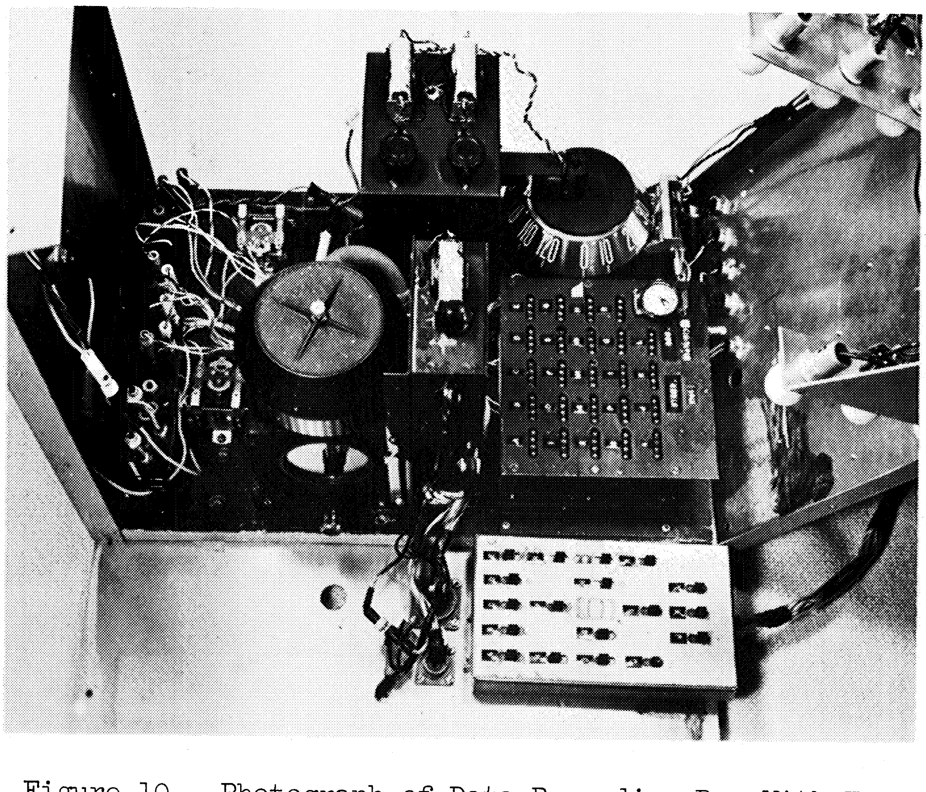

Figure 10. Photograph of Data Recording Box With Top and Sides Removed.

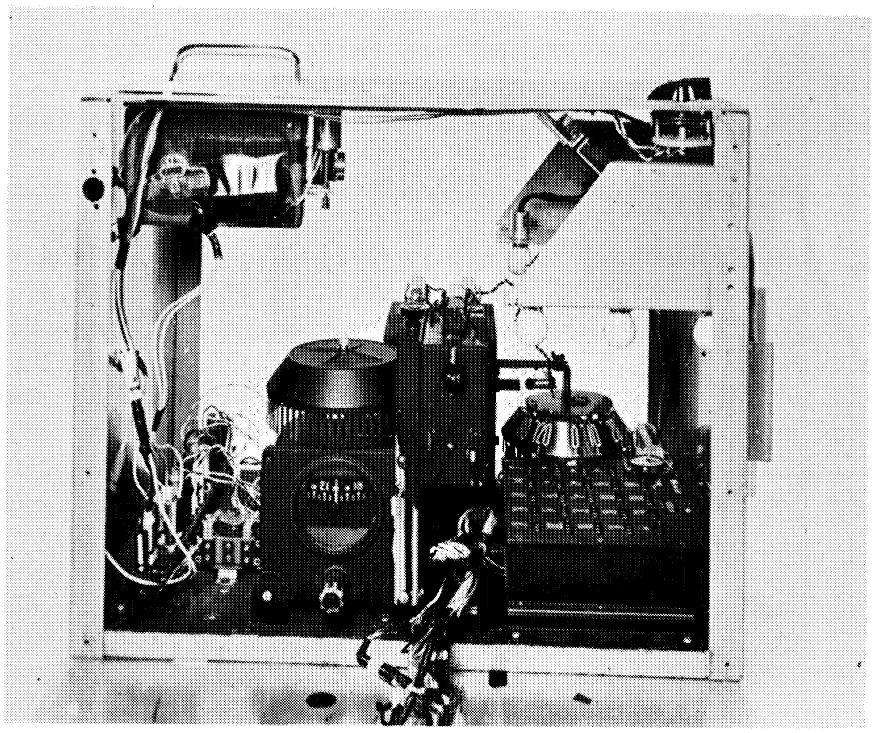

Plate I

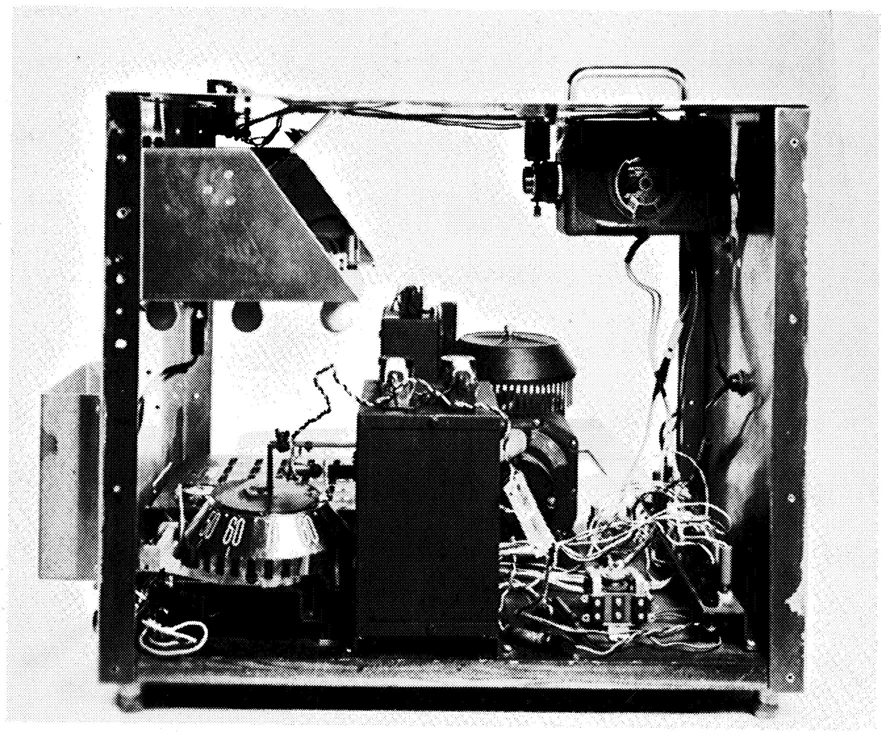

Plate II

Figure 11. Photographs of Interior of Data Recording Box Showing Camera in Position to Photograph Display Panel.

vehicle in this position. The test vehicle proceeded back to the residence retracing the shopper's route home where data was once again recorded. The data obtained from this procedure included the total values for the variables generated between the store and the shopper's home, as well as their periodic change every one-tenth of a mile recorded by the camera. The film record of the periodic change in variables also includes a notation indicating the values for the variables when the test vehicle moved from one functional classification of highway to another.

Arterial Highways.--After the test vehicle substantially completed re-driving the shoppers' routes to the supermarket, it was used in a program of arterial driving. Because of the variations in travel patterns along the arterials, it was desirable to divide each highway into sections for detailed study. Table 5 shows the arterial highways and their respective divisions for which data was collected.

The time period from 7:30 AM to 9:00 PM was divided into six time intervals on the basis of similar traffic volumes as follows: 7:30 AM- 9:00 AM; 9:00 AM- 11:30 AM; 11:30 AM- 1:00 PM; 1:00 PM- 3:30 PM; 3:30 PM- 6:00 PM; and 6:00 PM- 9:00 PM. Since traffic variations by day of the week are not too dissimilar, four groups of days were selected for study. These included Monday, Friday, and Saturday as separate days with Tuesday, Wednesday, and Thursday combined into a single group. The six time intervals and the four groups of days require twenty four sets of values to be developed for each section of arterial. Due to budget limitations, only those arterials within the range of travel to the supermarket were investigated.

Statistical Considerations

Constants

In the list of factors assumed to be constant for this study, there are some items enumerated which could vary with time. However, the field data was collected within a period of six weeks during the middle

TABLE 5

SECTIONS OF URBAN ARTERIALS OVER WHICH THE TEST VEHICLE WAS OPERATED IN ANN ARBOR, MICHIGAN

E & W Stadium Blvd.	**Packard Rd.**
Jackson Rd-Liberty	S. Main-S. State
Liberty-Pauline	S. State-E. Stadium
Pauline-Main	E. Stadium-Supermarket One
S. Main-White	Supermarket One-Platt Rd.
White-Packard	Platt Rd-Carpenter Rd.
Packard-Manchester	
Carpenter Rd (US 23)	**Washtenaw**
Washtenaw-Packard	Hill-Manchester
	Washtenaw-Carpenter Rd.
S. Main St.	**Pauline**
Packard-Pauline	W. Stadium-S. Main
Pauline-Stadium	

of the summer and it was felt that no substantial changes took place within this relatively brief period. The factors listed apply to the entire city: (1) the road behavior of the shopper's automobile; (2) the geometric design of the urban street system; (3) parking facilities; (4) traffic regulations and traffic control devices in effect; (5) the safety of highway movement; (6) zoning regulations which control the density and types of land use, and access thereto; (7) the general urban boundaries; (8) the goods and services offered in (a) the supermarket where shoppers were interviewed; (b) other stores of the same chain; and (c) other supermarkets of similar size within the market influence of the store where customers were interviewed; (9) for any individual shopper, his evaluation of shopping trip utility in relation to highway travel effort; and (10) the daily and weekly variation of highway traffic volumes on the arterial streets.

Variables

Table 6 is a summary of the variables which were recorded as a part of the single purpose home-to-store-home shopping trips. The driver actions and vehicle motions listed under measurement-type variables were also recorded as a part of the arterial driving program.

Sample Size

Shopping Trips For Test Sample.--It was desirable to define the spatial location of households from which trips to the supermarket originated. With the location of supermarket one as the origin, a series of radial lines and concentric rings were laid out as indicated on the map in Figure 21, rear pocket. The basis for location of the radial lines was population density. See Table 11 for distances between rings. The radii for the rings were influenced by the presumed discounting of functional accessibility to the store with distance. The intersection of the radial lines and circles defined areas called sector-zones. The location of households where supermarket trips originated could thus be

TABLE 6

CLASSIFICATION OF VARIABLES RECORDED FOR THE HOME-STORE-HOME SUPERMARKET SHOPPING TRIPS

Physical Classification	Statistical Classification: Measurement-type Variable	Statistical Classification: Attribute-type Variable
Individual	1. Radians of turning of steering wheel 2. Reversals of steering wheel 3. Number of brake applications 4. Number of accelerator pedal applications 5. Age of shopper	6. Sex and race 7. Place of employment 8. Collect TV stamps? 9. Shopping in response to advertisement? 10. Work address (if any) 11. Regular shopper at supermarket interviewed? 12. Driver or passenger in car? 13. If housewife, full or part time?
Family	14. Number of persons involved in shopping trip 15. Size of family	16. Home address
Vehicle	17. Total change in speed in MPH 18. Total change of direction in radians	19. Location parked in supermarket lot
Trip Environment	20. Elapsed time consumed 21. Time in motion 22. Walking distance from car to door of supermarket 23. Time of day trip made	24. Weather 25. Day of week trip was made
Trip Utility	26. Distance	27. List of store type visited (supermarket)

spatially referenced to the store in terms of a sector-zone number. By inventory of the total number of households in each sector-zone, a proportion could be calculated for the probability of trips originating from any sector zone. See Table 7.

The statistical controls for minimum sample sizes involved two considerations: (1) the total number of interviews completed at the store in relation to the number of households as represented by customers for the interview period: and (2) the number of single-purpose home-to-store-to-home trip origins by sector-zone in relation to the total number of interviews. The level of accuracy for (1) specified that the maximum likelihood value should be within ten per cent of the true value nine times out of ten and for (2) that the maximum likelihood value should be within twenty per cent of the true value two times out of three. The values in column four, Table 7, meet these criteria.

Test Car Data.--Budget and time limitations precluded redriving the shopper's route more than once. The time limitation imposed on the operation of the test car was due to changes in traffic characteristics known to occur in Ann Arbor with the end of the University of Michigan Summer Session. For the same reasons, only one observation was made for each of the twenty four time-of-day and day-of-week cells associated with each section of urban arterial highway.

TABLE 7

SINGLE-PURPOSE AUTOMOBILE SHOPPING TRIPS PER THOUSAND HOUSEHOLDS BY SECTOR-ZONE

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6
Sector-zone	Sector-zone Sample $n_{(s-z)}$	Sample Proportion $\hat{p}_{(s-z)}$ in % ($n_{(s-z)}$ x 100 ÷ N)	Maximum Likelihood Estimate of Trips ($p_{(s-z)}$ x U)	No. Households per Sector-zone	Trips (MLE) per 1000 Families
11	9	1.36	52.50	226	232.3
12	11	1.67	64.17	460	139.5
13	12	1.82	70.00	1644	42.6
14	1	0.15	5.83	1574	3.7
21	8	1.21	46.67	201	232.2
22	6	0.91	35.00	236	148.3
23	3	0.45	17.50	422	41.5
31	7	1.06	40.83	74	551.8
32	3	0.45	17.50	208	84.1
33	6	0.91	35.00	667	52.5
34	2	0.30	11.67	402	29.0
41	8	1.21	46.67	72	648.2
42	9	1.36	52.50	186	282.3
43	31	4.70	180.83	944	191.6
44	3	0.45	17.50	163	107.4
51	3	0.45	17.50	87	201.1
53	2	0.30	11.67	18	648.3
55	5	0.76	29.17	145	201.2
61	9	1.36	52.50	79	664.6
62	1	0.15	5.83	11	530.0
63	1	0.15	5.83	21	277.6
65	2	0.30	11.67	63	185.2
71	6	0.91	35.00	113	309.7
72	4	0.61	23.33	245	95.2
73	6	0.91	35.00	1393	25.1
81	2	0.30	11.67	82	142.3
82	18	2.73	105.00	509	206.3
83	8	1.21	46.67	1450	32.2
84	3	0.45	17.50	1799	9.7
85	1	0.15	5.83	1157	5.1
91	1	0.15	5.83	76	76.7
92	9	1.36	52.50	392	133.9
93	12	1.82	70.00	1933	36.2
	Totals 212	32.12	1236.67	17,937	

NOTE 1: The symbols used in the column headings are explained as follows:

a. U is the universe of trips from which the sample interview was taken and is equal to the total number of households counted at Supermarket One for six day period (3850).

b. N is the total number of trips interviewed at Supermarket One (660).

c. $n_{(s-z)}$ is the number of trips interviewed at Supermarket One for each of the sector-zones.

d. $\hat{p}_{(s-z)}$ is the sample proportion of trips originating in any sector-zone and is an estimate of the true population proportion $p_{(s-z)}$.

CHAPTER IV

DATA, ANALYSIS, AND CONCLUSIONS

This chapter consists of a summary of the data collected in the supermarket interviews, a weather summary for the interview period, and average values for the variables measured by the Driveometer for shopping trip and arterial highway travel. The Driveometer data is analyzed for relationships to supermarket travel behavior and the possibility of constructing indices of effective distance.

Data

Since the data collected is contained on the 660 individual Shopping Travel Inventory forms, pertinent sections of the Inventory form are summarized in Table 8. Table 8 indicates by hour of the day the total interviews completed and the household units counted during the twelve hour period from 9AM to 9PM for each of the six days, Thursday through Wednesday. A grand total of 660 interviews were completed and 3850 household units counted. The number of households counted at the supermarket interviewing station was very nearly equal to the total cash register sales.

Table 9 indicates the classification of single purpose trips by mode of transportation. Nearly forty-eight per cent of all trips made to supermarket one were single purpose.

This study did not contemplate redriving all single purpose trips, but only the home-to-store-to home trips. Table 10 shows a total of two hundred and sixty four single purpose trips. Of these, only two hundred and fifteen originated and terminated at the shopper's home.

TABLE 8

HOURLY HOUSEHOLD UNIT AND CUSTOMER INTERVIEW COUNT[1]

Col. 1	Col. 2						Col. 3	Col. 4	Col. 5	Col. 6
	Day of Week									
Hour	M	Tu	W	Th	F	S	Total 1 hr.	Hour[2]	Total for Time Period	Average/Hour for Time Period
9 a.m.								9 a.m.		
H.U.	23	22	26	28	36	58	193			
I.	6	10	3	6	10	7	42			
10 a.m.								H.U.	670	268
								I.	137	-
H.U.	32	42	32	52	66	83	307	(Time Period 2)		
I.	10	12	10	8	12	12	64			
11 a.m.										
H.U.	42	59	50	47	59	84	341	11:30 a.m.		
I.	9	12	9	9	9	14	62			
								H.U.	499	333
12 noon								I.	98	-
H.U.	40	36	37	58	73	84	328	(Time Period 3)		
I.	10	8	8	14	16	11	67			
1 p.m.								1 p.m.		
H.U.	33	42	21	40	51	91	278			
I.	10	6	3	7	12	11	49			
								H.U.	798	319
2 p.m.								I.	120	-
H.U.	49	55	21	55	47	103	330	(Time Period 4)		
I.	7	9	6	8	8	7	45			
3 p.m.										
H.U.	50	47	54	66	67	97	381	3:30 p.m.		
I.	8	7	6	12	9	10	52			
4 p.m.										
								H.U.	1015	406
H.U.	53	43	60	64	80	75	375	I.	153	-
I.	9	7	10	7	13	10	56	(Time Period 5)		
5 p.m.										
H.U.	81	61	74	61	87	85	449			
I.	13	13	12	11	12	10	71			
6 p.m.								6 p.m.		
H.U.	46	46	48	36	54	67	297			
I.	10	11	12	6	11	10	60			
7 p.m.										
								H.U.	868	290
H.U.	31	38	31	49	57	68	274	I.	152	-
I.	9	9	4	5	9	9	45	(Time Period 6)		
8 p.m.										
H.U.	29	47	52	51	51	67	297			
I.	6	5	9	10	9	8	47			
9 p.m.								9 p.m.		
Totals										
H.U.	509	538	506	607	728	962	3850			
I.	107	109	92	103	130	119	660			

NOTE 1: H.U. in table stands for household units counted and I. for interviews completed.

NOTE 2: Time periods selected in this column are those for which the hourly street traffic volumes are not too dissimilar over the period.

TABLE 9

SUMMARY OF SINGLE PURPOSE SHOPPING TRIPS
BY MODE OF TRANSPORTATION

Day	Mode					Total
	Auto	Walk	Bus	Bic'le	Other	
Thu.	42	7	1	1	-	51
Fri.	63	6	-	-	-	69
Sat.	60	4	-	1	2	67
Mon.	35	6	-	-	-	41
Tues.	35	12	1	2	-	50
Wed.	32	5	-	-	-	37
Total	267	40	2	4	2	315
% of all Trips	40.5	6.1	0.3	0.6	0.3	47.8

Included in the two hundred and fifteen trips were three for which the round trip travel distance was more than twenty five miles. This distance negated any assumption that the shopper's home base was within the maximum range of travel to the supermarket. These three trips were not used for further analysis.

Table 11 references the shoppers' homes in terms of distance and direction from supermarket one.

Weather Summary

A record of weather conditions was maintained during the period of the investigation. However, since substantially pleasant weather prevailed during this period, there is no significant weather data.

