MEMORANDUM
RM-3086-FF
APRIL 1962

A MULTIPLE EQUATION MODEL OF HOUSEHOLD LOCATIONAL AND TRIPMAKING BEHAVIOR

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PREFACE

In August, 1960, the Ford Foundation made a grant to The RAND Corporation to undertake an exploratory study of urban transportation. One objective of this study is to develop a generalized model of an urban complex, to be used in analyzing the intricate interrelationships between transportation and the spatial distribution of economic activities. The general approach to be followed in developing this model has been outlined in J. F. Kain and J. R. Meyer, A First Approximation to a RAND Model for Study of Urban Transportation, The RAND Corporation, Memorandum RM-2878-FF, October, 1961.

The present Memorandum is a report on work in progress directed toward the development of a submodel of household behavior for inclusion in the projected model of an urban complex. It served as a basis for discussion of these model-building efforts at the Committee on Urban Economics meeting held at RAND on March 15 and 16, 1962.

Our objective in circulating it to urban researchers at this point is to obtain a wider discussion, evaluation, and criticism of this research, in order that useful suggestions may be incorporated in the final household submodel.

SUMMARY

This Memorandum describes a multiple equation model of household locational and tripmaking behavior, to be used in RAND's study of urban transportation. It is an important first step toward the larger goal of developing a residential location and tripmaking submodel for use in the projected RAND model of an urban community.

The model presented here is a multiple equation recursive model, estimated by applying least squares multiple regression techniques to cross-sectional data obtained from the Detroit Area Traffic Study's home-interview origin and destination study. The worktrips of more than 40,000 sampled workers were aggregated to 254 spatially separate workplace zones. The model explains four types of locational and tripmaking behavior for the white workers employed in these 254 zones: residential space consumption, automobile ownership, modal choice, and length of journey-to-work. In all, the final model has seven statistical and two definitional equations. The dependent variables for these nine equations include four measures for residential space consumption, one for auto ownership, three for mode choice, and one for length of journey-to-work. The dependent variables for residential space consumption are the percentage of each zone's workers residing in single-family units, the percentage residing in two-family dwelling units, the percentage residing in multiple units, and the percentage residing in non-dwelling-unit quarters. The automobile ownership variable is the mean automobile ownership of a zone's workers. The three mode choice variables are the percentage of the zone's workers who are auto drivers, the percentage who are public transit users, and the percentage who are neither. The mean elapsed time spent by the zone's

workers in reaching work from their places of residence is the measure of the journey-to-work

The exogenous variables included in the model are the mean family income of the zone's workers, a proxy variable for the price of residential space for each zone's workers, the male proportion of the zone's workers, the proportion of the zone's workers belonging to families having a single wage earner, and the level of transit service at each workplace zone.

The proportion of explained variance for the seven statistical equations is uniformly high; the regression coefficients are in general statistically significant at the one-per-cent level, and they have signs consistent with the underlying consumer-choice hypotheses upon which the statistical model is based.

Both the direct and the indirect effects of exogenous changes in the independent variables are examined in the model. The effects of changes in the level of income, of shifts in the location rent surface, and of changes in the level of transit service on each of the dependent variables is considered in detail. The results appear largely as postulated *a priori*. In nearly every instance the indirect effects on the dependent variables of changes in the exogenous variables were as great or greater than were the direct effects.

As tests of the hypotheses underlying our model-building efforts and of our general approach as previously outlined,* these results are heartening. They apparently lend strong support to the appropriateness of the

*See J. F. Kain and J. R. Meyer, *A First Approximation to a RAND Model for Study of Urban Transportation*, The RAND Corporation, Memorandum RM-2878-FF, October, 1961.

general approach to the problems of urban transportation and development followed in the RAND study of urban transportation; and they reinforce our contention that these problems cannot adequately be dealt with piecemeal, but must be considered as a part of an interdependent process of urban growth and development.

CONTENTS

I. INTRODUCTION

This study deals with the locational and tripmaking behavior of Detroit workers. Locational behavior here applies to the consumption of an interrelated bundle of residential and transportation goods and services. Tripmaking in this context is limited to the weekday journey to and from work. The statistical analysis is designed to explore the interrelationships in consumption between the complementary goods, housing and transportation. It is hoped that it will provide information useful in understanding and explaining the location decisions of households and their implications for urban transportation and land-use planning.

The model deals with four complementary commodities that are of concern either to the planning and provision of transportation services or to the planning of the spatial distribution of urban activities. Underlying this model are a number of hypotheses concerning consumer choices or preferences. In part, the empirical work presented represents a test of these hypotheses; more importantly, however, the model is designed to make explicit some of the interrrelationships between land-use and transportation. It should be of use in helping to ascertain how changes in the availability of transportation services affect the spatial distribution of urban areas. The four commodities used as dependent variables are residential space consumption or residential density, automobile ownership, the choice of transportation mode for the journey-to-work, and the length of the journey-to-work. In essence, it is hypothesized that the household's choice of a residential density or residential space consumption is interrelated with its choice about automobile ownership, its choice of a journey-to-work mode, and the length of its journey-to-work. Its selection of a residential location is

in turn affected by the transportation facilities available, its income, the price these low-density residential services cost, etc. The residential density level at which it resides is in a like way interrelated. Similarly, the length of time the worker spends commuting and the distance he travels are determined by his preference for low-density residential services and whether he in fact consumes them, his income, the valuation he places on time, the characteristics and costs of available transportation, his choice of mode, etc. It is the purpose of this model to examine and explain these interrelationships.

A four-equation model is formulated as a means of systematically examining these interrelationships; the model's dependent variables were selected as representing key variables for urban land use and transportation planning.

Residential space consumption, the first equation in the model, largely determines the form, structure, and size of our urban areas. Much of the concern among urban land use planners may be traced to the fact that cities today appear to be developing at much lower densities than those of the past, while most urban planners have a predisposition for a high-density, compact urban form. The charged terminology adopted to describe today's residential development attests to their concern: urban sprawl, scatteration, and the like. In fact, however, today's urban development is largely a low-density residential development of an extent unparalleled in history.

The model's second equation is an automobile ownership function. A household's decision to buy or not to buy one or more automobiles clearly hinges on its decisions about its level of residential space consumption, the location of its workplace, the availability, efficiency, level of service and costs of alternative transportation modes, its income, etc. A

number of metropolitan traffic studies have used automobile ownership as a key predictive variable in their mode-choice and travel-prediction equations without adequately recognizing its interdependence with a number of other variables. This interdependence must be more fully understood for a high level of transportation and land-use planning.