TABLE 10

CLASSIFICATION OF SINGLE PURPOSE
AUTOMOBILE TRIPS TO SUPERMARKET

Classification	Thu	Fri	Sat	Mon	Tu	Wed	Total
Total, Either As Driver Or Passenger	42	61	59	35	35	32	264
Home-To-Store-Home Only, As Driver Or Passenger	38	50	52	25	29	21	215

TABLE 11

SECTOR-ZONE DISTRIBUTION OF THE HOME BASES FOR
HOME-STORE-HOME SINGLE PURPOSE SHOPPING TRIPS TO SUPERMARKET

Direction By Sectors	Radial Distance By Zones					Total
	(½ mi.) Zone 1	(1 mi.) Zone 2	(2 mi.) Zone 3	(3 mi.) Zone 4	(4 mi.) Zone 5	
1	9	11	12	1	-	33
2	8	6	3	-	-	17
3	7	3	6	2	-	18
4	8	9	31	3	-	51
5	3	-	2	-	5	10
6	9	1	1	-	2	13
7	6	4	6	-	1	16
8	2	18	8	3	1	32
9	1	9	12	-	-	22
Total	53	61	81	9	8	212
Percent Of Total	25	28 8	38	4.5	3.7	100

Driveometer Data

Shopping Trips

The variables measured with the Driveometer for each shopping trip redriven were aggregated by sector-zone and average values computed for each variable. These are listed in Table 12. The sector-zones of column one show the effect on the variables of increased radial distance in each sector. There were some sector-zones from which no interview trips originated: five-two is an industrial area with no residences; five-four is agricultural with low population density; six-four is agricultural; and seven-four had no interview trips.

Arterial Highways

The Driveometer data for the arterials consists of three hundred and twelve measurements that include 2,184 individual values. Table 13 gives the data collected for the six time periods on a Monday for one arterial highway section. These measurements were made for the four groups of days for all arterials studied.

Arterial Highway Intersections

In measuring values for arterial travel, it was necessary to have values for turning movements. The intersection where the largest number of turns were made was East Stadium- Packard Road. This intersection was chosen for a trial investigation. Values measured with the Driveometer are shown in Table 14.

TABLE 12

AVERAGE ROUND-TRIP VALUES BY SECTOR-ZONE FOR VARIABLES MEASURED WITH TEST VEHICLE BETWEEN SHOPPER'S HOME AND SUPERMARKET

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11
Sector Zone	Sample Size	Trips/1000 Households	Accelerator Applications	Large Steering Wheel Reversals	Change of Speed (MPH x 4)	Change of Direction (Radians x 10)	Time in Motion (Seconds)	Brake Applications	Miles x 10^2	Elapsed Trip Time (Seconds)
11	9	132	22	24	144	127	199	16	115	255
12	11	140	34	33	228	192	352	26	213	417
13	12	43	50	54	328	319	626	37	406	717
14	1	4	101	85	297	418	1327	62	801	1337
21	8	232	21	18	107	169	185	15	103	201
22	6	148	38	42	236	379	450	29	282	524
23	3	42	51	59	186	399	625	32	418	721
31	7	552	19	21	64	98	126	13	64	138
32	3	84	50	45	207	272	519	38	360	542
33	6	53	44	38	187	275	566	17	481	585
34	2	29	64	46	235	190	718	20	595	723
41	8	648	24	25	113	115	168	10	101	182
42	9	282	27	40	125	164	255	18	212	313
43	31	192	38	33	136	166	402	14	363	427
44	3	107	52	41	179	213	668	17	611	715
51	3	201	18	23	117	81	145	11	84	157
53	2	648	28	30	171	161	394	14	350	439
55	5	201	74	100	280	284	873	26	821	886
61	9	665	25	32	98	137	175	16	89	187
62	1	530	30	22	149	178	254	22	180	308
63	1	278	77	81	77	246	731	22	667	897
65	2	185	64	116	219	241	1008	25	1045	1074
71	6	310	16	21	91	79	116	15	65	129
72	4	95	29	22	175	149	281	17	195	344
73	6	25	41	36	181	245	530	29	435	633
81	2	142	13	14	35	48	125	9	75	135
82	18	206	27	26	132	137	270	18	181	325
83	8	32	50	48	222	161	456	29	325	536
84	3	10	79	69	245	266	877	38	679	1031
85	1	5	85	63	87	313	1240	33	1095	1375
91	1	77	21	18	50	134	203	17	125	255
92	9	134	29	35	236	148	317	23	242	386
93	12	36	45	43	224	193	458	31	318	557

TABLE 13

EXAMPLE OF DRIVEOMETER DATA COLLECTED FOR AN ARTERIAL HIGHWAY
ON A TYPICAL MONDAY, JULY-AUGUST, 1962, ANN ARBOR, MICHIGAN

(For Two Directions)

PACKARD ROAD

Section of Arterial	Time Period	Accelerator Applications	Large Steering Wheel Reversals	Change of Speed (MPH x 4)	Change of Direction (Radians x 10)	Time in Motion (Seconds)	Brake Applications	Miles x 10^2
	1	33	24	61	27	308	11	189
	2	21	22	96	16	307	12	188
State St. - Stadium Blvd.	3	39	29	106	23	312	12	190
	4	36	36	86	30	314	8	189
	5	39	37	98	40	301	21	187
	6	29	22	106	36	268	10	190
	Weekly Average	32.8	28.3	92.2	28.7	301.7	12.3	188.8

TABLE 14

AVERAGE DRIVEOMETER DATA FOR TURNING MOVEMENTS AT STADIUM BLVD-PACKARD ROAD
INTERSECTION, AUGUST, 1962, ANN ARBOR, MICHIGAN

Arterial Highway	Direction of Travel	Direction of Turn	Time Period	Accelerator Applications	Large Steering Wheel Reversals	Change of Speed (MPH x 4)	Change of Direction (Radians x 10)	Time in Motion (Seconds)	Brake Applications	Number of Times Measured
E. Stadium	E	R	4	2.6	2.4	9.0	14.6	8.4	1.4	5
E. Stadium	W	L	2	1.0	.1.2	7.4	22.2	9.2	1.2	5
Packard Rd.	NW	R	2	3.6	1.2	6.6	20.6	6.8	1.2	5
Packard Rd.	NW	L	2	8.4	1.4	4.2	12.8	6.6	1.0	5

Analysis And Discussion

Sample Adequacy

The store interview sample of six hundred and sixty was more than adequate to satisfy the level of accuracy specified. The sample could have dropped to five hundred and still be satisfactory. Only one Driveometer measurement was made for each shopping trip redriven and for each of the twenty-four cells for the sections of the arterials. This single measurement is not adequate to statistically characterize the probable values. The level of accuracy specified for the individual sector-zone maximum likelihood estimate of trips was not achieved. However, in view of the high correlation coefficients obtained between sector-zone maximum likelihood estimates and field data collected with the test car, it was concluded that satisfactory results can be obtained with a lower level of accuracy.

Store Interview Data

It was felt that a satisfactory level of accuracy was obtained from the data enumerated on the Shopping Travel Inventory Form. Out of a total of six hundred and sixty interviews completed, only two were discarded because of improper home address. During the interview, customers drew their routes with little hesitation. In most cases, the customer's notion of the map location of his residence corresponded well with the physical location. Map routes to the store which appeared illogical prior to redriving were, in most instances, considered to be both reasonable and logical after redriving.

Referring again to Table 8, the pattern of shopping trips is worth noting. At the bottom of column two, the daily totals indicate the variation by day of the week with Wednesday showing the fewest household contacts and Saturday the greatest number. Wednesday is the only exception to a continual increase in volume from Monday through Saturday. Column three shows the average hourly contacts. The latter increases gradually until twelve noon, drops for two consecutive one-hour periods, after which it begins to rise again until it reaches the maximum for the nine hour period between five and six o'clock. Table 15 lists typical hourly variations for Ann Arbor vehicle volumes near supermarket one. Comparison of street traffic volumes with supermarket household contacts suggests a similar pattern of hourly variation.

Table 11 shows that over fifty per cent of all single purpose automobile trips originated within a one-mile radial distance from the store and ninety one per cent within two miles. Column ten of Table 12 further indicates that the maximum travel distance from home to supermarket one was five and one-half miles. For these reasons, in the analysis the maximum range for functional accessibility was considered to be six miles. This resulted in a four mile radial limit for the specific road configuration around the store.

Inspection of columns one and three, Table 12, shows a pattern of decrease in trip generation with an increase in radial distance. There are some exceptions attributable to competing supermarkets, inconvenient access to store one, or lack of a convenient alternative store. Referring to the map in Figure 21, trip generations from sector-zones three-two, eight-one, and nine-one suggest an effect due to competing supermarkets. Trip generation from seven-two is influenced by both access and competing store. The residents of sector-zones five-three and five-five have no convenient alternative for shopping other than store one.

TABLE 15

SELECTED HIGHWAY INTERSECTION TRAFFIC VOLUMES[1]
ANN ARBOR, MICHIGAN

	Intersection Stadium & Packard	Intersection South Main & Stadium	Intersection Washtenaw & Stadium
	Tuesday	Wednesday	Monday
Hour	Cars	Cars	Cars
7-8	1618	1972	1903
8-9	1743	1680	1704
9-10	1244	1075	1263
10-11	1292	1070	1243
11-12	1333	1292	1230
12-1	1692	1519	1402
1-2	1460	1210	1483
2-3	1348	1211	1473
3-4	1855	2218	1852
4-5	2178	2263	2250
5-6	2505	2325	2314
6-7	1518	1608	1525
TOTAL	19786	19443	19642

[1] Data furnished by the City of Ann Arbor, Michigan.

Driveometer Data

Effective Distance Of Travel To Supermarket

Individual Driveometer Variables.--Referring to Table 12, when the shopping trip generation in column three is plotted against the variables in columns four through eleven, the result is a discounted functional accessibility curve. The variables are measurements for the effective distance of travel in relation to trip generation. Figure 12 Plates I through VIII show these relationships graphically. All of the graphs tend toward the same pattern but with different degrees of variability. Plate II depicting steering wheel reversals shows the least variability while Plate III-change of speed- and Plate IV- change of compass direction- indicate the greatest variability.

Referring to Plate II again, there are three points on the right side of the graph enclosed in a box. These points represent values for sector-zones five-five, six-three, and six-five. These rural areas are generating more trips per household than the general trend indicates. The residents of these sector-zones are forced to accept the effective distance of travel to supermarket one for lack of a closer alternative.

On the left side of the graph in Figure 12 Plate II, are three additional points set apart from the curve. These points represent values for sector-zones seven-two, eight-one and nine-one, and are reflecting the effect of the competing supermarket.

The dotted line passing through the triangles is a plot of the power curve relating trips per one thousand households (Y) as a function of effective distance, measured in units of steering wheel

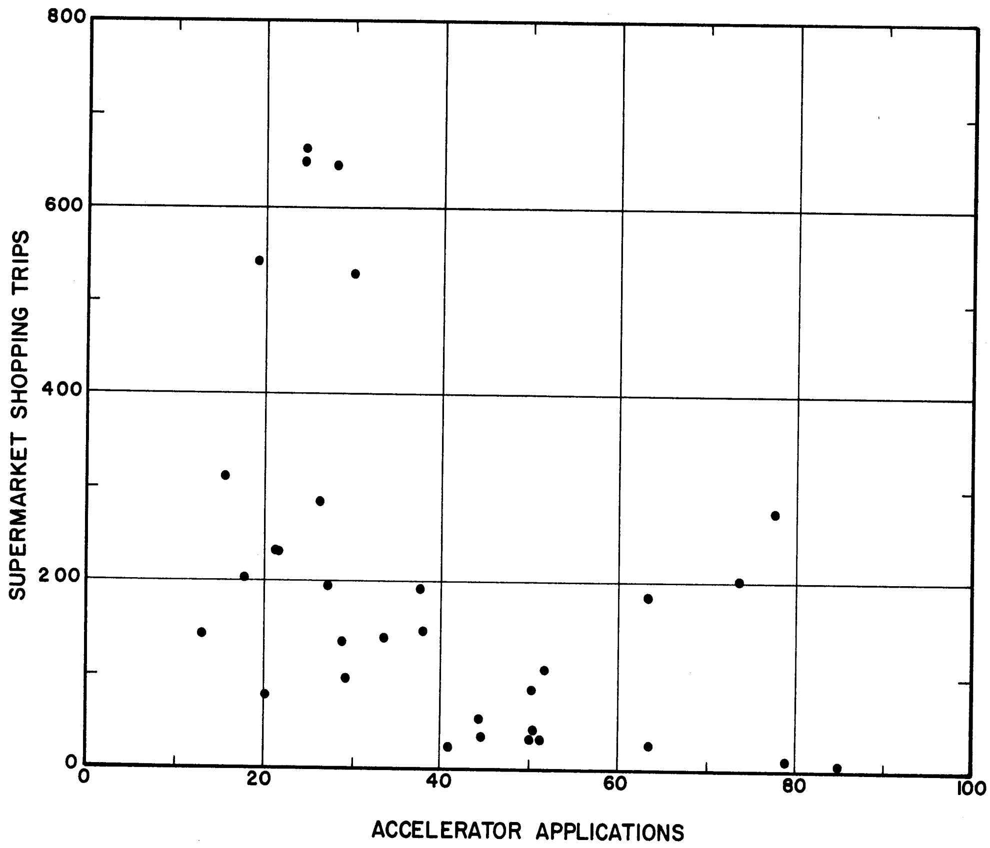

Figure 12, Plate I. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Number of Acclerator Applications, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

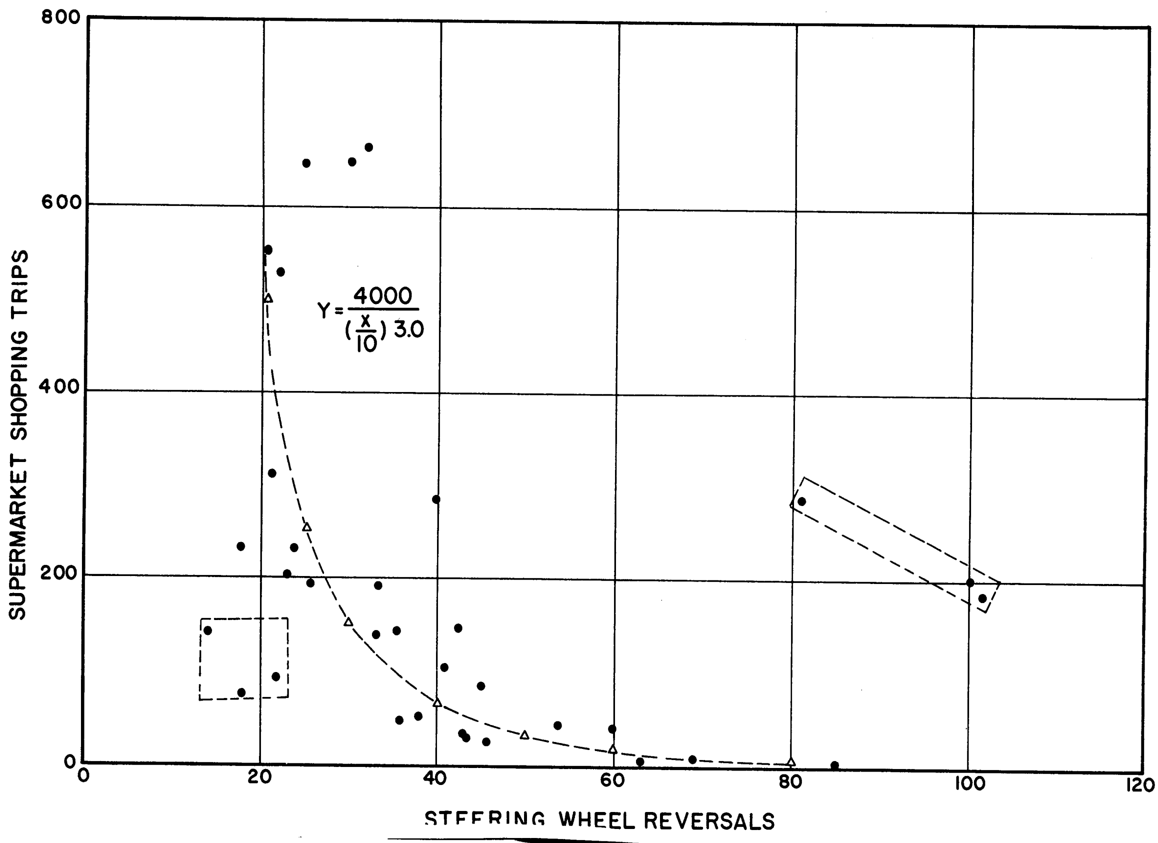

Figure 12, Plate II. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Number of Steering Wheel Reversals, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

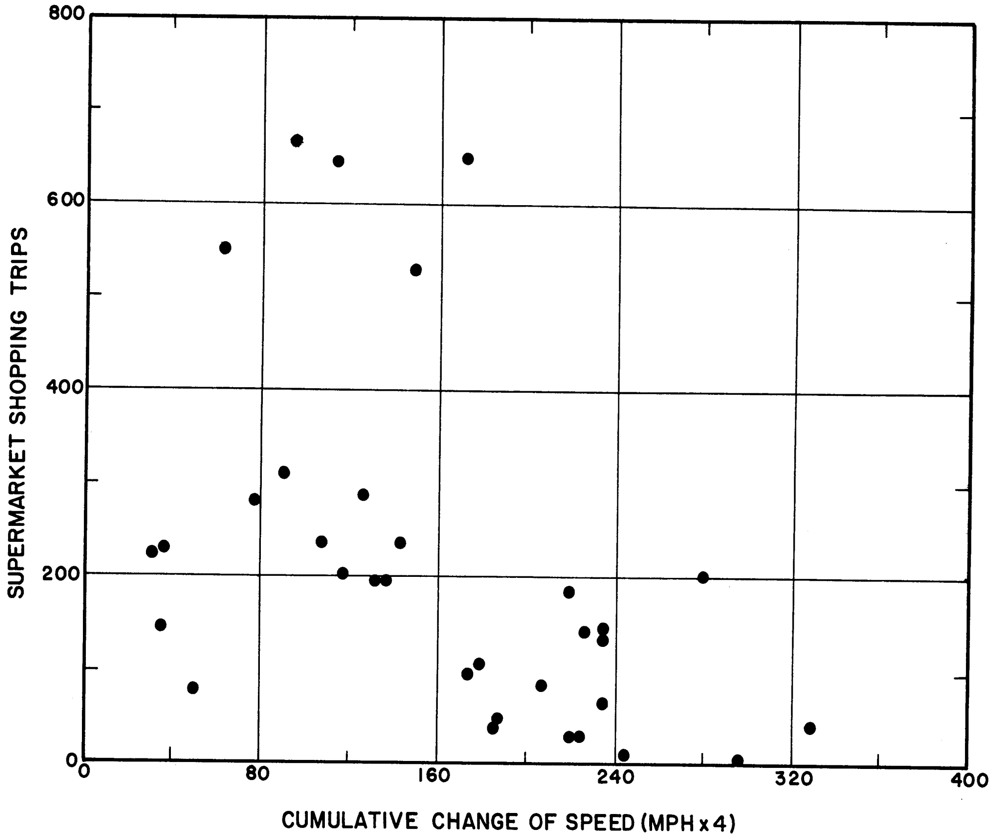

Figure 12, Plate III. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Cumulative Change of Speed in Miles Per Hour Times Four, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

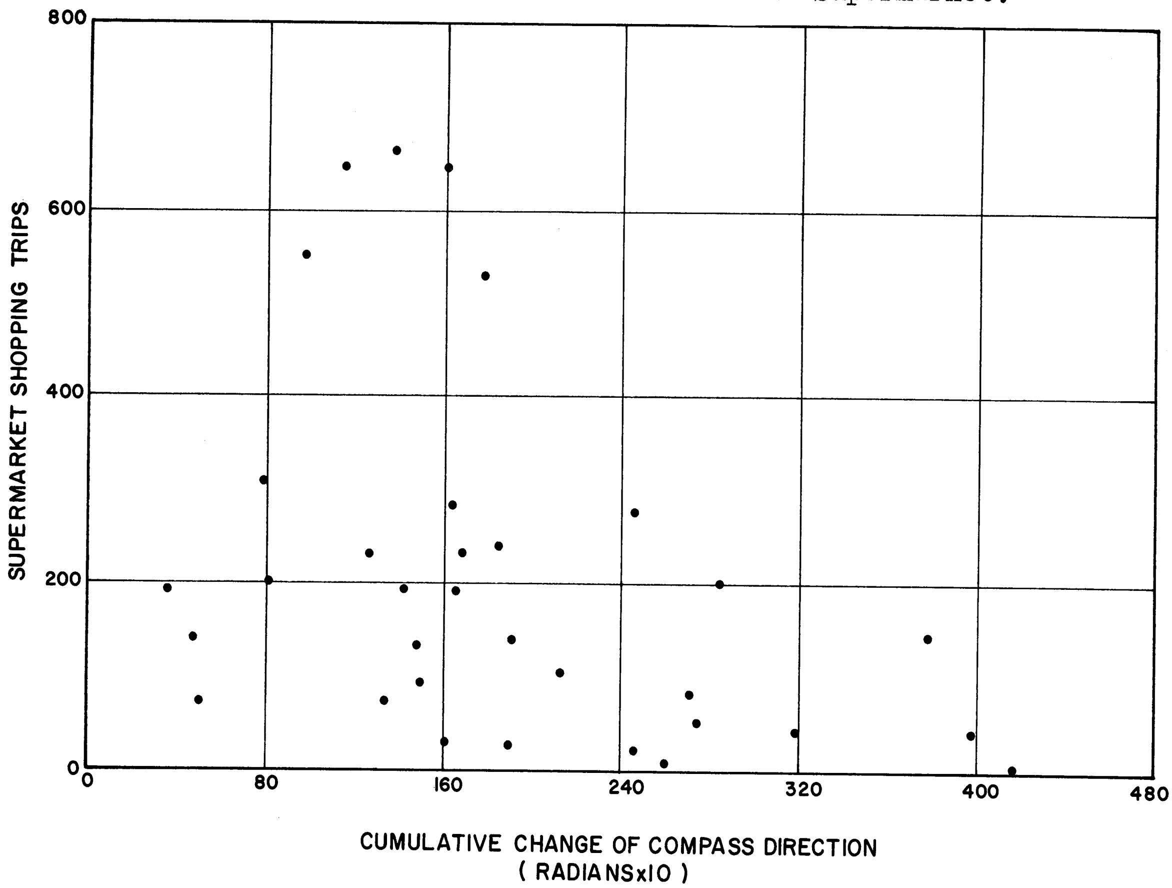

Figure 12, Plate IV. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Change of Compass Direction in Radians Times Ten, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

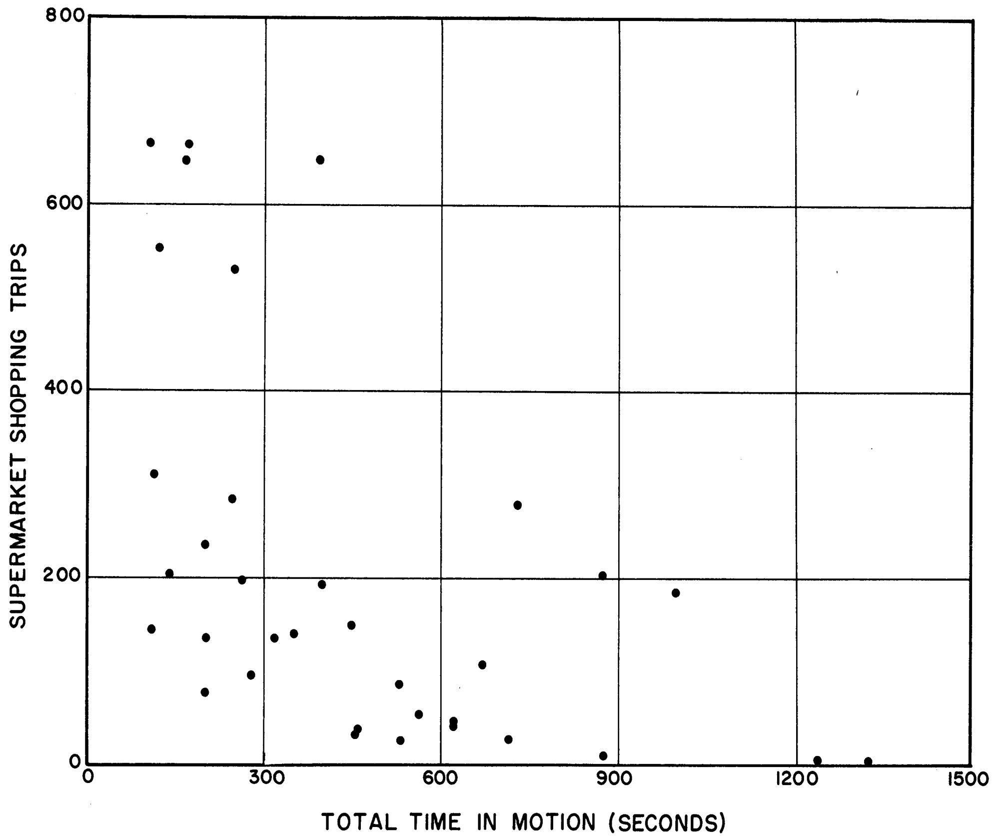

Figure 12, Plate V. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Total Time in Motion, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

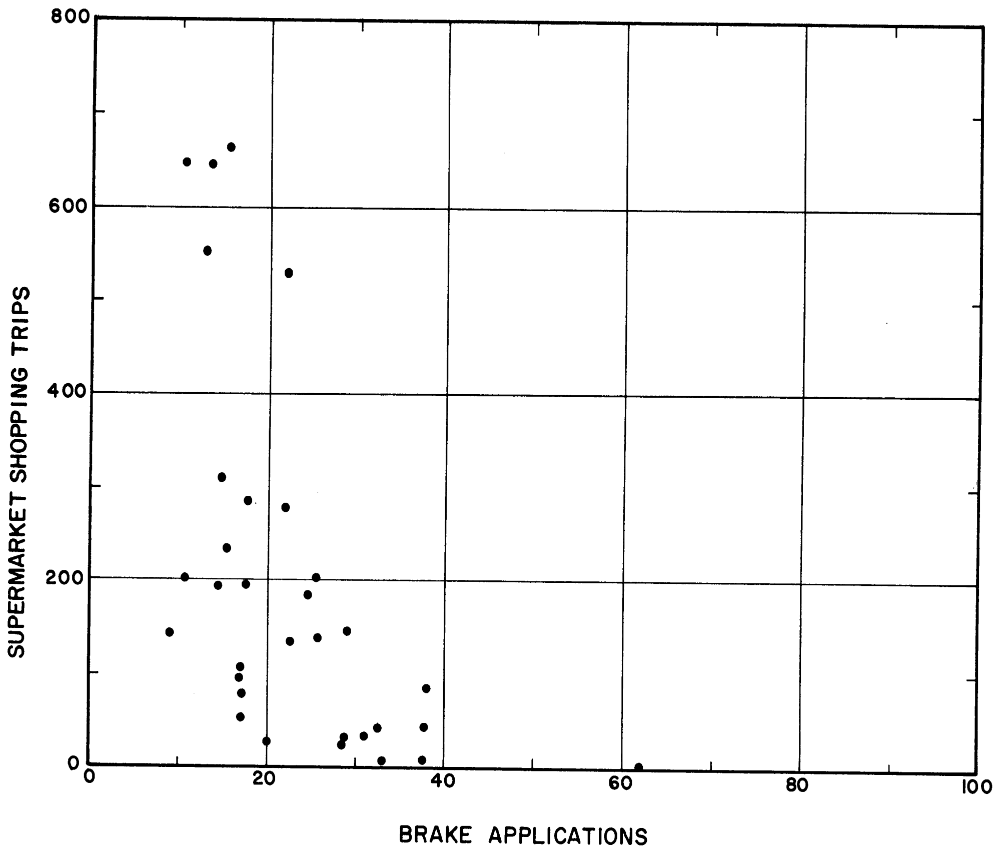

Figure 12, Plate VI. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Number of Brake Applications, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

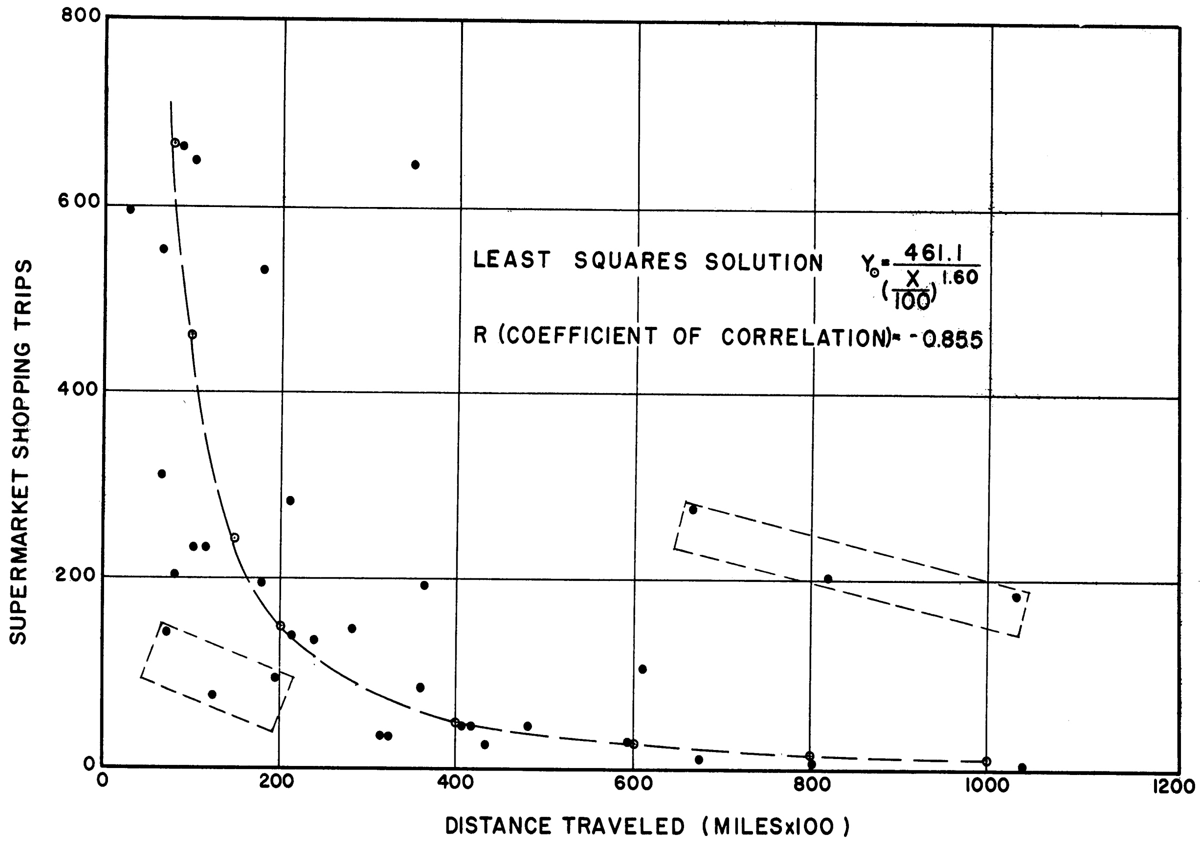

Figure 12, Plate VII. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Distance Traveled in Miles Times One Hundred, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

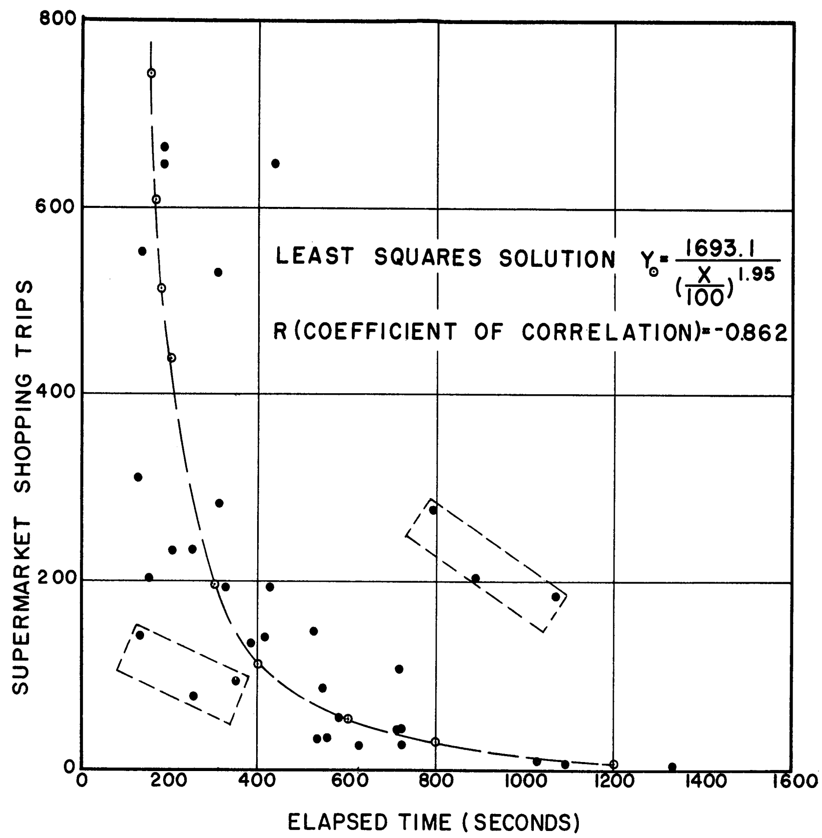

Figure 12, Plate VIII. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Elapsed Trip Time in Seconds, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

reversals (X), from which the following relationship is derived:

$$Y = \frac{4000}{\left(\frac{X}{10}\right)^3}$$

With the exception of the three points above six hundred on the Y axis, the fit is good. These three points represent sector-zones adjacent to the supermarket. The explanation for the displacement of these points is as follows: the parking maneuvers in the lot next to the supermarket generated variables that were dependent upon the number of cars in the lot and the amount of traffic on Packard Road, both of which are related to the time of day; when the parking lot variables were examined as a separate group, they were found to be independent of effective distance or route traveled; thus for shopping trips of short effective distance, the parking and unparking maneuvers contributed a disproportionate share to the total measurements for the trip. If the values of the variables generated in the parking lot are subtracted from the total measurements for each trip, and the values again aggregated by sector-zone, the points above six hundred are no longer displaced from the general trend. However, since certain combinations of Driveometer variables were subsequently deemed to be better indices of effective distance, no further analysis of the individual variables was made.

In order to make the above evaluation, Driveometer variables directly attributable to the supermarket parking lot were taken from the film record of the trip. These were aggregated by hour of the day to obtain average values. Table 16 shows examples of these variables for the parking lot.

Indices Of Grouped Driveometer Variables.--

Sum Of Driver Actions.-The best plot of grouped variables in relation to shopping trip generation per one thousand households resulted when the driver actions were summed. Figure 12 Plate IX shows this graphically. Three of the five points above five hundred on the Y axis represent sector-zones adjacent to the store and the other two were developed from small samples. In Figure 12 Plate X, values for the variables generated in the parking lot were subtracted from the total for the trip. In Plate XI, values for the driver actions were adjusted to an equivalent weekly average value in order to cancel the effect of hourly traffic variations on the driver actions. Data for Plates IX, X, and XI are listed in Table 17, columns one, four, and seven. Indices of the variables for the parking lot are shown in Table 18.

In Plate X, it was assumed that the best fitting curve relating X and Y would be a power curve of the type

$$Y = \frac{C}{X^n} ,$$

where both C and n are constants determined from the field data. A quadratic parabola was also fitted to the data of Plate X with the following results:

$$Y = 786.2 - 10.59 X + 0.03545 X^2.$$

The coefficient of correlation R for the parabola is -0.77 indicating that the quadratic parabola accounts for a smaller amount of the total variance than does the power curve.

Time Rate Of Driver Actions.-When driving an automobile, not only are the total driver actions important, but also important is the

TABLE 16

EXAMPLE OF AVERAGE HOURLY VALUES FOR PARKING LOT DRIVEOMETER VARIABLES

Time Period	Accelerator Applications	Large Steering Wheel Reversals	Change of Speed (MPH x 4)	Change of Direction (Radians x 10)	Time in Motion (Seconds)	Brake Applications	Miles x 10^2
9AM-10AM	5.5	5.7	18.0	47.0	29.6	4.9	9.2
1PM-2PM	6.9	7.5	34.1	42.9	37.2	3.8	10.1
4PM-5PM	5.6	7.9	33.4	43.6	38.7	5.0	11.3

TABLE 17

INDICES OF DRIVEOMETER VARIABLES

	Total From Home To Store			Total From Home To Store Less Parking Lot			Total From Home To Store But Adjusted For Hourly Traffic Variation		
	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
Sector-Zone	Driver Actions	Driver Actions Per Minute of Round Trip Travel	Vehicle Maneuvering Per Mile of Round Trip Travel	Driver Actions	Driver Actions Per Minute of Round Trip Travel	Vehicle Maneuvering Per Mile of Round Trip Travel	Driver Actions	Driver Actions Per Minute of Round Trip Travel	Vehicle Maneuvering Per Mile of Round Trip Travel
11	62	14.51	179	47	12.98	195	60	12.06	195
12	92	13.30	380	73	11.30	403	94	11.91	402
13	141	11.83	822	123	11.06	847	142	11.13	847
14	248	11.13	921	232	11.16	935	233	9.46	929
21	54	16.26	156	39	13.65	172	54	13.53	169
22	109	12.52	738	93	10.87	758	113	11.14	758
23	143	11.91	568	116	10.21	583	140	9.68	582
31	52	22.79	59	34	21.43	67	53	21.61	67
32	133	14.75	376	119	14.00	387	138	14.47	387
33	99	10.16	278	86	9.16	282	97	8.89	282
34	129	10.71	241	105	9.14	244	136	10.11	245
41	59	19.55	104	33	16.66	113	58	16.25	112
42	85	16.27	135	69	14.89	141	84	14.61	141
43	86	12.02	118	69	10.21	121	82	9.42	120
44	109	9.17	199	94	8.27	198	108	7.98	201
51	52	19.78	79	34	18.22	87	51	17.58	88
53	72	9.77	153	58	7.02	156	68	6.34	156
55	200	13.52	382	186	12.95	385	200	13.19	385
61	72	23.27	124	47	20.78	137	72	20.68	137
62	71	14.42	202	52	12.20	215	73	12.09	214
63	180	13.55	1006	163	13.68	1027	182	13.89	1027
65	204	11.40	240	190	11.08	243	197	10.70	242
71	52	24.09	63	38	21.89	72	52	22.24	72
72	68	11.77	205	48	9.70	216	68	9.84	217
73	106	9.95	287	89	8.71	297	104	8.55	296
81	36	16.00	13	20	8.00	13	35	6.19	10
82	71	12.99	153	55	10.92	160	73	11.53	161
83	127	14.23	262	108	13.13	271	126	13.29	270
84	186	10.83	433	168	10.04	452	193	10.91	451
91	181	7.90	152	160	7.09	153	162	5.91	156
92	87	13.48	248	67	10.86	259	84	10.25	257
93	119	12.77	337	104	11.72	348	119	11.89	348