The model's third function is a choice-of-mode function. The household's choice of mode is highly interrelated with its decision on whether or not to buy an automobile. If the worker owns an automobile there is a good chance he will use it in his journey-to-work; the male worker is more likely to do so than is the female. The decision on whether to use alternative modes is also highly dependent upon the level of service provided by the alternative modes and upon the worker's decision about the consumption of residential space. The labor-force participation of the worker's family is also important; when the family has more than one wage earner, it is highly probable that only one will be an automobile driver.

The final function in the residential-location and tripmaking model is the length of the journey-to-work, which again is highly dependent on the worker's consumption of residential space, the price of residential space in relation to distance from his workplace, whether he is a male or female, etc.

II. THE MODEL

Equations (1) through (4) describe the household locational and tripmaking model. Because it is necessary in some cases to use more than a single statistic to measure one of the dependent variables in Eqs. (1) through (4), the final statistical model includes more equations. The locational and tripmaking model includes four endogenous variables (i.e., determined within the model), and six exogenous variables (i.e., determined outside the model), and variables from which the variables included in the model are assumed to be substantially independent. The sequence of these four equations is important. It is assumed that the worker selects the residential density at which he wishes to reside on the basis of his space preference, his income, and the price per unit he must pay for residential space. In this model, space preference is measured by the variables of family size and other household and worker characteristics. The price of residential space is indicated by a proxy variable and depends largely upon the location of the workplace.

Having made his decision about his consumption of residential space, it is postulated he decides whether to purchase an automobile. This decision depends on his previous decision about the level of residential space consumption, his income, the level of transit service available at his workplace, and his preference for automobile ownership and operation. This preference is heavily dependent upon his sex and upon the size of his family.

(1) $$R_{ij} = f_1(F_{ij}, Y_{ij}, P_j, S_{ij}, N_{ij}).$$

(2) $$A_{ij} = f_2(R_{ij}, Y_{ij}, B_j, S_{ij}, F_{ij}).$$

(3) $$M_{ij} = f_3(R_{ij}, Y_{ij}, B_j, S_{ij}, A_{ij}).$$

(4) $$T_{ij} = f_4(R_{ij}, Y_{ij}, P_j, S_{ij}, N_{ij}, M_{ij}).$$

Endogenous Variables:

R_{ij} = the residential space consumption of the i-th worker employed at the j-th workplace;

T_{ij} = the length of the journey-to-work by the i-th worker at the j-th workplace;

A_{ij} = auto ownership of the i-th worker at the j-th workplace;

M_{ij} = the mode choice by the i-th worker at the j-th workplace.

Exogenous Variables:

Y_{ij} = the family income of the i-th worker at the j-th workplace;

P_j = a proxy variable for the price of residential space per unit at the j-th workplace;

S_{ij} = sex of the i-th worker employed at the j-th workplace;

N_{ij} = labor-force participation by ij's family; i.e., number of family members employed;

B_j = level of transit service at the j-th workplace;

F_{ij} = size of the i-th worker's family at the j-th workplace.

The fourth function states that the length of the journey-to-work made by the i-th worker employed at j is dependent upon his previous decisions about the consumption of residential space and his choice of mode, his family income, his sex, and the price of residential space at his workplace.

The reasoning underlying these statements will be considered at greater length below, when each function is estimated statistically.

III. THE METHOD

The analysis seeks to explain variations in the locational and tripmaking behavior of white workers employed in 254 workplace zones in the Detroit metropolitan area. (See Fig. 1.) These zones are the traffic analysis zones defined by the Detroit Area Traffic Study for its analysis.

The empirical work presented in this Memorandum uses as a data source the home interview origin and destination study conducted by the Detroit Area Traffic Study in 1953, which was part of a comprehensive metropolitan traffic study conducted for the Detroit metropolitan area in the same year. The data consist of the origins and destinations of worktrips, information on the characteristics of the workers making these trips, information on the characteristics of the households to which the tripmaker belonged, and certain attributes of the trips themselves, for a stratified random sample which includes information from approximately 40,000 Detroit households.

The model formulated above is expressed in terms of the locational and tripmaking behavior of a single worker. For the statistical analysis presented here, the model is aggregated to the 254 workplace zones in Fig. 1.

The unit of observation for the variables used in the model is thus the white labor force of each workplace zone, or the zone itself. The independent variables measure attributes either of the zone's white workforce or of the zone itself. These variables so defined are used to test or evaluate a model or set of hypotheses based on choice assumptions pertaining to an individual household. The implicit assumption underlying these statistical models is that there are systematic differences in the