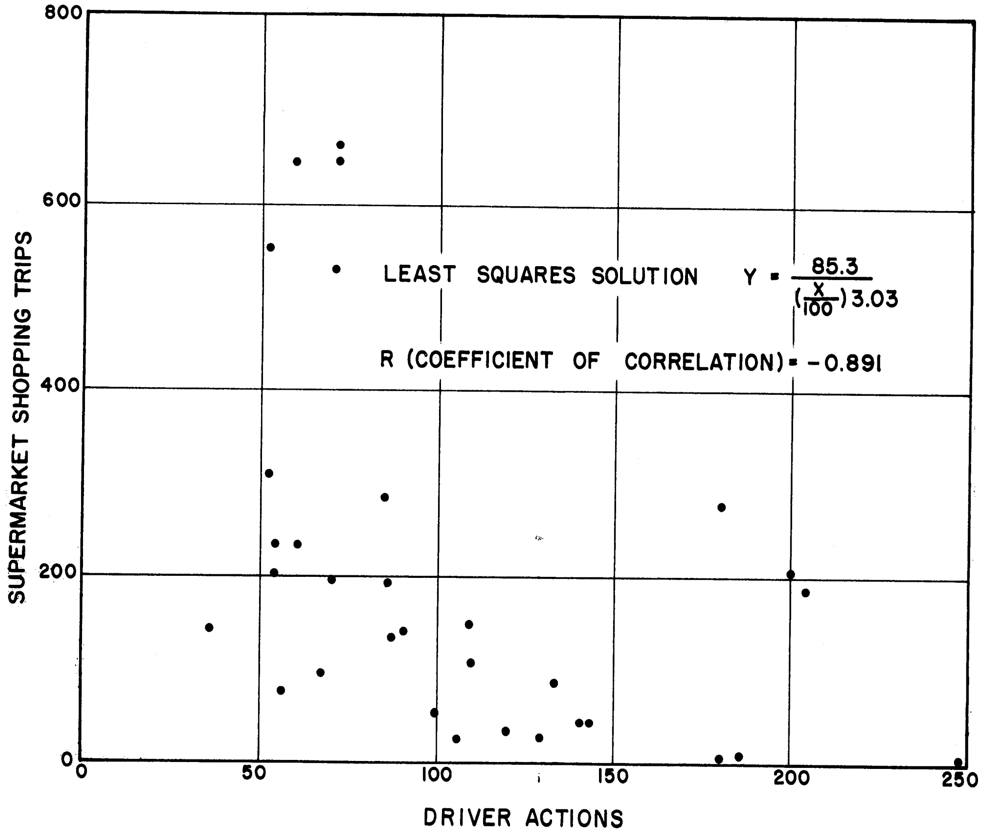

Figure 12, Plate IX. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Number of Driver Actions, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

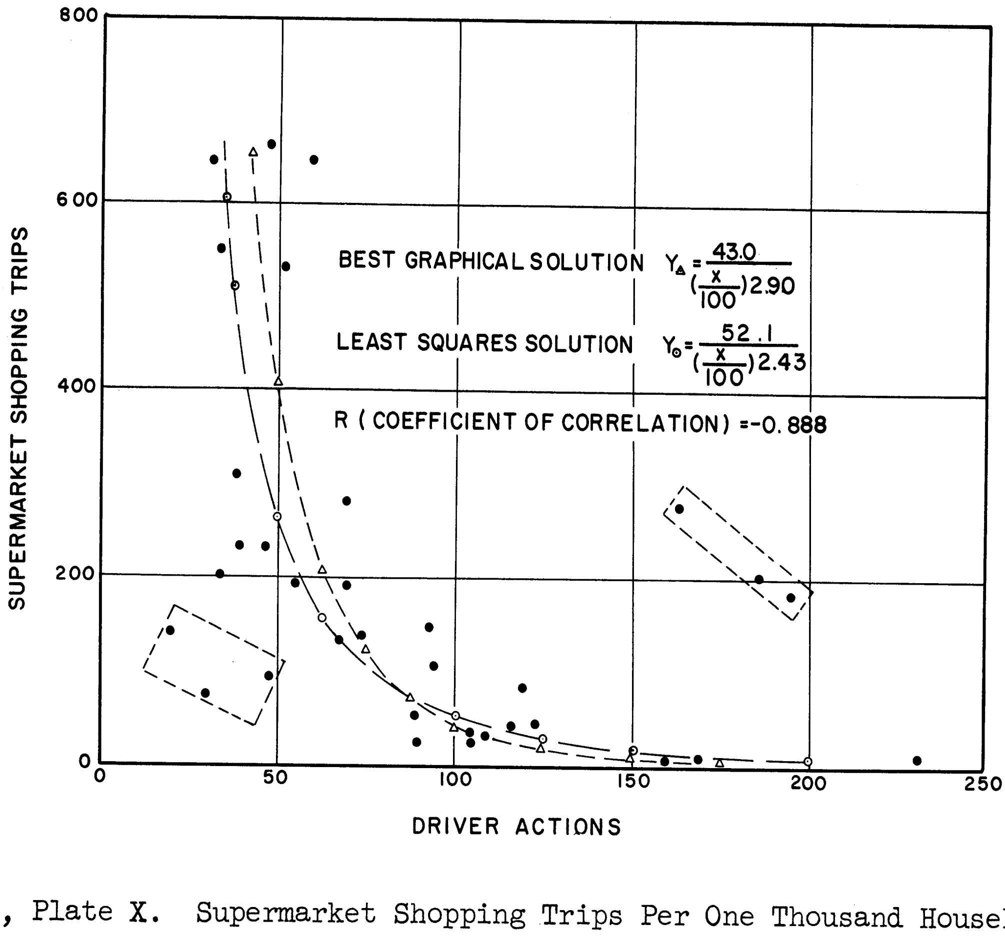

Figure 12, Plate X. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Number of Driver Actions, Less Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

TABLE 18

AVERAGE DAILY INDICES OF DRIVEOMETER VARIABLES FOR PARKING LOT

	Col. 1	Col. 2	Col. 3
	Index A	Index B	Index C
Time of Days	Total Driver Actions	Driver Actions Per Minute of Time of Vehicle Operation in Parking Lot	Distance Rate of Covariability of Vehicle Maneuvers Per Mile of Vehicle Operation in Parking Lot
9-10 a.m.	16.27	39.67	12.76
10-11	17.25	34.50	18.82
11-12	17.89	31.22	27.39
12-1 p.m.	16.73	29.33	25.97
1-2	18.20	30.48	26.11
2-3	14.29	42.99	28.90
3-4	19.50	33.07	25.66
4-5	18.64	33.70	22.42
5-6	16.50	27.04	28.63
6-7	18.79	31.07	21.10
7-8	16.57	29.76	22.10
8-9	13.14	23.10	17.06

time rate at which these actions are required. Figure 12 Plates XII, XIII, and XIV show the use of the time rate of driver actions as units of effective distance (X-axis). Data for these graphs is shown in Table 17, columns two, five and eight. The time is the elapsed trip time for driving to and from the supermarket. A drastic change in pattern has taken place. Plate XII suggests that the points may be tending toward a straight line. When the points plotted are identified by sector-zones, the graph indicates an inverse relationship between distance from the store and time rate of driver actions.

Sum Of Time And Vehicle Motions.-All of the foregoing indices involve driver actions. The manipulation of the operating controls of an automobile causes the car to either turn or to change speed. Using only these two variables, no significant relationship with shopping trip generation was discernable. But when time is added to the vehicle motions, the result is indicated in Figure 12, Plate XV. Data for this graph was taken from Table 12. While the relationship is good, the difficulty in using the sum of time and vehicle motions is that unlike characteristics are being added. In this instance, the sum involves time in seconds, turning in radians, and change in speed in miles per hour. Moreover, there is the additional question of weighting each of the characteristics for the summing process.

Aside from the problems of adding unlike units and deciding on weighting factors for each of the variables, the adding of these three quantities does seem to be reasonable. The variables represent quantities over which the driver can exercise a considerable amount of control, since

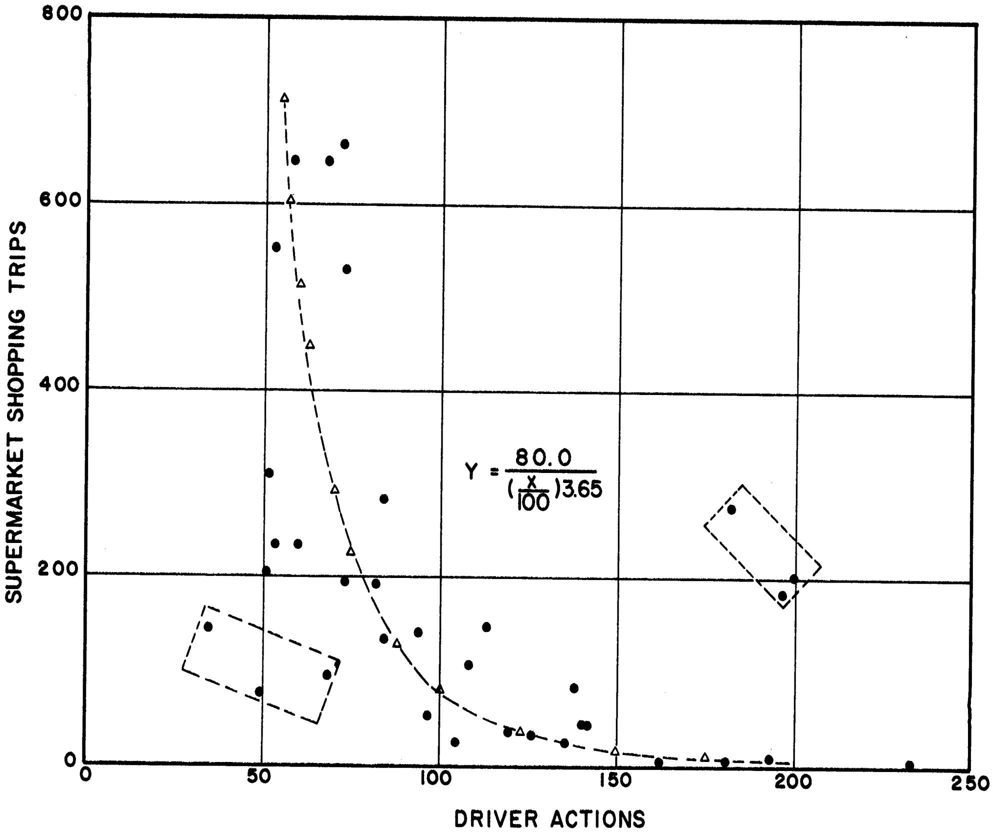

Figure 12, Plate XI. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Number of Driver Actions, Less Supermarket Parking and Unparking and Adjusted to the Weekly Average Highway Traffic Conditions, From Each Sector-Zone to the Supermarket.

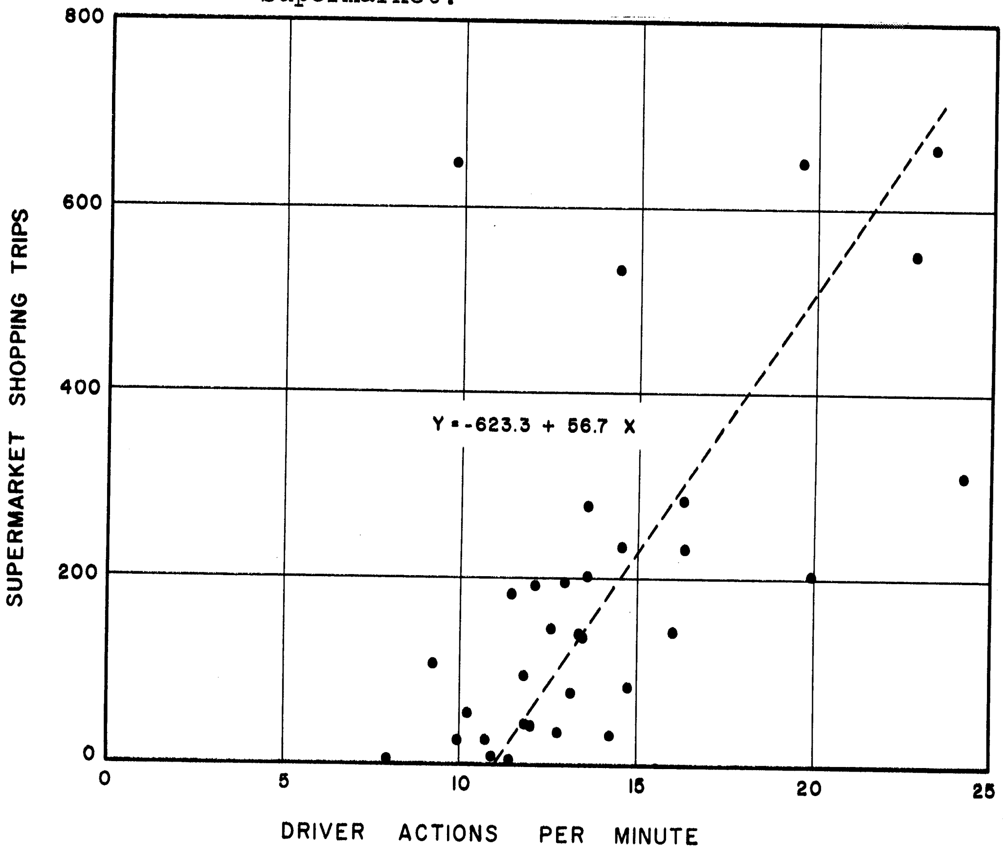

Figure 12, Plate XII. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Rate Per Minute for Driver Actions, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

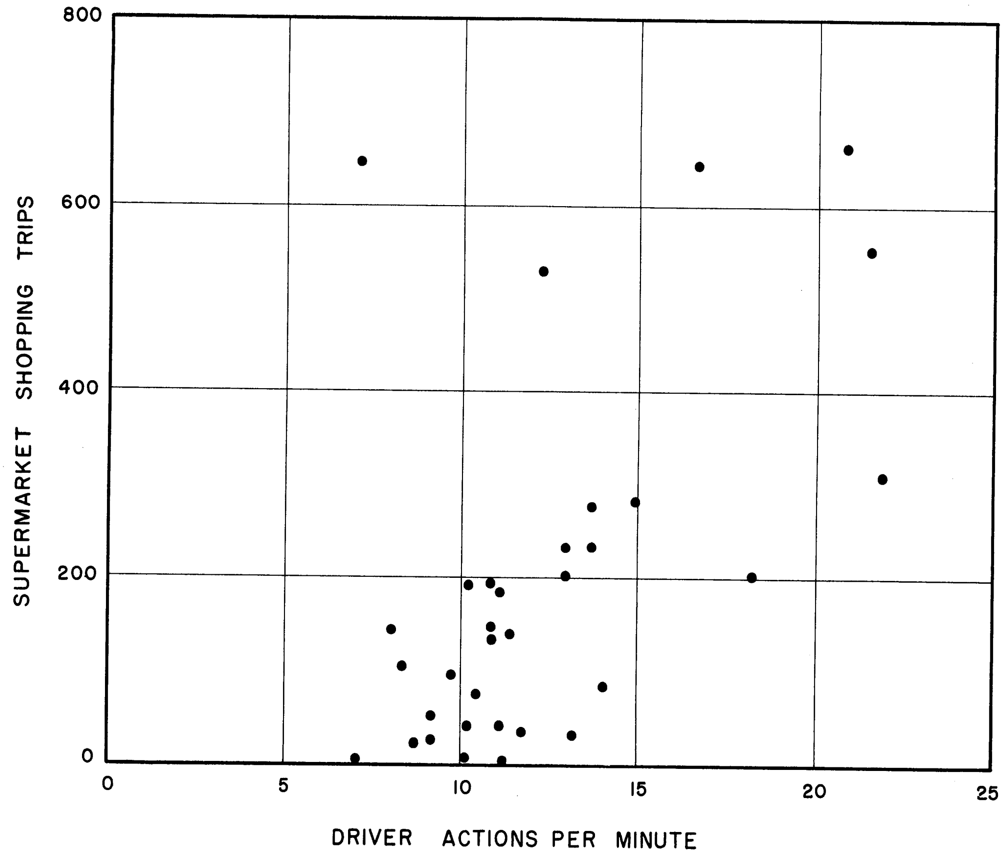

Figure 12, Plate XIII. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Rate Per Minute For Driver Actions, Less Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

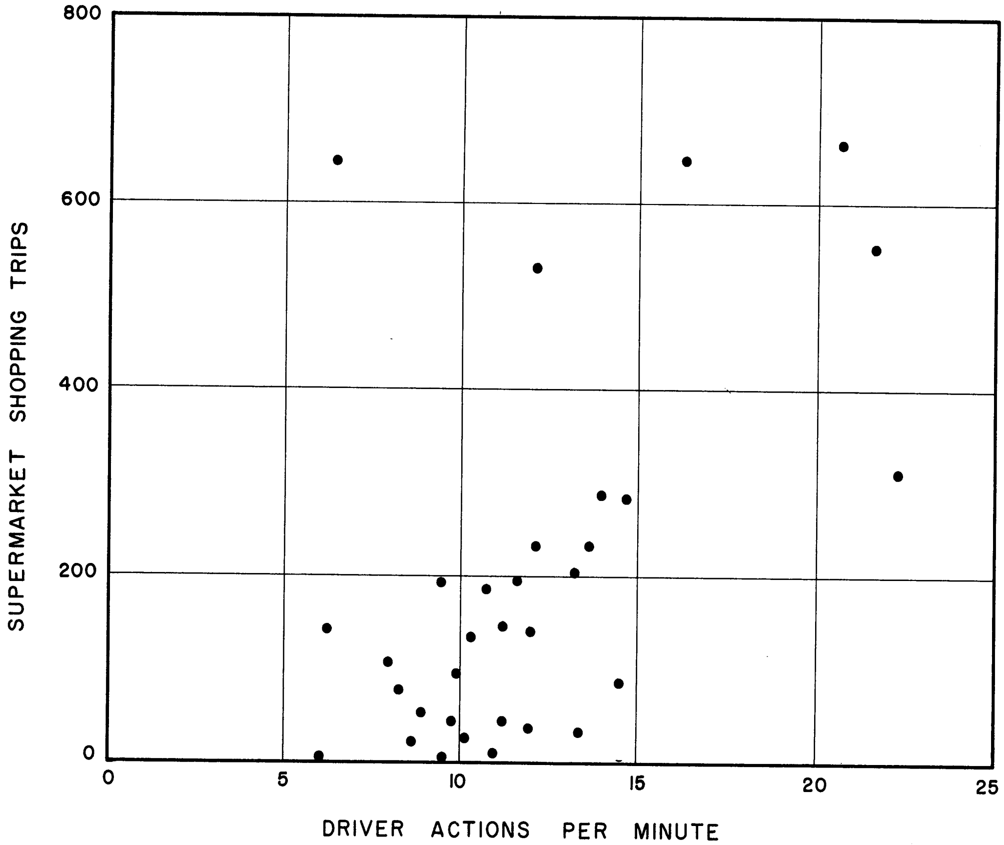

Figure 12, Plate XIV. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Rate Per Minute For Driver Actions, Less Supermarket Parking and Unparking and Adjusted to the Weekly Average Highway Traffic Conditions, From Each Sector-Zone to the Supermarket.

they are partially substitutable for each other. Thus it is quite likely that the driver may attempt to minimize the sum of the three in any given highway environmental situation. For example, travel time may be reduced for a certain trip by increasing the speed of travel. On the urban street system, increasing travel speed may produce an increase in acceleration, deceleration, and turning of the vehicle.

Distance Rate Of Covariability.-If the vehicle turning in radians and the change in speed in miles per hour and the elapsed trip time are all multiplied together, and the product divided by travel distance, the result is a value which the author has labeled the distance rate of covariability. In a physical sense, the denominator is a measure of the spatial separation of the shopper from his intended objective for which units of the variables in the numerator must be expended. Figure 12 Plates XVI through XVIII indicate the use of this index as a measure of effective distance. The data for the graphs is found in Table 17, columns three, six, and nine. Neither the subtraction of the values of the variables for the parking lot, nor the correction for the hourly variation of traffic appeared to make any significant change in the pattern of the index.