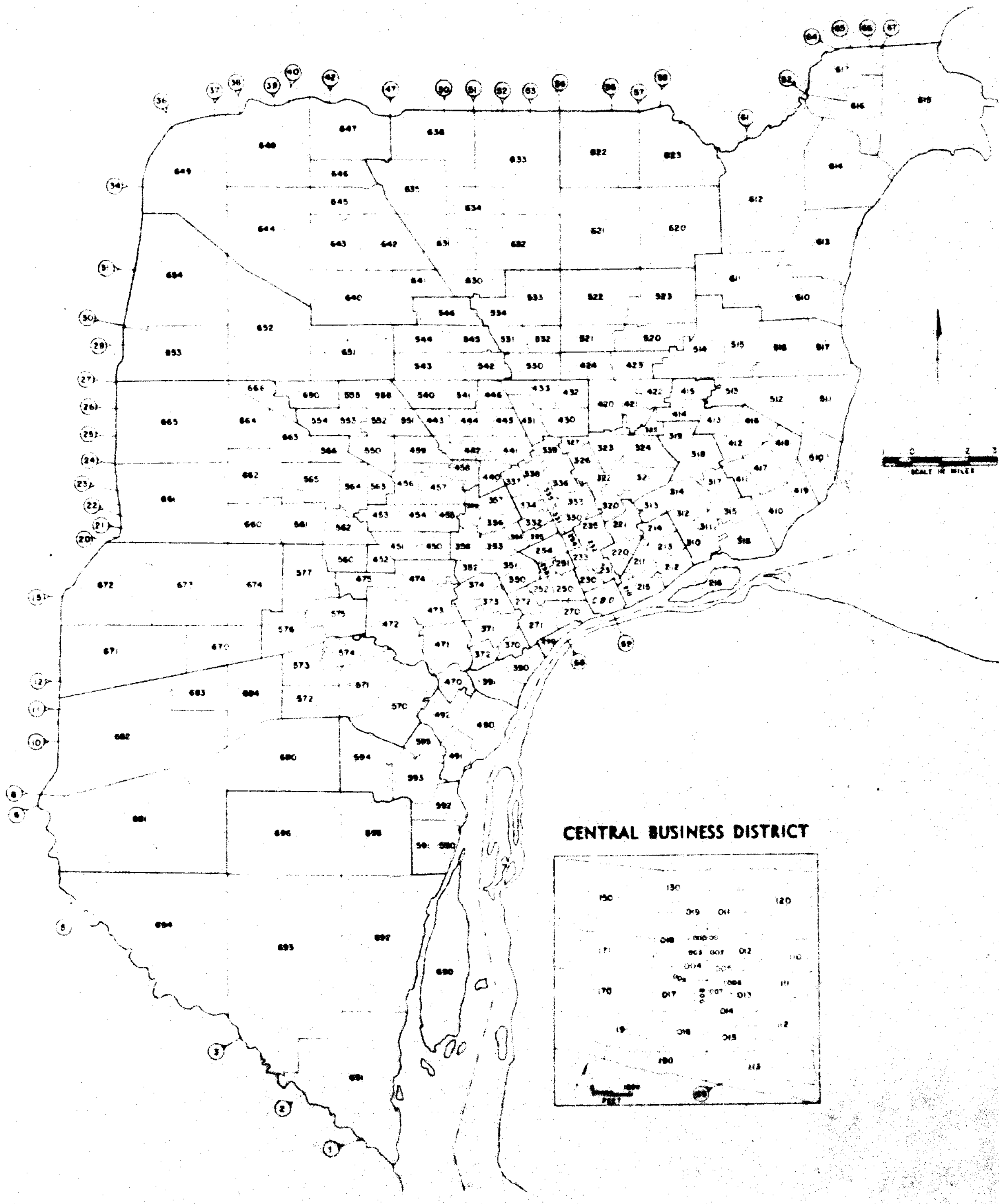

Fig. 1 -- Workplace Zones (Detroit Traffic Analysis Zones)

labor forces of the various workplace zones and in the zones themselves, which are reflected in the independent variables included in the consumer choice model. It is further assumed that these systematic variations are reflected in a meaningful way by the aggregation procedures. In a sense, the aggregation performed here defines a representative worker for each workplace zone reflecting the characteristics of the constituent labor-force members. It is hypothesized, therefore, that the behavior of this representative worker's household should be consistent with that postulated from the consumer choice model for an actual household having characteristics of the representative household. This represents the rationale underlying the empirical tests presented here.

The functions themselves are estimated from cross-sectional data using least-squares multiple-regression techniques. The actual estimation equations are given in following sections. As noted previously, these equations are designed to estimate four types of functions: residential space consumption, auto ownership, mode choice, and length of journey-to-work. The results of the estimating procedures for these four sets of equations are given individually in sections that follow, along with a discussion of the theory or hypotheses underlying each set of estimating equations and the implications of the results. A set of "best" estimating equations is presented in the last section, and the implications of the model as a whole are discussed.

IV. STATISTICAL ESTIMATION OF THE MODEL'S FUNCTIONAL RELATIONSHIPS

THE RESIDENTIAL SPACE CONSUMPTION FUNCTIONS

Because of the characteristics of the data available from the Detroit Area Traffic Study, which must be used to measure residential space consumption, more than a single dependent variable -- and thus more than a single equation -- must be used to measure and estimate the consumption of residential space by Detroit households. The theoretical concept of residential space underlying the consumer choice model is closely approximated by lot size in the case of single-family units, and by some proportion of the land used for the structure in the case of multiple units. Ideally, lot size should be weighted by neighborhood density and the density of the immediate community. Data collected by the Detroit Area Traffic Study did not include the amount of space occupied by each dwelling unit; since this preferred measure was unavailable, it was necessary to use structure type as a measure of residential density. This measure has a number of obvious shortcomings, the most important probably being that it fails to account for significant differences in lot size for single-family dwellings. Even so, the structure-type variable is probably closely related to the one the author would have preferred using for this analysis.

In addition to representing somewhat less than the desired definition, structure type is also an attribute-statistic, not easily used in a multiple regression model like the one employed in this study. For these reasons it is necessary to use four dependent variables to define the residential space consumption of zone j's workers: the percentage of zone j's workers residing in single-family dwelling units, the percentage residing in two-family dwelling units, the percentage residing in multiple

dwelling units, and the percentage residing in other types of dwelling places, including rooming houses, hotels, trailer camps, etc.

In place of Eq. (1), we then have for estimating purposes three linear statistical and one definitional equation. The aggregation to workplace zones is indicated by the omission of the i subscript.

(1a) $$R_j^s = \alpha + \alpha_1 F_j + \alpha_2 Y_j + \alpha_3 P_j + \alpha_4 S_j + \alpha_5 N_j \,.$$

(1b) $$R_j^2 = \alpha' + \alpha_1' F_j + \alpha_2' Y_j + \alpha_3' P_j + \alpha_4' S_j + \alpha_5' N_j \,.$$

(1c) $$R_j^m = \alpha'' + \alpha_1'' F_j + \alpha_2'' Y_j + \alpha_3'' P_j + \alpha_4'' S_j + \alpha_5'' N_j \,.$$

(1d) $$R_j^o = 1 - R_j^s - R_j^2 - R_j^m \,.$$

Dependent Variables

R_j^s = the percentage of zone j's workers residing in single-family units;

R_j^2 = the percentage of zone j's workers residing in two-family units;

R_j^m = the percentage of zone j's workers residing in multiple units;

R_j^o = the percentage of zone j's workers residing in other types of dwelling places -- rooming houses, hotels, trailers, etc.

Independent Variables

Five independent variables are included in the residential space consumption models:

F_j = the percentage of zone j's workers belonging to families having more than two members;

Y_j = the mean household income of zone j's workers;

P_j = proxy for the price of residential space, viz., 11.5 minus zone j's distance from the central business district, with a maximum of 11.0 miles;

W_j = the percentage of zone j's workers belonging to families having a single wage earner;

S_j = the percentage of zone j's workers that are male.

Equations (1a) through (1d) are linear multiple regression equations estimated by least squares. Equation (1a) states that the proportion of zone j's workers residing in single-family dwelling units is a linear function of some constant term a, the proportion of j's workers belonging to families having more than two members, the mean family income of j's workers, a proxy variable indicating the price per unit that households must pay for residential space, the percentage of j's workers that are male, and the percentage of its workers belonging to families having a single wage earner.

INTERPRETATION OF THE RESIDENTIAL SPACE CONSUMPTION EQUATIONS

The postulate was stated above that the household's locational and tripmaking behavior is determined by a complex utility maximization procedure by households. Households consume varying amounts of residential space that depend on the satisfaction they derive from lower-density residential living, on the cost of such low-density residential services, and on their incomes. With their decision made about residential space consumption, we now postulate that this decision, given the transportation alternatives available at the wage earners' workplaces, strongly affects the households' decision whether to purchase one or more automobiles,

their decision to use public or private transportation and, finally, the length of time spent in reaching their residences.

Preference Variables

Three of the five independent variables might be interpreted as indicators of the relative space preferences of each of the workplace zone's employees.