Sensitivity Of Effective Distance Indexes To Traffic Variations.--Any index composed of combinations of Driveometer variables should be sensitive enough to distinguish between two different highway environments at the same time of the day, or the same highway at different times of the day. The second of these requirements can be checked by taking a sector-zone from which shoppers used basically the same route to store one and

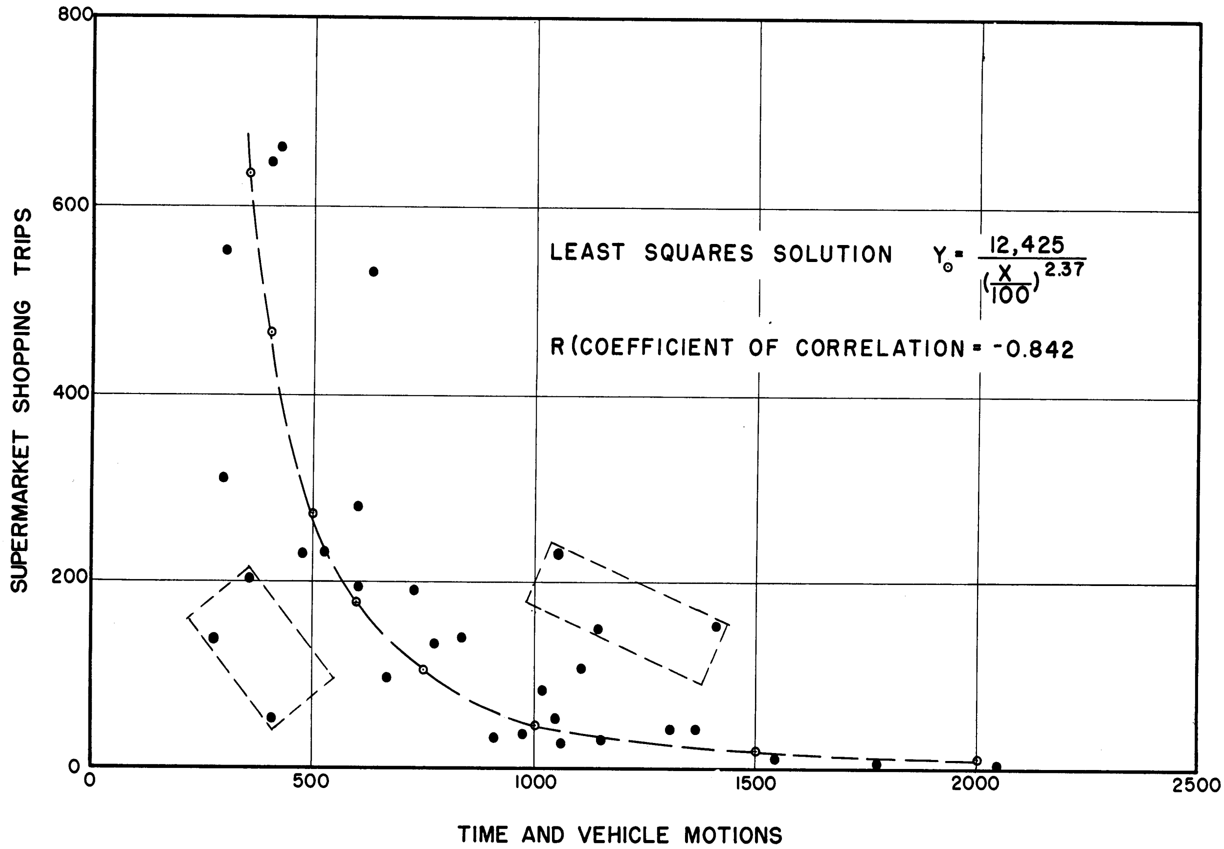

Figure 12, Plate XV. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Time and Vehicle Motions, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

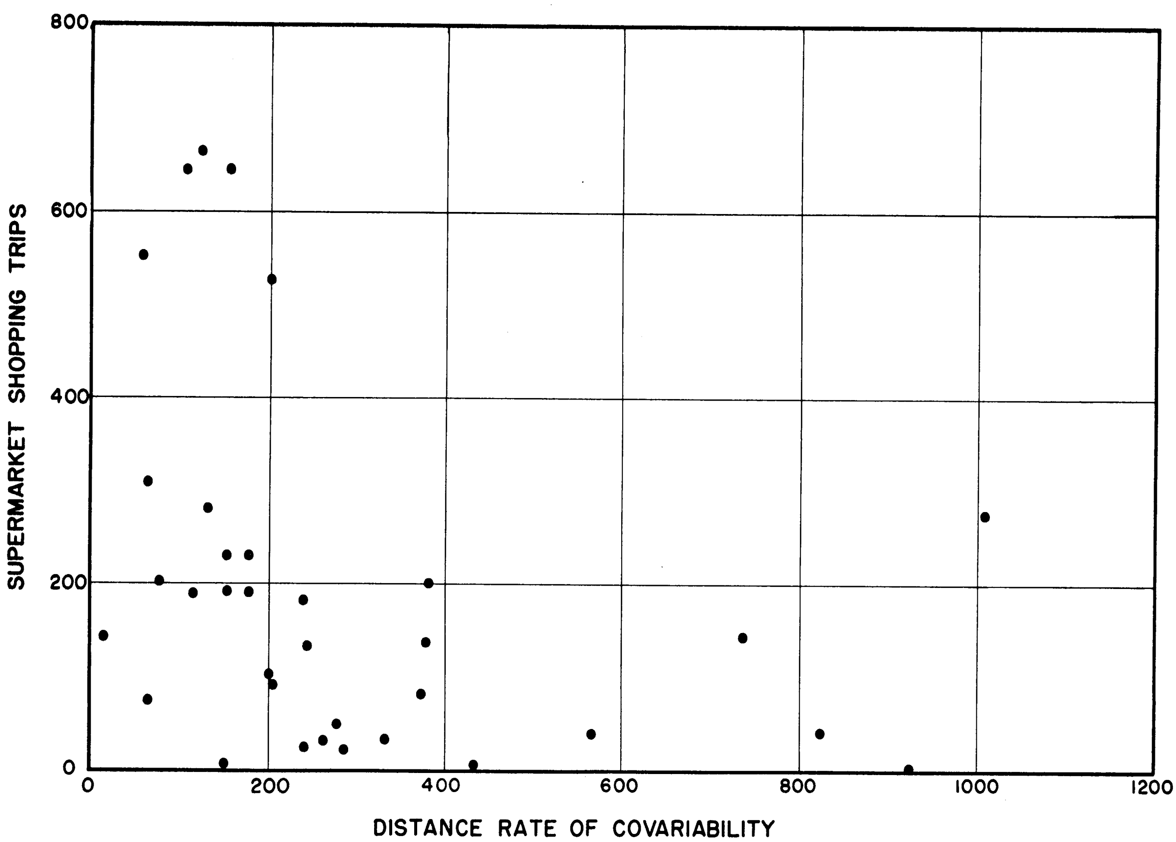

Figure 12, Plate XVI. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Distance Rate of Covariability, Including Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

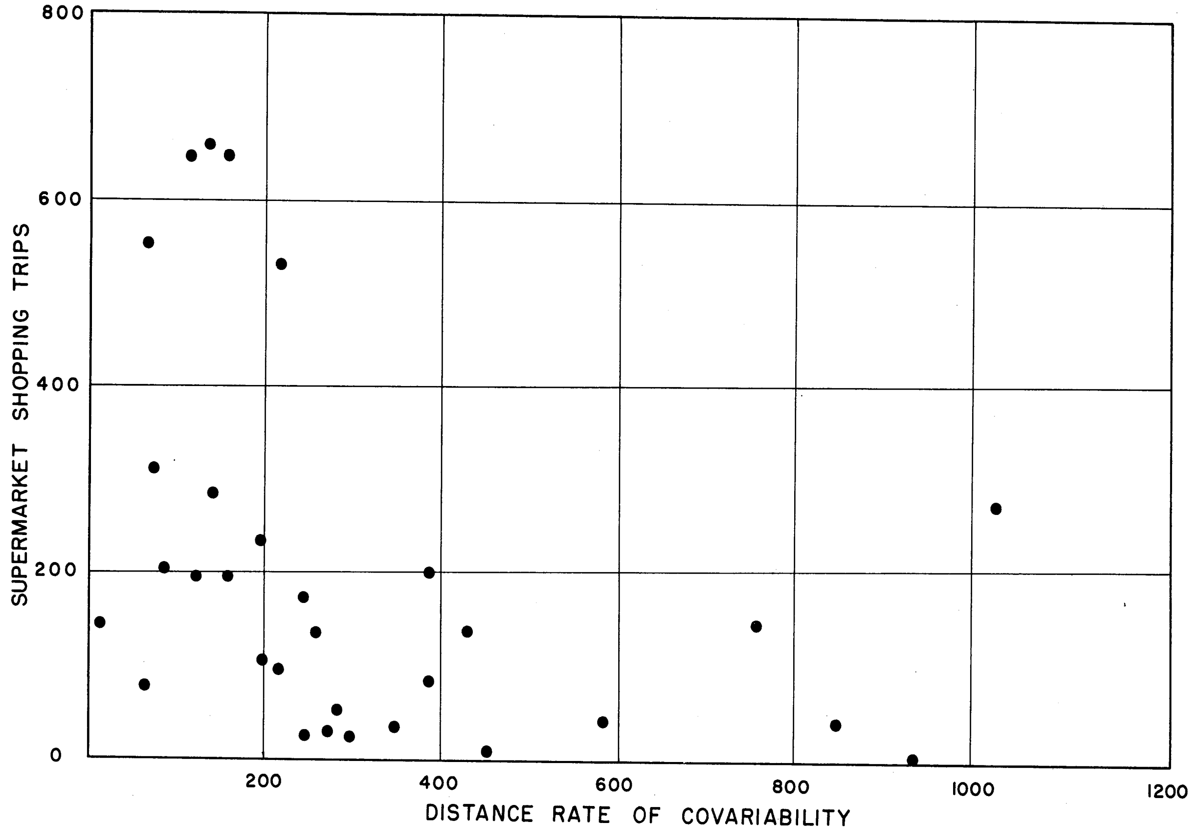

Figure 12, Plate XVII. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Distance Rate of Covariability, Less Supermarket Parking and Unparking, From Each Sector-Zone to the Supermarket.

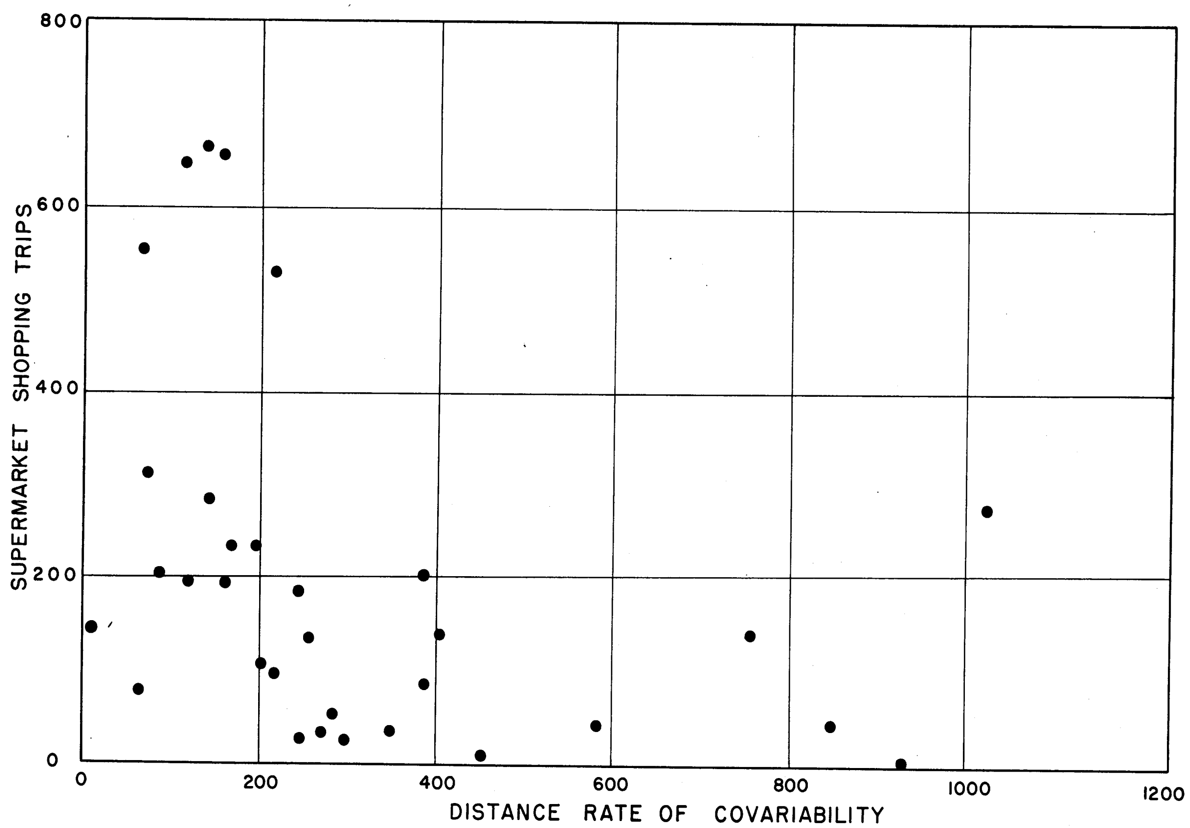

Figure 12, Plate XVIII. Supermarket Shopping Trips Per One Thousand Households Per Week by Sector-Zone in Relation to the Average Distance Rate of Covariability, Less Supermarket Parking and Unparking and Adjusted to the Weekly Average Highway Traffic Conditions, from Each Sector-Zone to the Supermarket.

plotting the values of the indexes by hour of the day. This was done for the residents for sector-zone four-three using the values of the Driveometer variables generated between the shopper's home and the supermarket. Figure 13, Plates I through IV, are the result of this technique. Both driver actions and the time rate of driver actions indicate a band of values.

Arterial Highways

The Driveometer measurements made on the arterials were translated into the same travel indices used in the analysis of the effective distance of travel for supermarket shopping trips. The values shown in Table 19 for each time period are the average of four observations made for the four groups of days. If neither time nor money were restricting factors, the six daily time periods should be divided into smaller intervals of ten minutes. These ten minute intervals should then be randomly sampled for the four groups of days.

It would be desirable to compare an index characterizing highway environment with the standard used to describe the loading and capacity of a highway, the number of motor vehicles per unit of time. The only current and publicly available data on Ann Arbor traffic volumes are given in Table 15 which outlines hourly trends. Inspection of Table 19 reveals that the indices reflect the time pattern variation of street traffic volumes. The first, third, and fifth time periods usually contain the peak values for the indices.

The indices have additional implications. Figure 14, Plate I is a plot of the time rate of driver actions, Index B, by hour of the day

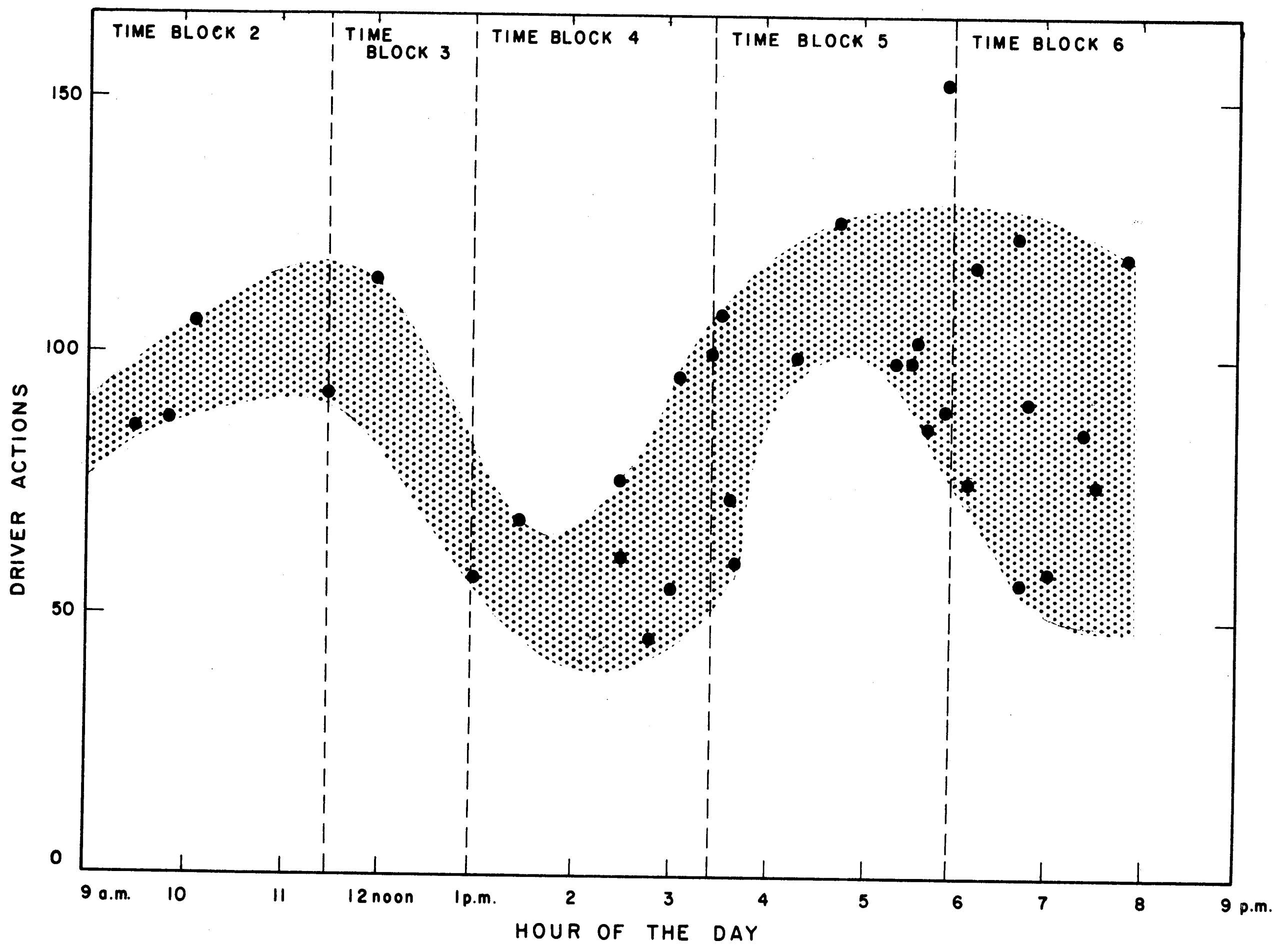

Figure 13, Plate I. Variation of Driver Actions by Hour of the Day for Trips from Households in Sector-Zone 43 to Supermarket and Return.

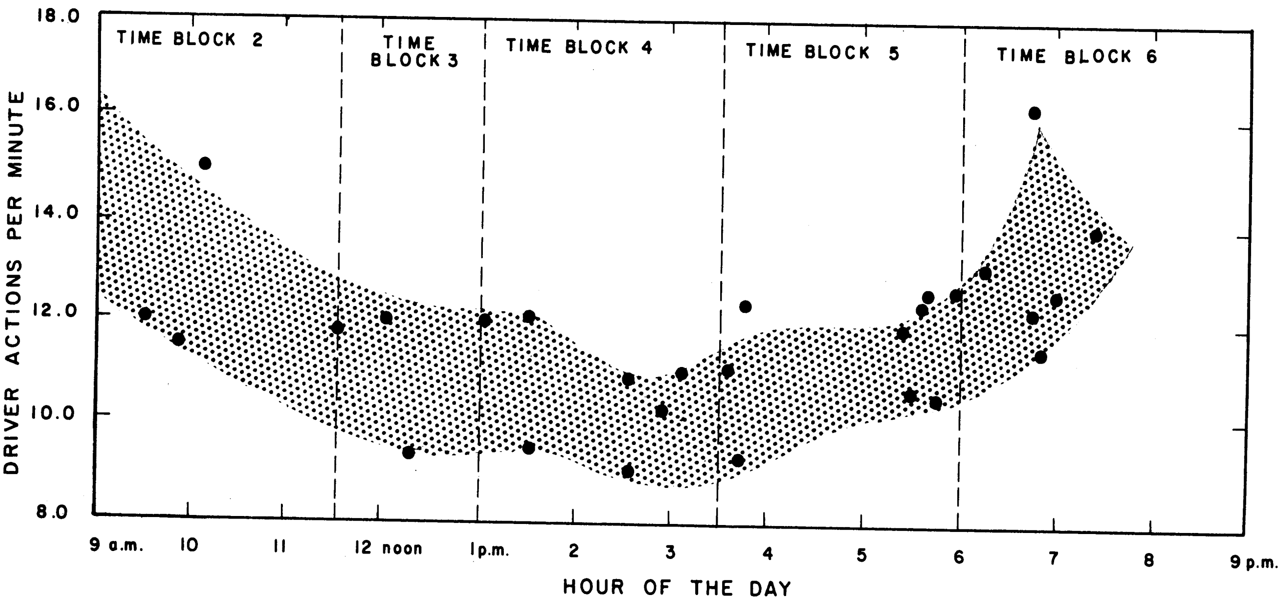

Figure 13, Plate II. Variation of the Time Rate of Driver Actions by Hour of the Day for Trips from Households in Sector-Zone 43 to Supermarket and Return.

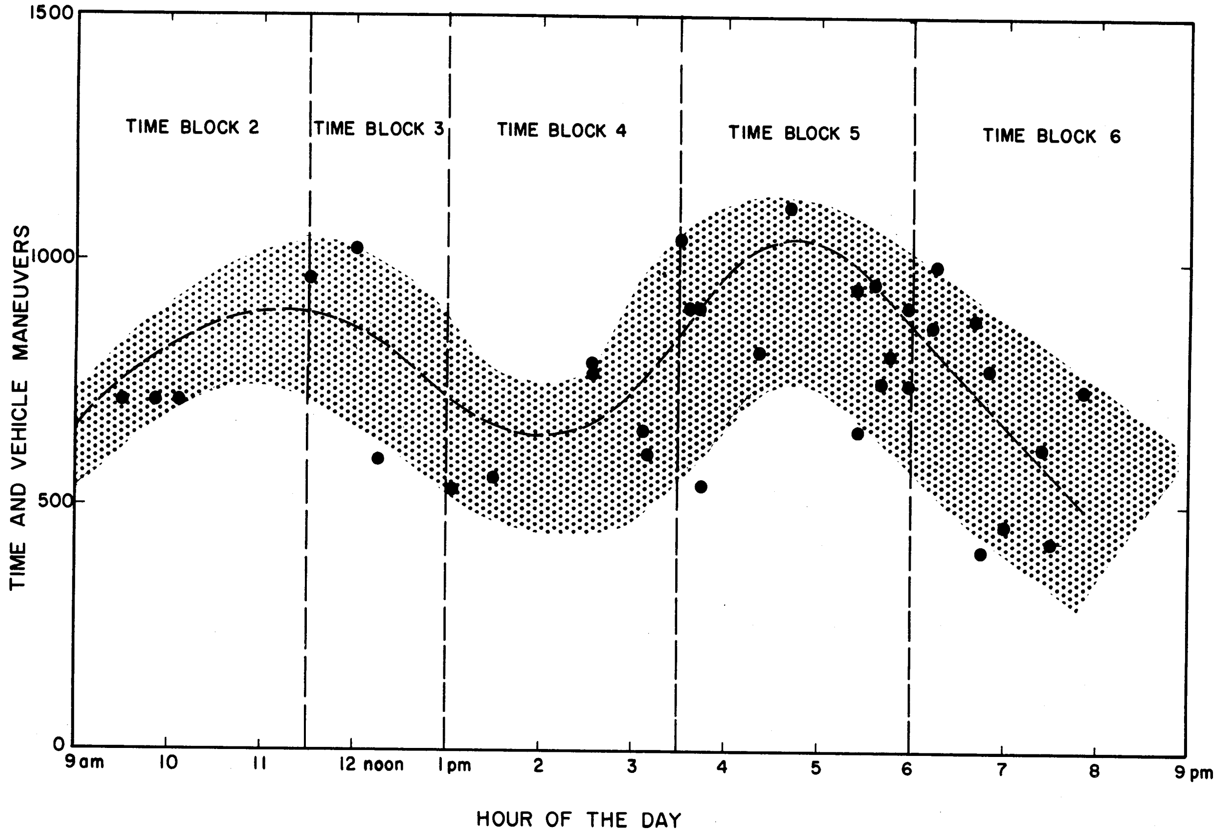

Figure 13, Plate III. Variation of the Sum of Time and Vehicle Maneuvers by Hour of the Day for Trips from Households in Sector-Zone 43 to Supermarket and Return.

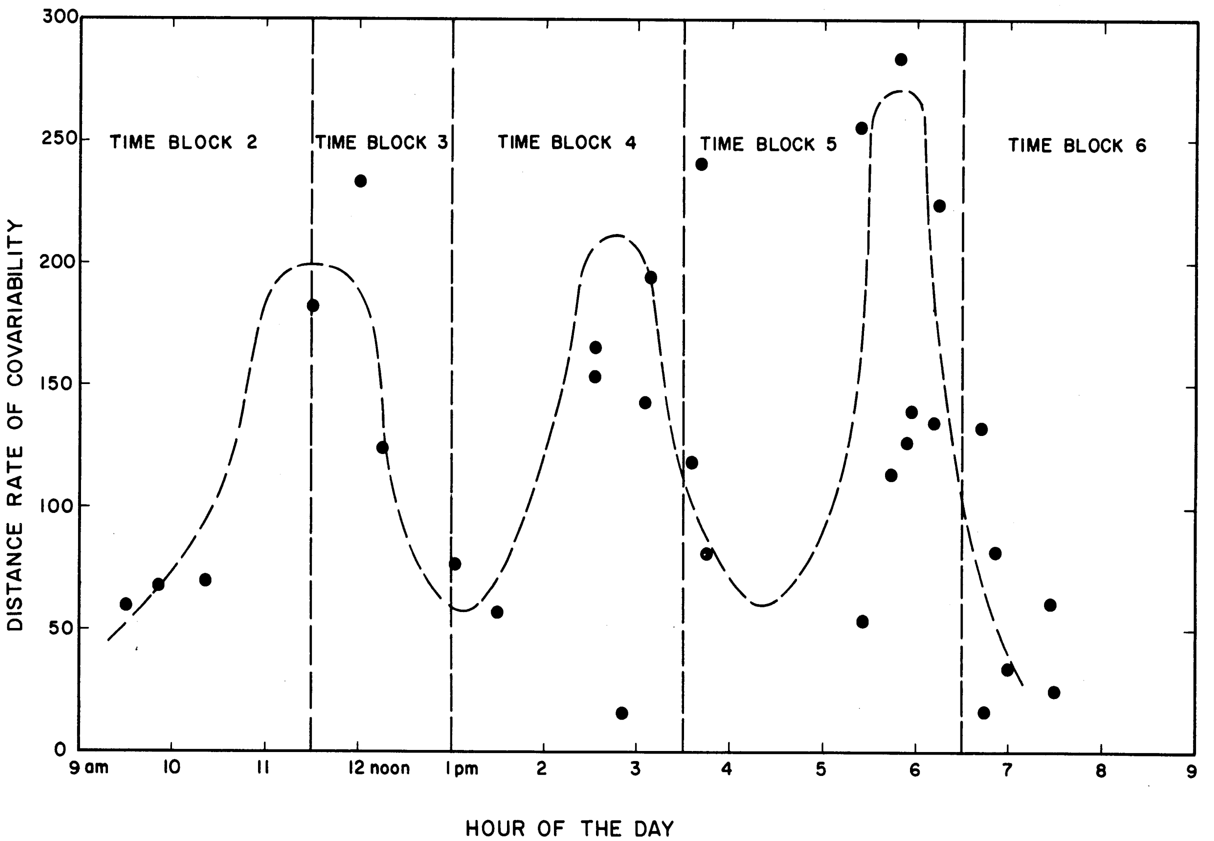

Figure 13, Plate IV. Variation of the Distance Rate of Covariability of Vehicle Maneuvering Alternatives by Hour of the Day for Trips from Households in Sector-Zone 43 to Supermarket and Return.

TABLE 19

INDICES OF DRIVEOMETER VARIABLES FOR ARTERIAL PORTIONS OF THE ANN ARBOR URBAN STREET SYSTEM

(SUMMARY FOR TWO-DIRECTIONS)

Packard Road

Sections of Arterial	Time Period	Driver Actions Index A	Time Rate Dri. Actions Index B	Dist. Rate Covar. Index C
Main-State	1	55.2	15.6	19.1
	2	47.2	13.5	11.0
	3	57.8	17.2	19.1
	4	57.8	14.1	24.7
	5	55.3	13.7	22.5
	6	53.7	15.3	16.6
Weekly Average		54.2	14.7	18.7
State-Stadium	1	65.0	15.8	10.6
	2	65.3	14.0	9.8
	3	87.2	19.6	22.8
	4	62.2	13.2	18.9
	5	77.0	14.8	32.9
	6	71.2	16.0	13.2
Weekly Average		70.6	15.3	18.1
Stadium-Supermarket 2	1	35.7	19.0	3.4
	2	26.7	16.2	2.2
	3	34.8	20.9	2.5
	4	26.0	14.2	1.6
	5	31.7	21.0	2.0
	6	28.7	16.2	3.1
Weekly Average		29.7	17.5	2.4
Supermarket 2-Platt Road	1	79.2	13.2	4.3
	2	95.3	15.4	5.9
	3	82.2	13.3	10.7
	4	73.3	13.0	11.3
	5	103.3	17.0	11.1
	6	93.3	15.2	9.0
Weekly Average		88.9	14.5	8.7

TABLE 19 (CONT'D)

Section of Arterial	Time Period	Driver Actions Index A	Time Rate Dri. Actions Index B	Dist. Rate Covar. Index C
Packard Road				
Platt Road-Carpenter Rd.	1	44.8	13.0	1.3
	2	63.0	17.8	4.6
	3	57.3	14.5	10.1
	4	48.5	12.6	3.5
	5	75.2	18.9	6.1
	6	62.5	15.9	3.6
	Weekly Average	59.8	15.7	4.7
Stadium Blvd.				
Jackson Rd.-Liberty	1	34.3	15.4	4.3
	2	36.7	16.3	3.3
	3	30.0	13.8	3.6
	4	29.8	13.3	3.9
	5	49.2	24.7	5.5
	6	44.3	20.5	11.2
	Weekly Average	38.4	17.9	5.7
Liberty-Main	1	67.7	10.4	7.4
	2	80.3	11.9	18.6
	3	63.2	9.9	13.5
	4	60.0	8.8	17.1
	5	78.0	11.8	7.4
	6	66.7	10.4	17.0
	Weekly Average	69.7	10.6	14.1
Main-White	1	29.5	13.7	2.9
	2	35.0	17.2	2.9
	3	36.3	17.1	6.7
	4	23.8	11.3	2.8
	5	31.7	15.5	1.1
	6	31.2	16.2	4.0
	Weekly Average	31.0	15.2	3.2

TABLE 19 (CONT'D)

Section of Arterial	Time Period	Driver Actions Index A	Time Rate Dri. Actions Index B	Dist. Rate Covar. Index C
Stadium Blvd.				
White-Packard	1	30.5	14.2	2.3
	2	28.0	11.2	3.0
	3	29.8	14.1	2.6
	4	24.7	12.2	3.6
	5	24.7	11.0	2.2
	6	30.8	12.1	3.5
	Weekly Average	27.9	12.2	3.0
Packard-Manchester	1	58.2	14.3	6.2
	2	64.0	13.3	11.3
	3	44.8	9.8	15.3
	4	47.8	10.9	8.4
	5	65.3	13.9	8.3
	6	41.5	10.1	8.0
	Weekly Average	53.5	12.0	9.3
Washtenaw				
Hill-Manchester	1	66.7	12.3	6.1
	2	71.0	13.3	12.2
	3	64.7	12.1	8.5
	4	76.0	13.0	17.8
	5	78.2	15.1	6.4
	6	75.3	14.7	12.1
	Weekly Average	73.0	13.6	11.0
Manchester-Carpenter	1	61.7	11.5	2.7
	2	72.8	12.3	11.0
	3	59.3	10.3	11.6
	4	63.6	10.4	22.0
	5	82.2	15.3	6.0
	6	73.5	14.0	8.0
	Weekly Average	70.2	12.6	10.6

NOTE 1: Time 1 7:30 - 9:00 a.m.
2 9:00 -11:30 a.m.
3 11:30 - 1:00 p.m.
4 1:00 - 3:30 p.m.
5 3:30 - 6:00 p.m.
6 6:00 - 9:00 p.m.

for a section of an urban arterial used by the residents of sector-zone four-three traveling to supermarket one. The rate increases in the morning reaching its peak during time period three. During this interval traffic congestion is also increasing but there still are opportunities for maneuvering. During period five, the great increase in traffic volumes has probably forced the driver to accept restricted movement within a platoon of vehicles. This has the effect of increasing his travel time, reducing vehicle maneuvers, and thereby decreasing the rate. During the sixth time period, vehicle volumes are decreasing, the driver again finds that he has some maneuvering alternatives, and his elapsed travel time decreases. This causes an increase in the time rate.

Figure 14 Plate II, shows the extreme sensitivity of Index C, the distance rate of covariability, to changes in traffic conditions. The dotted line indicates a trend for the points plotted. Undoubtedly there is a range of values for this index, which could be determined by further field studies.

Index A was omitted from Figure 14. Although the residents of sector-zone four-three used a common arterial, the distance and elapsed time for each trip varied. Thus the sum of driver actions alone was not meaningful.

Arterial Highway Intersections

The Driveometer data collected at the East Stadium- Packard Road intersection was converted to Indices A, B, and C. The results are shown in Table 20. It was concluded that the variables generated in turning movements at arterial intersections were of sufficient magnitude to necessitate their consideration when measuring arterial travel.

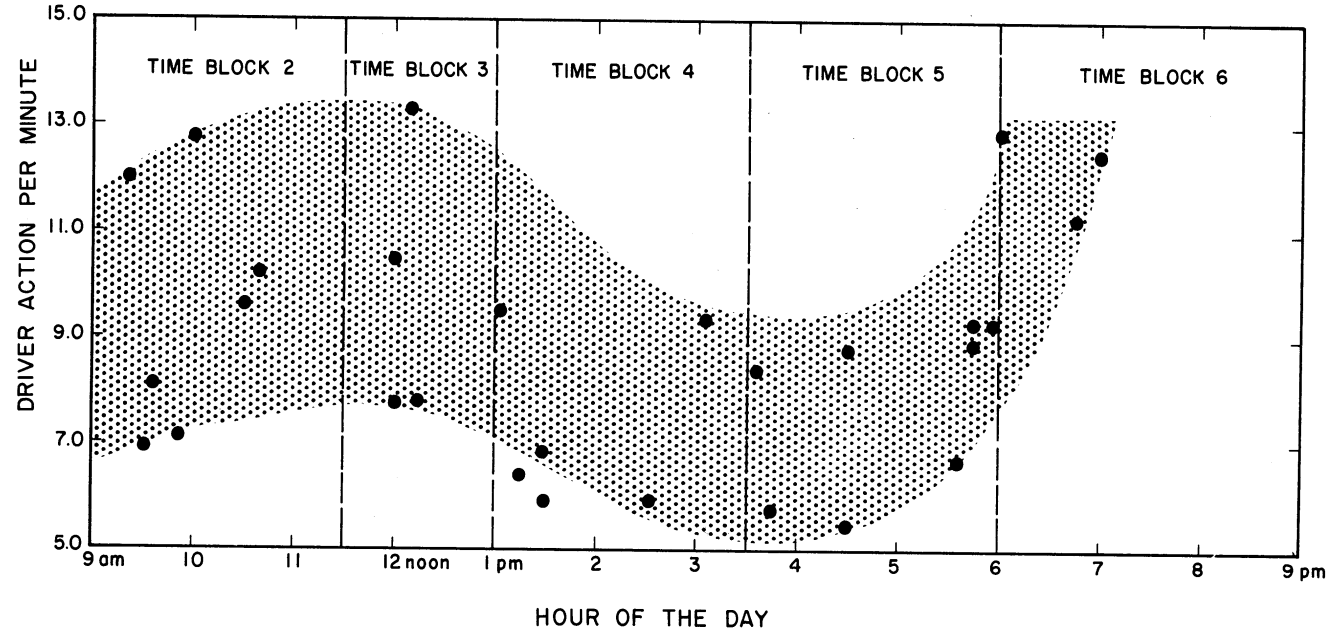

Figure 14, Plate I. Variation of the Time Rate of Driver Actions by Hour of the Day for the Arterial Portion of Highway Trips from Households in Sector-Zone 43 to the Supermarket and Return.

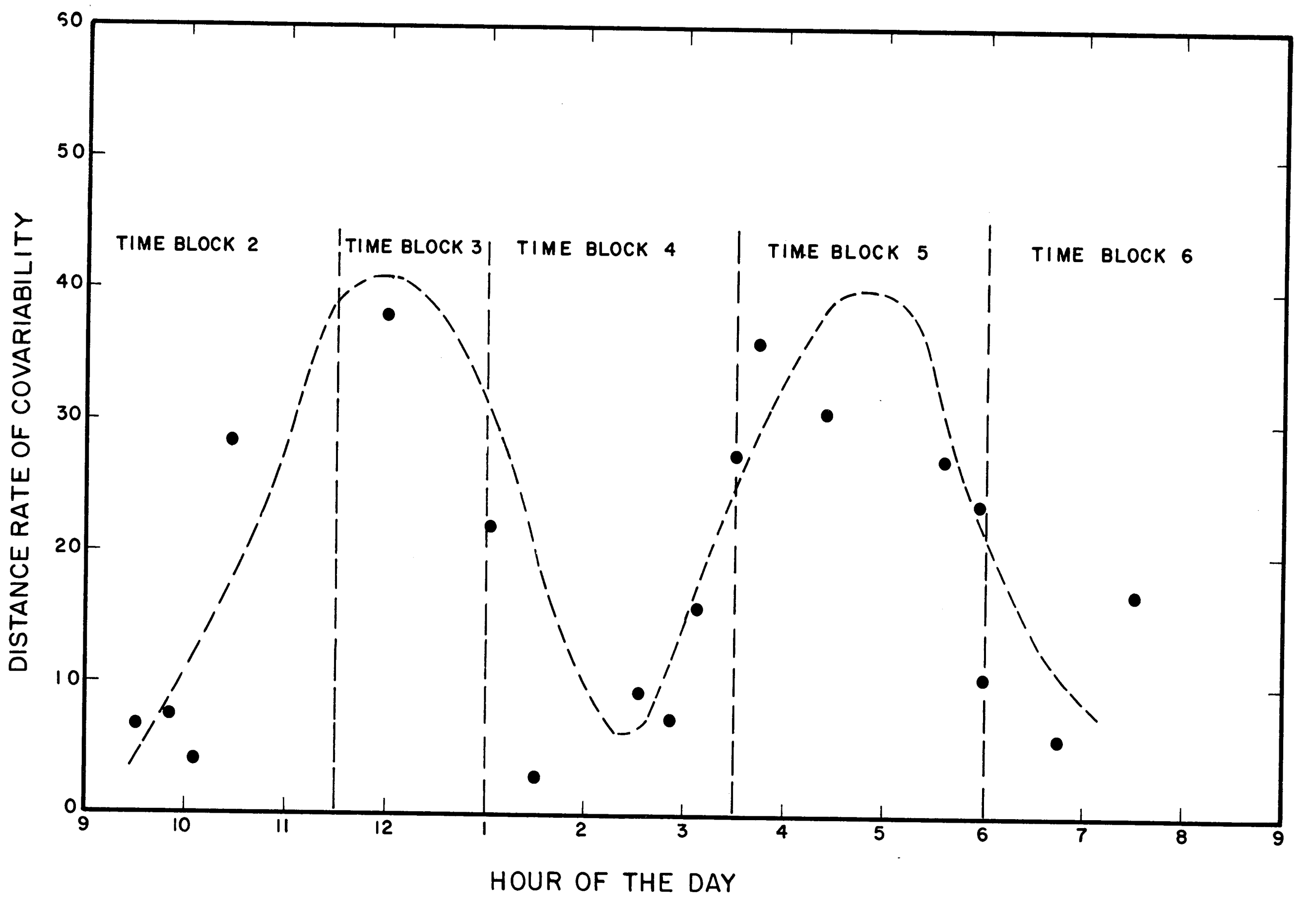

Figure 14, Plate II. Variation of the Distance Rate of Covariability by Hour of the Day for the Arterial Portion of Highway Trips from Households in Sector-Zone 43 to the Supermarket and Return.