The percentage of workers belonging to families with more than two members is the most obvious indicator of a household's preference for residential space. Families with more than two members probably spend much more time in the home than do one- and two-person families, both out of choice and necessity. The home is the focus of a far broader range of activities than it is for the one- and two-person family. Families with children value having an attached play-yard, and certainly neighbors value the air space between their respective dwelling units.

The male percentage of a zone's workers also represents a variable which may stratify the worker population into groups having greater or lesser space preferences. Workplaces employing a large proportion of females are probably heavily weighted by firms employing large numbers of female clerical and secretarial workers. Members of this group are most often single, or belong to two-person families without children. The positive incentives for consuming larger quantities of residential space are therefore probably weaker for this group. This is true for still another reason: since women have to do most of the housekeeping, the burden is much heavier for them when they are holding outside jobs, and the larger the living space the heavier the burden becomes. For many working females, larger living space may thus actually have a negative

utility. In addition, since working wives spend less time in the home they have less opportunity to enjoy it.

The percentage of j's workers belonging to families with a single wage earner is in some way similar to the variable described above. A disproportionate number of multiple-wage-earner families are smaller families, and probably spend more time outside the home than do families with a single wage earner. Consequently, this group probably also places a lower value on residential space.

Income Variables

The most obvious income measure included in the analysis is the mean family income of j's workers. The Detroit Metropolitan Area Traffic Study did not include family income on its survey questionnaire. For the empirical testing carried out in this study, a household income variable was estimated from each worker's occupation. This defines an extremely crude income index. Occupation was coded in the study only for the census one-digit occupational codes. The study used the median earnings of Detroit's workers in 1949 for each of these occupational groupings. Table 1 lists these one-digit occupational groupings.

The family income estimate was obtained by assigning to each family member in the labor force the 1949 median income for the appropriate occupational group, and summing these medians over all working members within the family. Even if each worker's income were correct, this definition of family income would fail to include non-wage and salary income. Despite its crudeness, however, the estimate may reflect the underlying relationships and be useful in the analysis.

Table 1

INCOME BY OCCUPATION AND SEX FOR DETROIT WORKERS, 1949

Occupation	Median Males	Median Females
Professional, technical and kindred workers	$4,711.	$2,807.
Managers, officials, proprietors	4,777.	2,495.
Clerical	3,332.	2,272.
Sales workers	2,529.	1,442.
Craftsmen, foremen	3,784.	2,397.
Operatives	3,144.	2,238.
Service workers, excluding private	2,863.	1,372.
Laborers, except farm and mine	2,688.	1,944.

SOURCE: U.S. Bureau of the Census, U.S. Census of Population: 1950. Vol. II, Characteristics of the Population, Part 22, Michigan, U.S. Government Printing Office, Washington, D.C., 1952. Table 78, Income in 1949 of the Experienced Civilian Labor Force by Occupation and Sex, for the State and for Standard Metropolitan Areas of 250,000 or more: 1950.

Price Variables

The most important and probably most controversial variable included in the estimating equation is that of distance from the Central Business District. It is interpreted as a proxy variable describing the relative price of residential space for whites employed in each of the 254 workplace zones. The actual variable employed is defined as 11.5 minus the miles distant from the Central Business District, with a maximum value of 11.0.

Figure 2 illustrates the function employed in the regression equation as a location rent proxy.

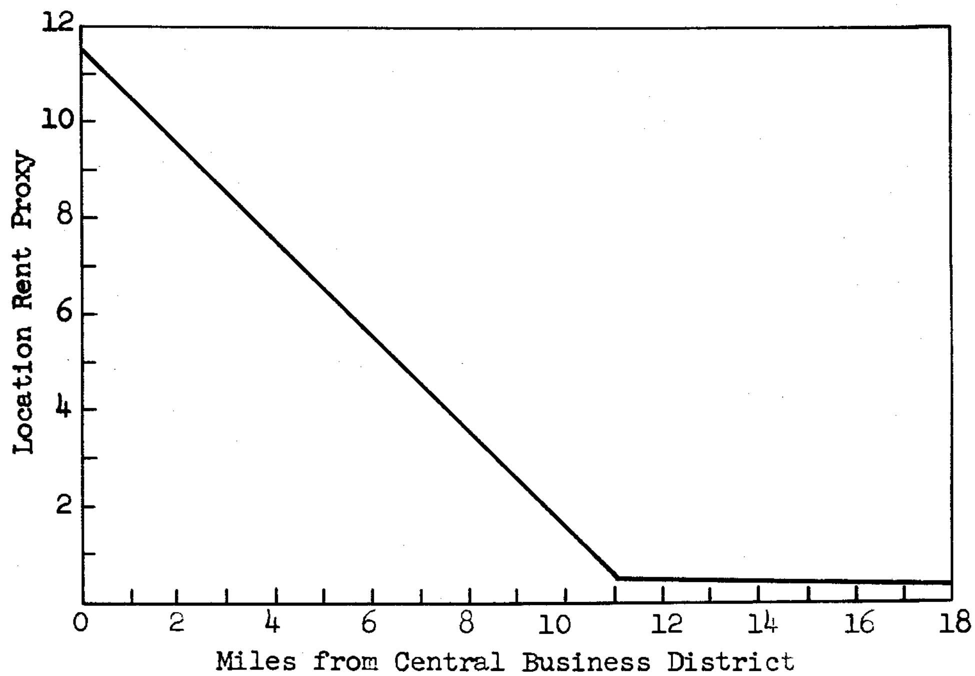

Fig. 2 -- The Location Rent Proxy for Workplaces at Various Distances

The author offers, as a provisional hypothesis, that there is a market for residential space and that there exists in each urban area a set of prices or rents for residential sites that vary from one location to another. These prices are an economic rent that landlords can obtain from households for more accessible sites. The rents on these more accessible sites arise because of households' collective efforts to economize on transportation costs. These rents, referred to hereafter as location rents, are a direct function of distance from major workplaces and the level of employment at these workplaces, and an inverse function of the supply of urban space.

This hypothesis is a simplification of the urban land market. Other forces, in addition to the distribution of employment, affect location

rents in urban areas. Government, industry, and businesses all compete with households for urban space. Households also value access to major cultural, commercial, and recreational centers. All of these forces, and a large number of others, affect both the level and distribution of location rents. Despite this the major determinant, to an overwhelming extent, of at least residential location rents is probably the level and distribution of employment.

It is assumed that the location rents Detroit whites must pay per unit residential space of a given quality and amenity decrease with distance from the center, with rents very high near the business district and very low near the circumference. The rate of decrease is assumed to be substantial near the center and very slight near the periphery. The use of the term "Detroit whites" is intentional, since the nonwhite market for residential space is dissimilar from that for whites, because of racial segregation, and requires a much different definition.

These assumptions about the shape of the location rent surface are obtained from the above premises about the determinants of the surface. It is stated there that location rents result from the competition for nearby residential space among workers employed in the same general area.

If we draw concentric rings around the Central Business District, the number of workers employed in each ring may be thought of as representing the number of demanders for residential space within the ring, and the number of acres in the ring as the supply of residential space. In Detroit Ring 1, the Central Business District, includes only 0.2 per cent of the available space within the study area, but provides jobs for nearly 11 per cent of Detroit's workers. Detroit has 60 per cent of its employment

located within six miles of the Central Business District, but only 10 per cent of the land within the study area is located there. This indicates excess demand for space in the close-in rings, and a substantial lessening of demand in the outer. The relatively low level of demand for urban use in the outermost ring is indicated by the large proportion of land which is not in urban use within the ring. A full 68 per cent of the available land in Ring 6 is vacant; if land devoted to streets and alleys were subtracted, this figure would be even higher.

Thus, it is reasonable to expect that location rents would be very high in the Central Business District and nearby, and very low in the outermost ring. The high demand for residential space in the inner rings is indicated by the high employment -- and, for that matter, high residential densities. The low demand in outer areas is indicated by low employment densities, low residential densities, and the large quantities of vacant land. Beyond eleven miles, the area is largely rural and the decrease in location rents beyond this point would be very minimal.

It was noted that this is perhaps the most controversial variable included in the equation, or at least this study's interpretation of it. A number of excellent theoretical works -- those by Alonso and Wingo, for example* -- have obtained site rent or location rent surfaces in an urban area assuming positive transportation costs and utility maximization by households.

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*William Alonso, "A Theory of the Urban Land Market," Papers and Proceedings of the Regional Science Association, Univ. of Pennsylvania, Philadelphia, 1960; and Lowdon Wingo, Jr., Transportation and Urban Land, Resources for the Future, Inc., Washington, D. C., 1961.

These works have a common shortcoming, a lack of adequate and explicit treatment of time, depreciation, obsolescence, and other problems of housing market dynamics; however, these excellent although admittedly incomplete theoretical treatments, plus common sense and some fragmentary empirical evidence, support the hypotheses about location rents as being reasonable. Arrayed against this provisional interpretation of the location rent function is the opinion of a number of knowledgeable institutional real estate economists and other urban researchers, who instead stress precisely those elements that lack adequate theoretical foundation. (Later on, this study presents some indirect evidence on the appropriateness of these assumptions, by analyzing some of the results obtained from the estimating equations.)

THE ESTIMATING EQUATIONS FOR RESIDENTIAL SPACE CONSUMPTION

The regression equations for residential space consumption are given in Tables 2 through 4. The equation for the percentage of zone j's workers residing in single-family dwelling units explains 56 per cent of the total variance in the dependent variable. The equation for the percentage residing in multiple units explains 44 per cent of the total variance, and that for two-family dwelling units only 23 per cent. All the regression coefficients except that for income differ significantly from zero at the one-per-cent level in Eqs. (1a) and (1c). In the two-family-dwelling equation, only the location rent proxy and the family labor-force-participation variable are statistically significant at that level.

At least two interpretations are suggested by the income variable's low level of significance. The proportion of the zone's workers residing

Table 2

EQUATION (1a): REGRESSION EQUATION FOR THE PERCENTAGE RESIDING IN SINGLE-FAMILY DWELLING UNITS

Variable	F_j	S_j	Y_j	P_j	N_j
Regression Coeff.	.254	.136	.023	-2.62	-.184
Std. Error	.062	.050	.073	.197	.043
Partial Corr. Coeff.	.25	.17	.02	- .65	-.26
Coeff. of Det.	.56	Inter-cept	59.40	Std Er-ror Est.	8.66

Table 3

EQUATION (1b): REGRESSION EQUATION FOR THE PERCENTAGE RESIDING IN TWO-FAMILY DWELLING UNITS

Variable	F_j	S_j	Y_j	P_j	N_j
Regression Coeff.	.084	-.066	.016	1.43	.141
Std. Error	.054	.043	.063	.17	.038
Partial Corr. Coeff.	.10	-.10	.02	.47	.23
Coeff. of Det.	.23	Inter-cept	1.77	Std Er-ror Est.	7.54

Table 4

EQUATION (1c): REGRESSION EQUATION FOR THE PERCENTAGE RESIDING IN MULTIPLE DWELLING UNITS

Variable	F_j	S_j	Y_j	P_j	N_j
Regression Coeff.	-.215	-.115	.015	1.235	.098
Std. Error	.043	.034	.050	.135	.029
Partial Corr. Coeff.	-.30	-.21	.02	.50	.21
Coeff. of Det.	.44	Inter-cept	1.77	Std Er-ror Est.	7.54

in single-family, multiple, or two-family dwelling units may be invariant to the workplace zone's mean household income. If the aggregation procedures employed are valid, this would suggest that the household's consumption of residential space is income inelastic. In this instance, it is possible that the definitional shortcomings of the dependent variables are important. The choice of structure type may be relatively insensitive to variations in the level of income, but there may be a significant and unmeasured relationship between lot size and income. The second admissible interpretation is that the income estimate fails to measure household income adequately. (The potential shortcomings and crude nature of the variable were discussed above.) The income variable is statistically significant, however, in some of the equations to follow. Even so, it is still possible that there is a significant income-structure type relationship that is not exhibited here because of inadequacies of the data. If this is true, it suggests that in those equations where the variable is statistically significant the relationship is probably also understated.

In addition, some of the income effects may be picked up by the percentage of workers belonging to families with a single wage earner and percentage male variables. Both of these would be expected to be positively correlated with household income.

Of the remaining four variables, the most important in all three equations appears to be the location rent proxy obtained from the truncated distance from the Central Business District variable. Its sign is what would be expected a priori for all variables.

In the first equation, for the percentage of the zone's workers residing in single-family dwelling units, the sign is negative. This is

interpreted to mean that the proportion of a workplace's employees residing in single-family dwelling units decreases as the price per unit of residential space increases. In the remaining two equations the converse is true.

Truncating the workplace's distance from the Central Business District at eleven miles in constructing the location rent proxy significantly improves the explanatory power of the estimating equations. It was postulated earlier that location rents should initially tend to decrease with distance from the Central Business District, but that they should tend to flatten out or to decrease only slightly with distance from the center once predominantly rural areas are reached. For purposes of comparison, identical regression equations were estimated for Eqs. (1a) and (1c), using the location rent proxy without the truncation (i.e., P_j = 11.5 minus j's distance in miles from the Central Business District). The results were very similar, with only two important differences: the coefficient of multiple determination was only 0.47 for the first equation and 0.40 for the second. The partial correlation coefficient for the non-truncated location rent proxy was -0.42 in the first equation and 0.44 in the second. Thus this simple modification of the location rent proxy in terms of our *a priori* beliefs about the determinants and characteristics of the location rent surface substantially increased the explanatory power of the estimating equation. This suggests that further improvements may be achieved, if a more adequate location rent proxy is obtained.