Travel Indices For Functional Highway Classifications

Table 21 indicates that travel indices A, B, and C for the three functional classifications of highways and streets are quite different. The tabular values resulted from aggregating the shopping trip Driveometer variables by functional street classification. The table indicates that on the average, an arterial highway requires fewer driver actions and vehicle maneuvers per mile of travel, and fewer driver actions per minute of travel time than a residential street. It also shows that the residential street has the lowest average speed and requires the greatest number of driver actions per mile or per minute of travel. Index C is largest for rural roads but this figure is suspect due to the poor surface condition of the gravel rural roads at the time the field data was collected.

The mean values reported in Table 21 were further investigated using an analysis of the variance within each of the indices. The hypothesis tested stated that the samples recorded for each of the functional street classifications within any one index are from populations with the same mean. At the five per cent level of significance this hypothesis was rejected for all three indices and we must conclude that there are differences among the means for each of the functional classifications within any one index.

Next, the mean values in Table 21 within each of the indices were tested, two at a time, using the hypothesis that the sample values recorded are from populations with equal mean values. The hypothesis was accepted at the five per cent level for the following comparisons: index

TABLE 20

INDICES OF DRIVEOMETER VARIABLES FOR HIGHWAY TURNING MOVEMENTS

(Typical Example)

Intersection: West Stadium-Packard Road

Approach Leg & Direction	Turning Direction	Driver Actions (Index A)	Time Rate of Driver Actions (Index B)	Distance Rate of Covariability (Index C)	Average Time	Average Distance Miles x 10^2
Stadium East	R	6.4	45.7	221	8.4	5.6
Stadium East	L	6.2	23.8	1140	15.6	5.9
Stadium West	R	4.8	36.9	94	8.0	5.7
Stadium West	L	3.4	22.1	302	9.2	5.8
Packard NW	R	6.0	52.9	115	6.8	5.1
Packard NW	L	10.8	98.2	71	6.6	5.8
Packard SE	R	6.6	60.0	132	6.6	5.3
Packard SE	L	4.3	23.0	22	11.2	5.7

TABLE 21

INDICES OF DRIVEOMETER VARIABLES BY FUNCTIONAL STREET CLASSIFICATION

Highway and Street Classification	Index A		Driver Actions/ Minute Index B	Covariability Rate of Vehicle Maneuvers Index C	Av. Trip Length (mi.)	Av. Speed (MPH)
	Per Trip	Per Mile				
Residential	39.0	68.1	18.4	83.8	0.57	20.8
Arterial	36.2	27.6	12.7	38.4	1.31	27.4
Rural	100.0	20.7	11.6	100.0	4.83	35.0

A (per mile), rural versus arterial; and index C, residential versus rural. For all other comparisons the hypothesis was rejected. The principal reason for the acceptance of the hypothesis is the small sample size for rural trips.

Simulating Driver Actions For Shopping Trips

In redriving the shopping trips, sections of Packard Road and Stadium Boulevard were repeatedly used to gain access to the supermarket. Other collector streets joining residential neighborhoods to arterial outlets were used a number of times. A more efficient technique for generating the Driveometer variables between the customers's home and the store would involve making a functional classification of the highways within the maximum range of travel to the store and operating the test car and Driveometer over these roads. Once the measurements are known between appropriate intersections for the urban highway net, travel indices can be synthesized from any origin to any destination within the maximum range.

In order to check the feasibility of this technique it was decided to compare travel index A for the arterial portion of the shopping trip with the value of this same index using the variables measured during the arterial driving program. Figure 15 is a plot of Index A for the arterial portion of the shopping trip redriven with the test car against the appropriate value of Index A selected from Table 19. While there is considerable variability, a correspondence is indicated. Much of the variability may be due to the fact that the values from Table 19 are average weekly values for Index A, while the indices constructed from the shopping trips have all of the hourly and daily traffic variation included.

In an effort to decrease the variability of Figure 15, all shopping trips redriven were classified according to the arterial used and the place of entrance and exit on the arterial. This grouping resulted in fifty nine different arterial egress and ingress points. All locations with two or less trips entering or leaving the arterial were discarded. Those points on the arterials with three or more trips entering or leaving were inspected for hourly and weekly distribution in an effort to obtain groups of trips representing weekly highway conditions. As a result of this classification, seventeen arterial access points were selected which included ninety two of the two hundred and twelve shopping trips. Round trips varied from three-quarters of a mile to four miles. The average value of Index A for each of the seventeen sections was calculated and plotted against appropriate values from Table 19. Figure 16 is the result, and indicates that much of the variability in Figure 15 has been reduced. On the average, the values of Index A obtained by using data from the arterial driving program were larger than the indices developed for the same arterial sections using data from the redriving of the shopping trip. The consistent bias in favor of the X-axis cannot be explained without additional field measurements.

On the basis of the above analysis for the simulation of driver actions on arterials, it would seem that the same technique could be applied to urban streets of other functional classifications.

Conclusions

This investigation was oriented toward the use of the Driveometer to measure the response of one driver to different highway environments and to determine if this response could be used to characterize the highway and to describe the travel behavior of customers to a supermarket.

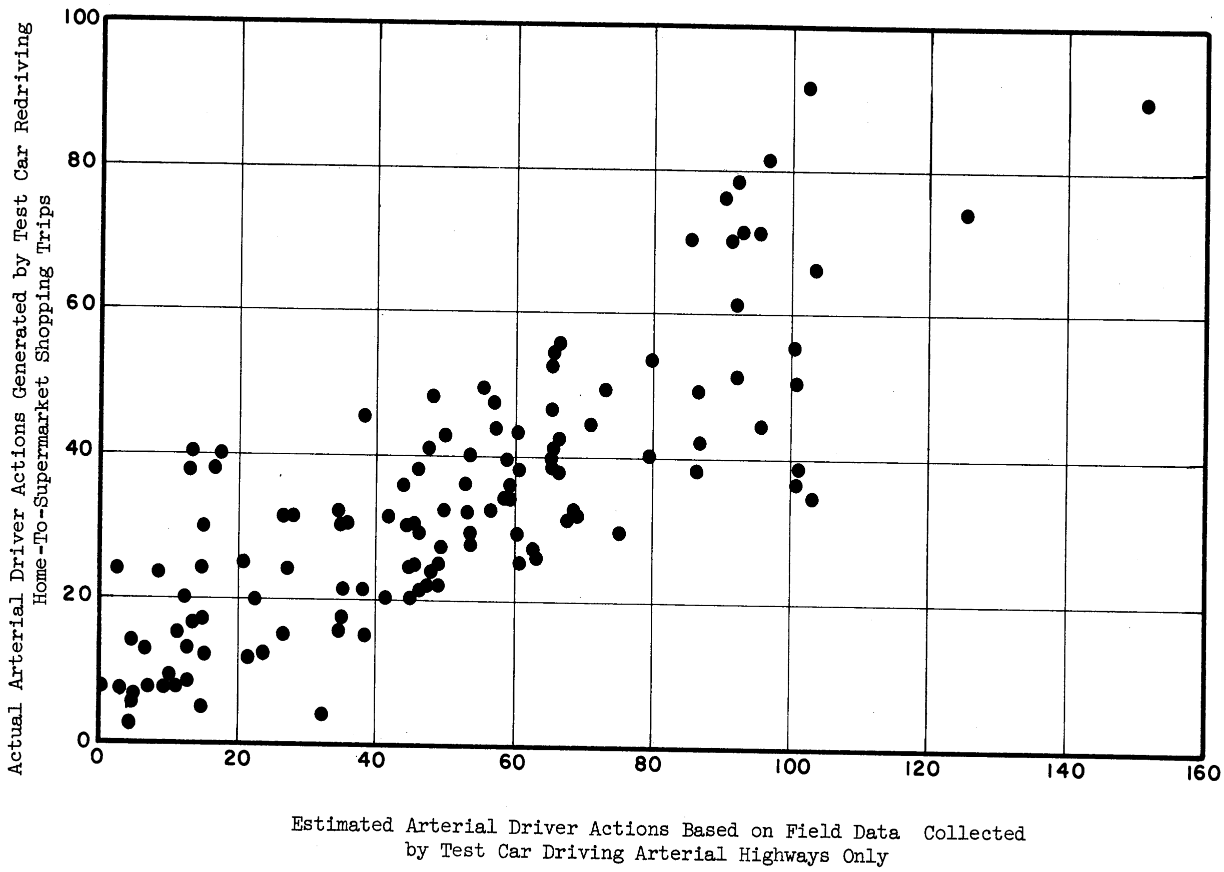

Figure 15. Evaluation of the Technique for Estimating Arterial Driver Actions, Using a Plot of Actual Versus Estimated for Individual Trips.

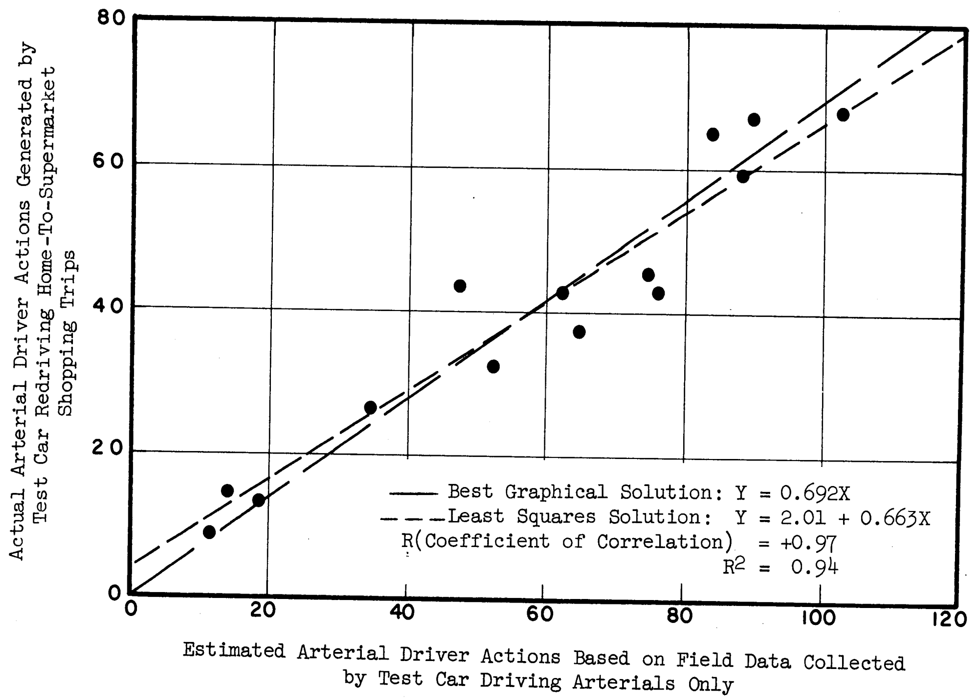

Figure 16. Evaluation of the Technique for Estimating Arterial Driver Actions, Using a Plot of Actual Versus Estimated for Groups of Trips Using Identical Arterial Routes.

The results of the study indicate that the Driveometer can be used to measure effective distance of highway travel. The Driveometer records variables that reflect differences in highway travel along one route, or between two different routes. These variables can be combined into indices that quantitatively denote these differences, and are thus measures of effective distance. The best index is the sum of driver actions, and is a more meaningful expression for effective distance than either time or distance.

When the Driveometer was used to record the cumulative driver responses for the highway routes used by shoppers traveling to the supermarket, it was found that the driver actions are inversely related to household contacts at the supermarket in the form of a power curve. This curve indicates the decrease in household contacts with increasing effective distance and is a discounting curve for the functional accessibility of the supermarket. Here again, driver actions are a more precise measure of effective distance in the discounting relationship than either time or distance.

When the urban highway system was classified according to the traffic service function, the mean values for driver actions per mile, driver actions per minute, and the distance rate of covariability were significantly different at the five per cent level for residential and arterial streets. The study also indicated that the driver actions recorded in a program of urban arterial driving can be used to estimate the average number of driver actions generated by groups of shoppers for the arterial portion of the highway net used for shopping trips.

The driver actions developed from the arterial driving program are consistently biased when compared with the arterial values generated by redriving the shopping trip routes. However, the two values can be linearly related.

APPENDICES

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APPENDIX A

SHOPPING TRAVEL INVENTORY FORM

1. Did you start this trip at either your home or at your place of work:

   Origin: Home_____; Work_____; Neither of these_____.

2. After doing all the things you planned for this trip, will you end the trip at your home or your work place?

   Final Destination: Home_____; Work_____; School_____; Other_____.

3. What other stops have you made prior to stopping at this store? (Specify in sequence) NONE-Circle if applicable

Type of Place	Location (Address)	Type of Parking (code)	Location where parked	Purpose of Stop (code)
(1)				
(2)				
(3)				
(4)				
(5)				

Stop Code:	Parking Code:	
1 = Shopping	A = Street curb free	G = Garage pay
2 = Work	B = Street curb meter	H = Car service or repair
3 = Personal business	C = Lot-free	J = Cruising
4 = Social-recreational	D = Lot pay-attendant	K = Standing
5 = Serving passenger	E = Lot pay-meter	L = Not parked
6 = Other (explain)	F = Garage free	M = Other (explain)

4. What stops do you intend to make after leaving this store: (Specify in sequence) NONE - Circle if applicable

Type of Place	Location (Address)	Where do you plan to park? Location	Type of Parking (code)	Purpose of Stop (code)
(1)____				
(2)____				

5. Did you come by car?
   a. Automobile________as the driver____or as a passenger___(check two)

      (1) If as a passenger who was the driver: Male Female (circle one)

      (2) If by automobile mark location where parked on attached sketch.

      (3) How many people came in the car with you________?
      (number)

      (4) How many people who came with you in the vehicle will make separate or individual purchases at this store?

   b. Walking_____, c. Bus_____, d. Bicycle_____, e. Other__________
   (Specify)

6. How long has it been since you last visited this store:
   Yrs._______; Months_______; Weeks_______; Days_______.

7. Do you collect Kroger TV stamps? Yes_____ No_____; Have you ever turned in the Kroger TV stamps for some merchandise? Yes_____ No_____

8. Are you shopping at this store in response to an advertisement in the newspaper? Yes_____ No_____.

9. How many persons are there in your family who are living together and sharing the same household facilities:

   Adults (Sixteen and over): 1 2 3 4 5 _____

   Children (Under sixteen): 1 2 3 4 5 _____

10. Is interviewee: Male / Female ; if female indicate whether she is

    Housewife Yes / No : full time, part time

11. Work address:________________________________ NONE
    type of place Location (address) circle

12. Home address:________________________________
    Number Street RFD Route City

13. Interviewer: Mark on the attached map the precise highway route used by the shopper in getting to this store.

14. Interviewer: Indicate the following about the shopper:

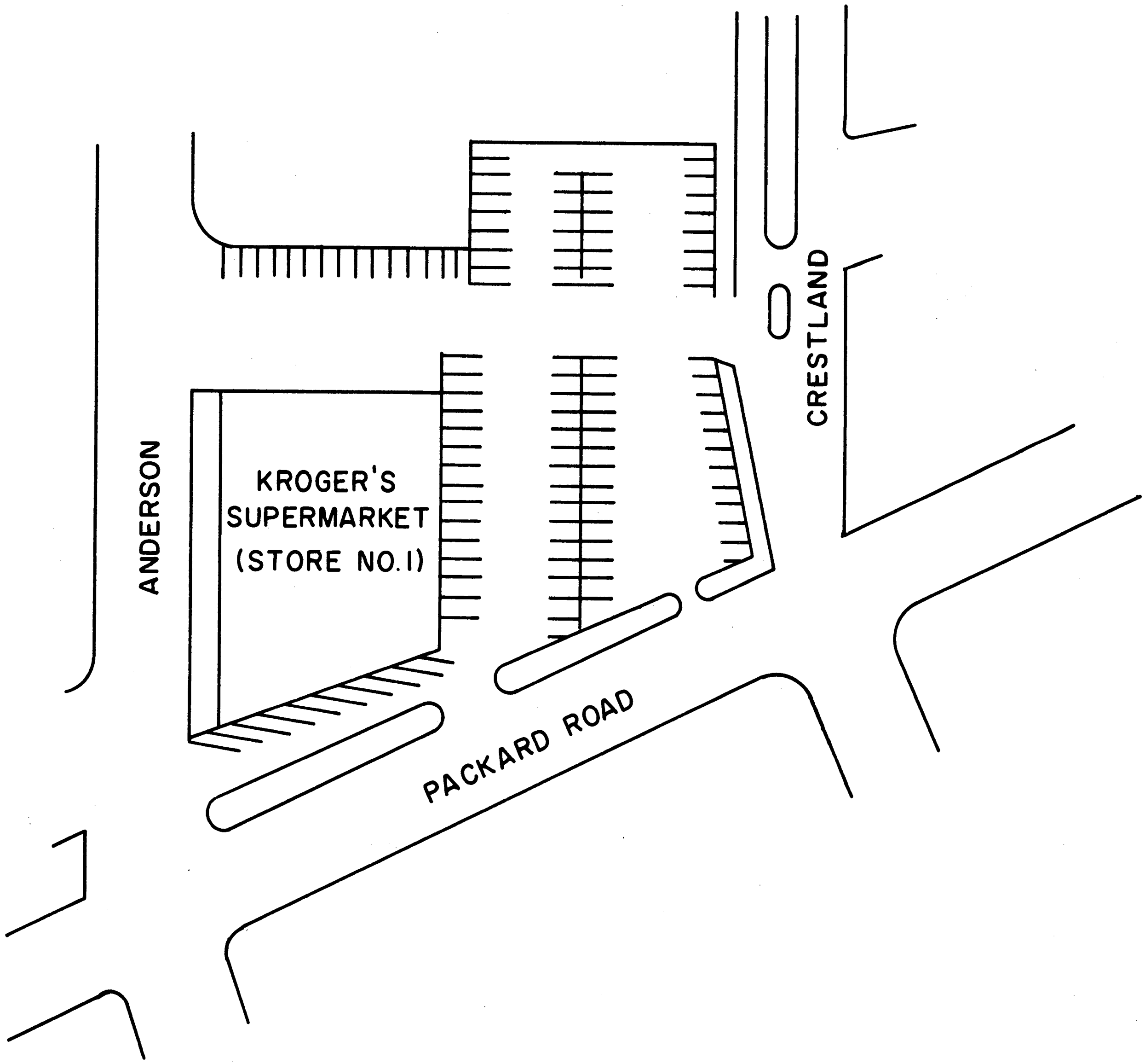
Approx. age________; Race W N M __________

15. Interviewer: Indicate precise location parked on parking lot sketch.

______________________ (Name of interviewer)

______________________ (Name of recorder)

______________________ (Time interview concluded)


KROGER'S
SUPERMARKET
(STORE NO.1)
ANDERSON
CRESTLAND
PACKARD ROAD

APPENDIX B

WEATHER MATRIX FOR CHARACTERIZING CLIMATIC CONDITIONS

	A	B	C
0	No visible clouds in the sky	Light fog	Stopped drizzling within the past hour. No freezing.
1	Clouds visible but generally disappearing	Patches of shallow fog	Stopped raining within the past hour. No freezing.
2	Clouds visible, but no change in the visible state of the sky	More or less continuous shallow fog	Stopped snowing within past hour. No rain in the snow.
3	Clouds generally forming or developing	Lightning visible, no thunder heard	Stopped raining and snowing (combined) within past hour.
4	Visibility reduced by smoke	Rain in sight in distance, but not on ground at observer's location	Freezing rain or freezing drizzle stopped within past hour.
5	Haze		Rain showers stopped within preceding hour.
6	Widespread dust suspension in the air, but not raised by wind		Hail, or wind and hail, stopped within previous hour.
7	Dust or sand raised by wind	Thunder heard, but no precipitation at observer's location	

	A	B	C
8	Dust swirls	Rain squalls within sight	Fog present during preceding hour, but which has presently cleared.
9	Dust or sand storm going on or in sight	Funnel clouds within sight	Thunderstorm within the previous hour.
	D	**E**	**F**
0	Slight or moderate dust or sand storm	Fog, but only in the distance and not locally	Slight intermittent drizzle
1	Severe dust storm	Fog in patches	Very light continuous drizzle
2	Slight or moderate low drifting snow	Fog, with sky visible, but with fog becoming thinner	Moderate intermittent drizzle
3	Heavy drifting snow, not very high	Fog, with sky not visible, with fog becoming thinner	Moderate continuous drizzle
4	Slight or moderate drifting snow, generally high	Fog, sky visible, with no change in preceding hour	Heavy intermittent drizzle
5	Heavy drifting snow, generally high	Fog, sky visible, but becoming thicker	Heavy continuous drizzle

	D	E	F
6		Fog, sky not visible and becoming thicker during preceding hour	Slight freezing drizzle.
7			Moderate freezing drizzle.
8			Rain and drizzle, slight.
9			Drizzle and rain, heavy.