There are other important reasons for discovering another location rent proxy in addition to increasing the size of its regression coefficient and/or reducing the amount of unexplained variance. We would expect the

surface of location rents to be modified by changes in transportation technology, by changes in the availability and cost of alternative transportation services, and by growth and development of the metropolitan area. If we are to be successful in our efforts to understand and explain these urban processes, it is essential that we be able to explain and predict changes in this surface. The simple proxy variable used here, although yielding what are in many ways useful and interesting results, does not incorporate any of these market dynamics.

There is an interesting relationship between the location rent proxy and the family-size variable exhibited in the three equations. Two-family structures have many of the characteristics of both single-family and multiple units. In particular, they have much of the privacy, size, and other attributes of single-family units. These are achieved at much higher densities, however. Comparison of its estimating equation and that for single-family units may suggest some of the relationships that would appear if the single-family dwelling unit variable reflected differences in lot size. The first equation states that a high proportion of workers resides in single-family units in those zones where the price of residential space is low and where there is a high proportion of workers belonging to families of more than two persons. The second equation, for two-family dwelling units, also states that higher proportions of two-family occupancy are found in those zones having a larger proportion of workers in larger families, but it differs from the first in that higher occupancy is also found in zones where the price of residential space is high. The final equation states that there is a high occupancy of multiple units both when location rents are high and when there is a large proportion of one- and two-member families.

This suggests the following interpretation. Larger families and those with children have a clear preference for single-family detached units because of their privacy, greater space, attached play-yards, and the like. When wage earners are employed at workplaces where surrounding land values or location rents are reasonably low -- that is, in outlying areas with low employment densities -- they will nearly always occupy single-family dwelling units. As the price of residential space or land values rise around the more central workplaces with higher employment densities, more larger households begin to accept higher-density types of living arrangements. The duplex is a logical compromise where location rents or site rents are very high since, as noted above, it has many of the attributes of the single-family house, but is much more parsimonious in its utilization of scarce and expensive urban space.

The higher occupancy of single-family units by zones having a large proportion of workers belonging to families with more than a single worker suggests the possibility of an income effect. An income effect is also suggested by the positive sign for "percentage male" in the first equation and the negative sign for "percentage male" in the other two equations.

ANALYSIS OF THE RESIDUALS

In this section an analysis of the spatial distribution of the residuals obtained from Eq. (1) is carried out to determine if these residuals appear to have any noticeable spatial pattern. This is done in order to provide evidence about the appropriateness of the assumptions made here about the location rent surface, and to point toward ways to improve the model. The residuals, or the differences in the actual and predicted values of the dependent variable, were computed for each of the 254

workplace zones shown in Fig. 1; they were then aggregated to workplace districts, composed of a number of contiguous workplace zones. For each of these workplace districts the mean residual was obtained. This aggregation, it was felt, should tend to cancel out many of the non-spatial variations in the residuals. The mean residuals for each of the 40 workplace districts are shown in Fig. 3. A minus sign indicates that the percentage of workers residing in single-family dwelling units was on the average overestimated for the workplace zones included in that district. A plus means the percentage was on the average underestimated. If all the remaining differences in the residuals (i.e., those not removed by the aggregation to districts) were accounted for by shortcomings in the proxy variable for location rents, the meaning would be that the price of residential space is understated in those districts where the sign is negative and overstated where it is positive.

The mean residuals in Fig. 3 exhibit an interesting and suggestive spatial pattern. For the shaded districts in the figure they have a minus value exceeding -1.0 -- an event considered particularly rare. Earlier in this Memorandum, as well as elsewhere, the author has contended that there should be a metropolitan schedule of location rents, and that this schedule should be directly related to the distribution and level of employment and inversely related to the supply of urban space available for residential use.* Consideration of the employment distribution for Detroit may

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*More elaborate comments on the surface of location rents may be found in J. F. Kain, "The Journey-to-Work as a Determinant of Residential Location," Papers and Proceedings of the Regional Science Assoc., 1962; and idem, unpublished Ph.D. dissertation of the same title, Univ. of Calif., Berkeley, 1961.

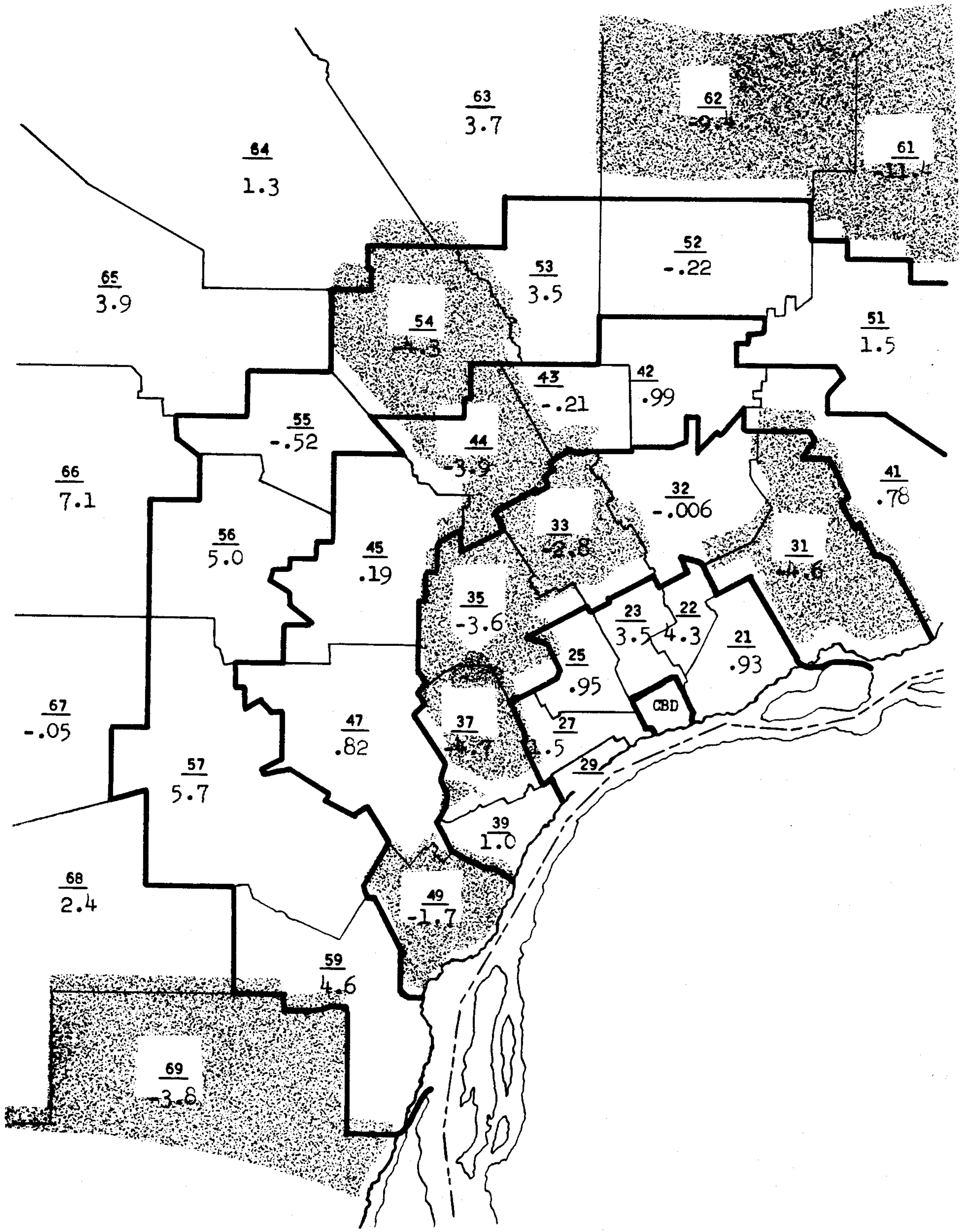

Fig. 3 -- Mean Residuals Obtained for the Regression Equation upon the Percentage Residing in Single-Family Units

therefore be helpful in interpreting the pattern of mean residuals shown in Fig. 3.

Part 1 of the Report of the Detroit Area Traffic Study describes Detroit's employment distribution as follows:

> Although the pattern of worker distribution may appear somewhat confused and complex at first glance, the basic form is relatively simple. Primary and most intense concentration is in the Central Business District. Abutting the downtown and spread out in both directions along the waterfront are high density workplaces. Similar accumulations exist a short distance out the major radials. Along Woodward Avenue, however, a heavy concentration exists along the entire distance to the New Center Area (Woodward and Grand Boulevard) where another peak of commercial employment exists. To the east of the New Center Area, a band of high density industrial workplaces extends to a peak at the Dodge plant in Hamtramck. Surrounding this heavy core of workplace concentrations is a ring of industrial workplaces along the belt railroad at a distance of five to six miles from the city center.*

The above quotation is presented because its description of the employment surface correlates closely with the overestimates of residential space consumption shown in Fig. 3. A large proportion of the areas for which the location rent proxy is apparently too low are included in the above quotation from the Detroit report.

Figure 4 gives the employment for each of the workplace districts. The largest concentration of employment is of course in the Central Business District: 102,000 workers. This level is nearly reached in two other districts shown in Fig. 4. The heavy industrial employment concentrations mentioned in the above quotation, at from five to six miles from the Central Business District, are clearly shown in Fig. 4.

*Detroit Metropolitan Area Traffic Study, Part I, Data Summary and Interpretation, July, 1955, p. 36.

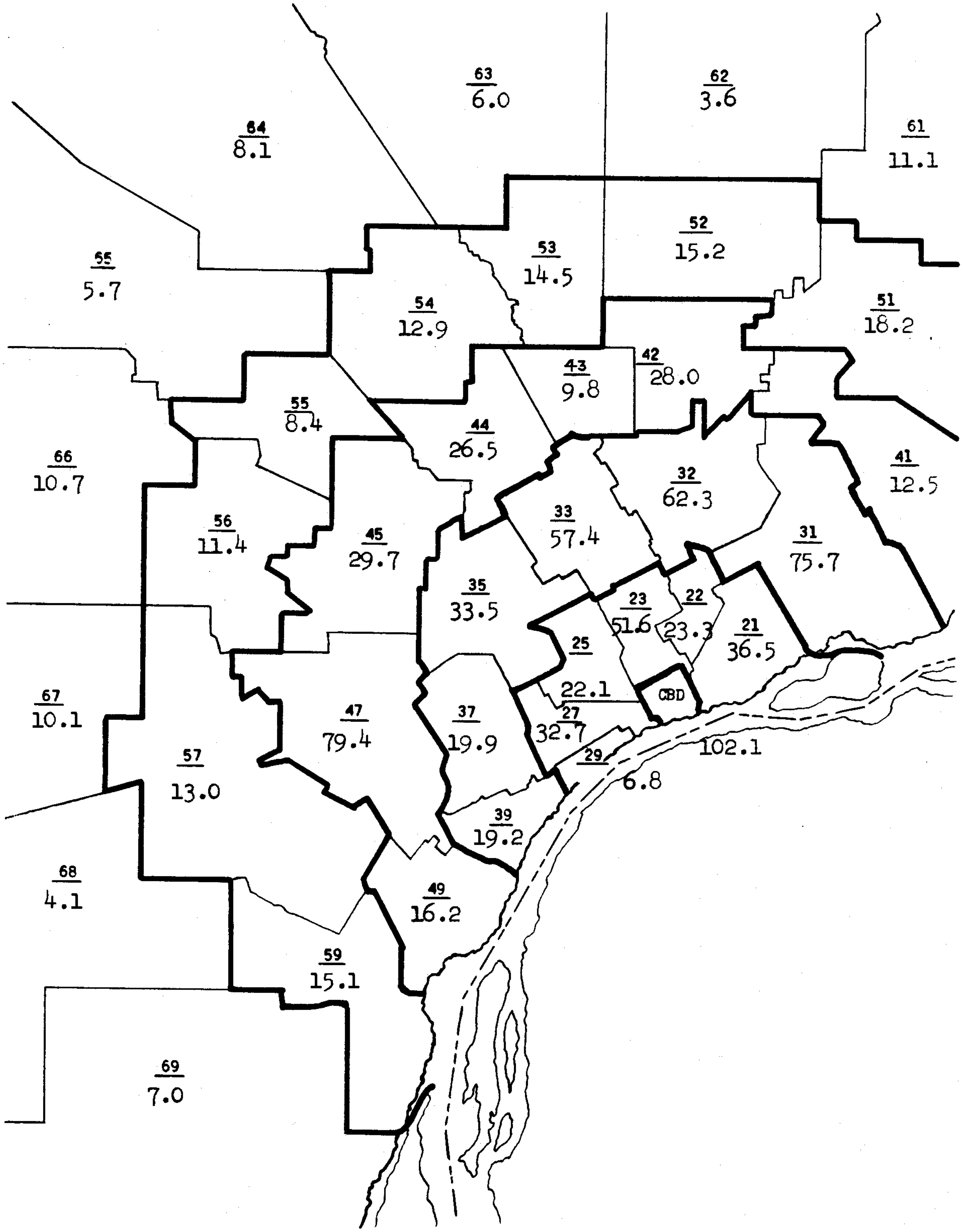

Fig. 4 -- Employment by Workplace Districts (in Thousands)

This examination of the employment distribution in Fig. 4 and of the distribution of mean residuals in Fig. 3 suggests that the proxy variable defined from the variable of distance from the Central Business District probably understates the price of residential space for workers employed in those zones located in the high employment density ring described in the Detroit study report. This includes Districts 31, 32, 33, 35, and 37. Districts 44 and 54 straddle Woodward Avenue, Detroit's major commercial arterial, which provides by far the highest level of transit service for central business workers. All of these factors would be expected to raise the price of residential space for workers employed in nearby areas.