	G	H	I
0	Slight intermittent rain	Intermittent fall of snow-flakes, small in amount	Slight rain showers.
1	Continuous rain, but in small amounts	Continuous fall of snow-flakes, small in amount	Moderate to heavy rain showers.
2	Intermittent rain, but in moderate amounts	Intermittent fall of snow-flakes, in moderate amounts	Violent rain showers.
3	Continuous rain in moderate amounts	Continuous fall of snow-flakes, in moderate amounts	Slight showers of rain and snow mixed.

	G	H	I
4	Intermittent rain, heavy amounts	Intermittent fall of snow-flakes, in heavy amounts	Moderate to heavy showers of rain and snow mixed.
5	Continuous rain in heavy amounts	Continuous fall of snow-flakes, in heavy amounts	Slight snow showers.
6	Slight		Moderate to heavy snow showers.
7	Moderate to heavy freezing rain		Slight hail
8	Rain or drizzle and snow, slight		Moderate to heavy hail
9	Rain or drizzle, and snow, moderate to heavy amounts		

APPENDIX C

SCHEMATIC ARRANGEMENT OF KEYBOARD CONTROL PANEL

All of the counter-register dials listed below are controlled by hand switches on the keyboard that measure the total number of seconds that a given traffic event continues to occur.

A Car in intersection on the left.	B Car approaching in opposing lane or lanes.	C Two or more cars ahead.	D Total time of run.	E Car in intersection on the right.
M Cars parked on the left.		F At least one car ahead.		N Cars parked on the right.
O Not used.	G A car passing on the left.		H A car passing on the right.	X Not used.
		Test Vehicle		
Q Not used.		I At least one car following.		R Not used.
	J Pedestrians on the left.	K Pedestrians crossing in front.	L Pedestrians on the right.	

APPENDIX D

SCHEMATIC ARRANGEMENT OF DISPLAY PANEL FOR COUNTER-REGISTER DIALS

All Dials Read in Seconds
Except X - 1 - 2 - 3 - 4 - 6
(These give an absolute count or indicated conversion)

A Car in intersection on the left.	B Car approaching on opposing lane or lanes.	C Two or more cars ahead.	D Total time of run.	E Car in intersection on the right.
1 Count of the No. of times the accelerator is depressed and released.	0 Not used.	F At least one car ahead.	5 Total time car is in motion.	6 Counts the No. of times the brake is depressed and released.
2 Measures large steering wheel reversals.	G A car passing on the left.	M Cars parked on the left.	N Cars parked on the right	H A car passing on the right.
3 Measures change of speed. (multiplied x 4)	X Not used.	I At least one car following.	Q Not used.	R Not used.
4 Measures change of direction. (multiplied x 10)	J Pedestrians on the left.	K Pedestrians crossing in front.	L Pedestrians on the right.	Watch
			ODO Odometer Standard Odo measures miles and tenths.	

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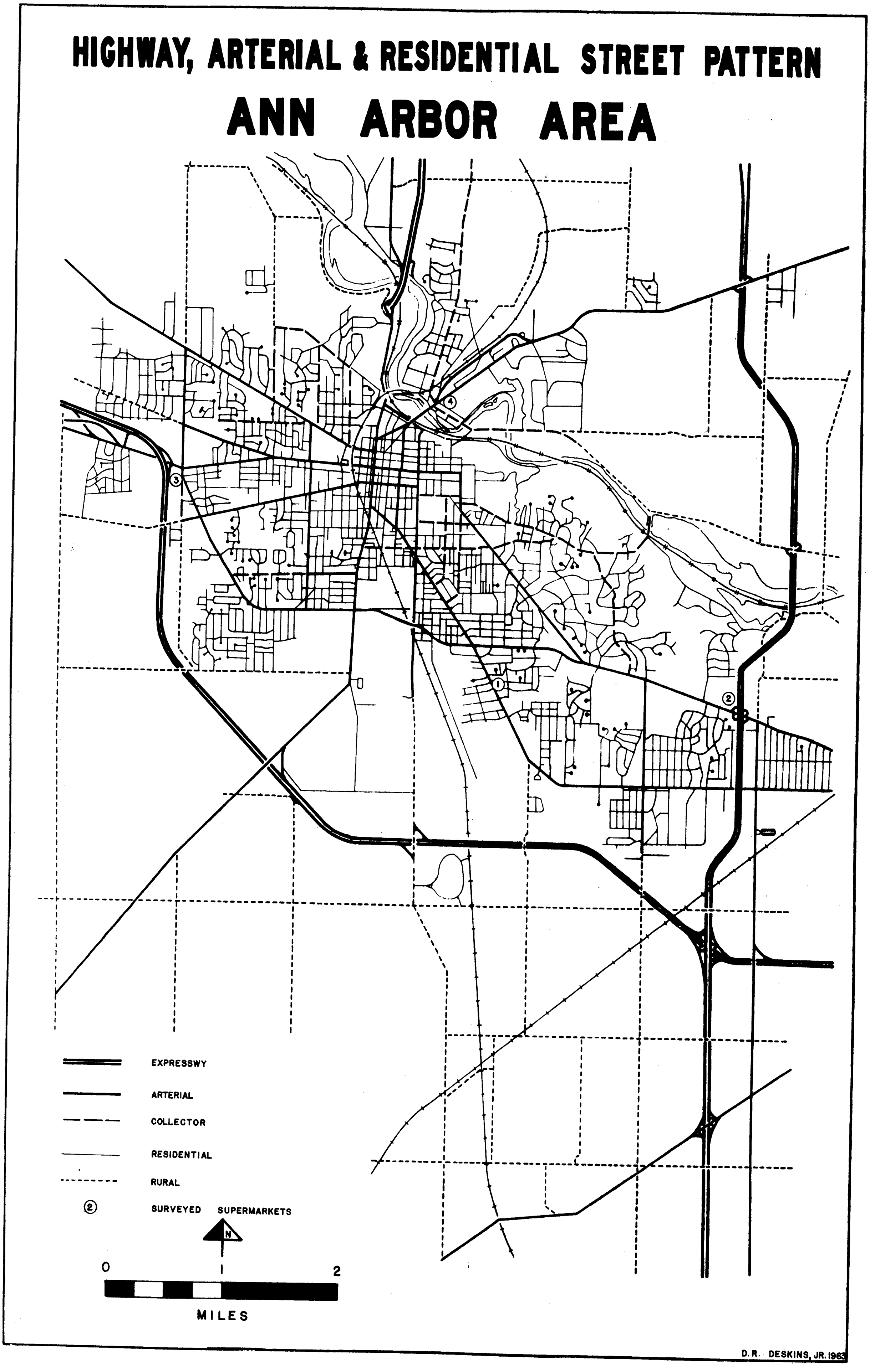
HIGHWAY, ARTERIAL & RESIDENTIAL STREET PATTERN
ANN ARBOR AREA
EXPRESSWY
ARTERIAL
COLLECTOR
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D.R. DESKINS, JR. 1963

Figure 18.

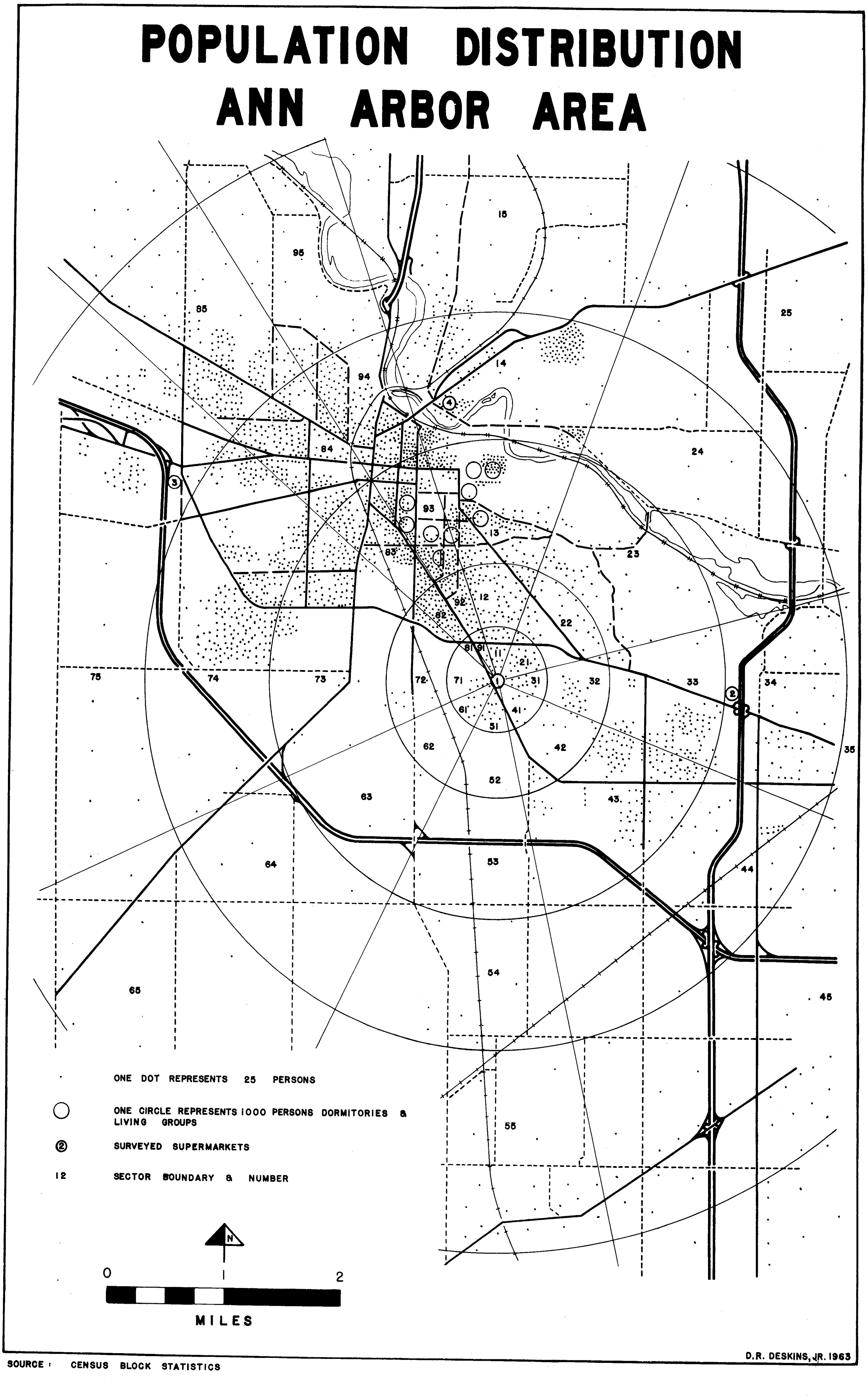
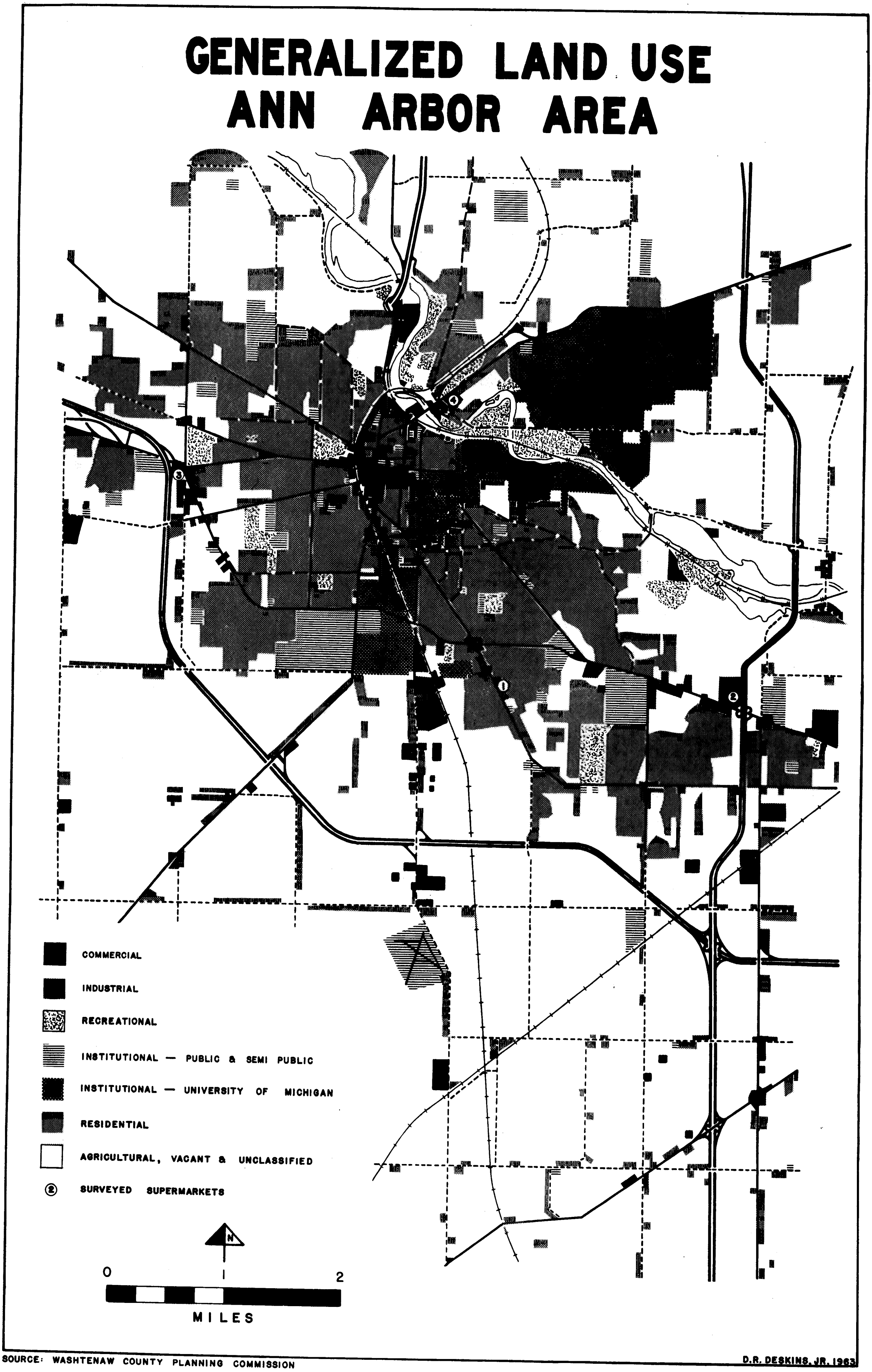

POPULATION DISTRIBUTION
ANN ARBOR AREA
ONE DOT REPRESENTS 25 PERSONS
ONE CIRCLE REPRESENTS 1000 PERSONS DORMITORIES & LIVING GROUPS
SURVEYED SUPERMARKETS
12 SECTOR BOUNDARY & NUMBER
0 1 2
MILES
D.R. DESKINS, JR. 1963
SOURCE: CENSUS BLOCK STATISTICS

Figure 19.


GENERALIZED LAND USE
ANN ARBOR AREA
COMMERCIAL
INDUSTRIAL
RECREATIONAL
INSTITUTIONAL — PUBLIC & SEMI PUBLIC
INSTITUTIONAL — UNIVERSITY OF MICHIGAN
RESIDENTIAL
AGRICULTURAL, VACANT & UNCLASSIFIED
② SURVEYED SUPERMARKETS
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SOURCE: WASHTENAW COUNTY PLANNING COMMISSION
D.R. DESKINS, JR. 1963

Figure 20.

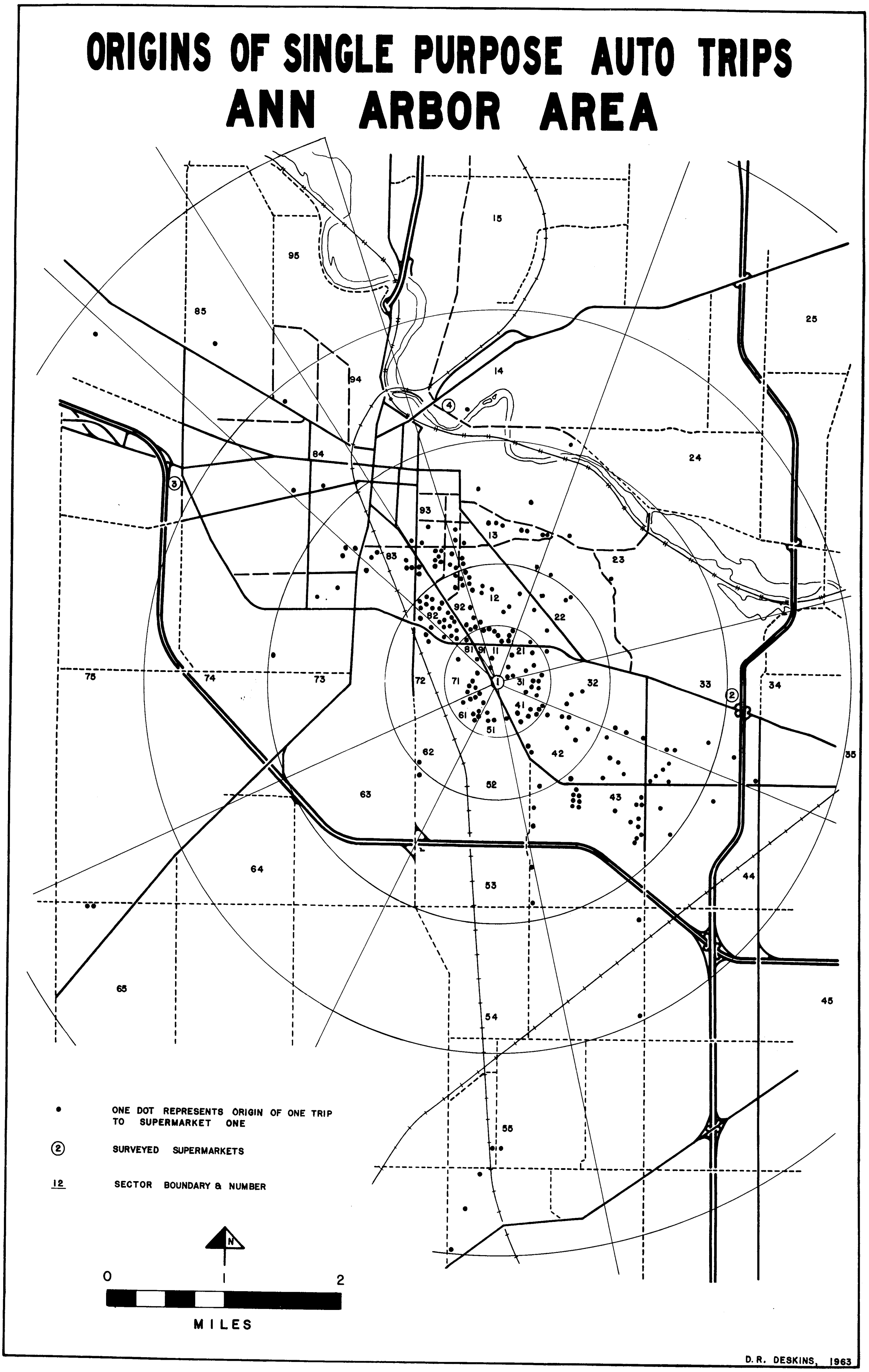
ORIGINS OF SINGLE PURPOSE AUTO TRIPS
ANN ARBOR AREA
ONE DOT REPRESENTS ORIGIN OF ONE TRIP TO SUPERMARKET ONE
SURVEYED SUPERMARKETS
SECTOR BOUNDARY & NUMBER
MILES
D. R. DESKINS, 1963

Figure 21.