This evidence tends to support the assumptions made about the surface of location rents and the interpretation of the location rent proxy. Undoubtedly this interpretation drastically oversimplifies the operation of the urban land market. The competitive demands of business, government, and industry have already been noted. Market imperfections, especially residential segregation, would have to be explicitly considered in a complete theory of the urban land market. Nevertheless, this analysis strongly suggests spatial regularities in the price households must pay for residential space; and it suggests that these prices are an important influence on household consumption of residential space.

THE AUTOMOBILE OWNERSHIP FUNCTION

A number of metropolitan traffic studies have used automobile ownership in their analysis for predicting the number of trips made by households, the mode choice of households, etc. In Part I of the *Detroit Metropolitan Area Traffic Study*, the authors state that a "knowledge of

car ownership is the best single predictor of trips per dwelling unit . . . if car ownership is used to predict the number of trips made by residents in each of the 224 areas, highly reliable results are obtained." The authors further state that, "Income and car ownership are closely related and one would expect them to exert a similar effect on trip production."*

In Volume II of the Chicago Area Transportation Study a similar use is made of the automobile ownership variable.

> The fact of increasing automobile ownership appears to be the most important factor correlated with the declining use of buses. It is a good index of what is probably the ultimate cause-- rising income. With higher income, people are able to buy a more personalized type of transportation which is consistent with the increased value they ascribe to their personal time. Higher quality, as measured by speed and convenience, is provided by automobiles.**

Net residential density is also used as a variable in predicting trip volumes and modal split in both reports. This use of auto ownership behavior as the major predictive variable is acceptable as far as it goes. Our quarrel with this technique is that the auto ownership decision is far more interdependent than these studies have suggested, or else that the interrelationships have not been made explicit enough. It is probably true that, *ceteris paribus*, automobile ownership and therefore automobile use will increase with rising incomes. A number of other considerations, however, influence a household's decision on whether to buy an automobile and use it in the journey-to-work; these include the household's preferences and decisions about the consumption of residential space, the transportation alternatives available to the worker, etc.

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*Ibid., pp. 78-80.

**Chicago Area Transportation Study, Final Report, Volume II, Data Projections, July, 1960, p. 68.

The Wilbur Smith report for the Automobile Manufacturers Association points out the interdependence of car ownership and a number of these factors: "Transit service tends to be more frequent and more extensive in larger cities, thereby diverting more travel from automobiles at every level of car ownership." The report also points out the relationship between car ownership, residential density, the quality of public transportation, income, etc:

> Usually there are more car owners in single-family residential areas than in high density apartment areas. Density and income being equal, fewer cars are owned and used by persons living near the central city than those in outlying areas. Quality of public transportation is a factor since areas with efficient and frequent public transit often have lower car ownership and use than areas with poor transit service. High density areas are often in proximity to employment and commercial outlets, thereby minimizing the need for private transportation.*

The authors also report that car ownership apparently is functionally related to family size.

In the multiple equation system presented here, the attempt is made to explain variations in the mean automobile ownership of workers employed in spatially separate workplace locations, given variations in income, alternative service levels of public transportation, varying consumption of residential space (determined in the first equation, which itself depends on income prices and preferences), the price of residential space, the preference for residential space, the worker's sex, and whether he is the only wage earner in the family.

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*Wilbur Smith and Associates, <u>Future Highways and Urban Growth</u>, under commission from The Automobile Manufacturers Association, New Haven, February, 1961.

Equation 2 gives the estimating equation for automobile ownership.

$$A_j = \beta + \beta_1 R_j^s + \beta_2 Y_j + \beta_3 B_j + \beta_4 S_j + \beta_5 F_j \ , \qquad (2)$$

where:

A_j = the mean automobile ownership of j's workers;

R_j^s = the percentage of j's workers residing in single-family units;

Y_j = the mean family income of j's workers;

B_j = the coach miles of public bus service within the workplace zone in 1958;

S_j = the male percentage of j's workers; and

F_j = the percentage belonging to families with more than two members.

This equation is also a linear multiple regression equation to be fitted by least squares.

The worker's decision to buy an automobile -- and hence the mean automobile ownership of each workplace zone -- is thus postulated to be an interdependent decision that partly depends on his decision about the density at which he wishes to reside, the quality and level of service of alternate modes, the price per unit of residential space, whether he is a male (or, for the zone as a whole, the proportion of males in the labor force), and the size of his family (or the percentage belonging to families exceeding two persons).

The reasoning for this has to do with the underlying consumer choice model and the relative prices of alternative services. If the worker wishes to reside at a low-density site, his journey-to-work will probably be quickest and cheapest if he drives his own auto since, by and large, low-density residential sites have rather poor public transportation

services. He can choose bus-commuting only by paying much higher site rents for those few low density sites with good transit access; in the more usual low density areas he faces a very time-consuming commutation without an auto. In either instance, for a majority, the private automobile is probably the cheapest form of commutation if low-density residential services are consumed. Thus, we would expect to find a positive correlation between mean automobile ownership and the percentage of zone j's workers residing in single-family dwelling units.

The quality of public transportation services at his workplace would also be expected to significantly affect his decision on buying an automobile. The author would expect the mean automobile ownership to be much lower in workplace zones well serviced by public transportation, and thus that there should be a negative relationship between the level of bus service in the zone and mean automobile ownership. The measure of bus service levels used in this analysis is the number of coach miles per acre within the zone in 1958. Coach miles are defined as the number of miles of transit lines within the workplace zone times the number of buses on each line in a 24-hour period.

For a number of reasons, the author would also expect automobile ownership to be greater in zones with high percentages of males. First, there has been a cultural factor at work which has made it less likely for females to own and operate automobiles; this factor is probably becoming less important, however. Two-car families are still moderately rare even among those with more than a single wage earner. Workplaces with a high proportion of females are probably represented by many multiple-worker families. Moreover, since women earn less than men, they

are less likely to own automobiles; for the same reason, single women are less likely to own them than are single men. Finally, for the reasons outlined in the discussion on residential space consumption, it is likely that women consume less residential space than men do.

It is fairly obvious that income should be positively related to automobile ownership, even if the effects of residential space consumption, sex, and the level of transit service are held constant. Automobiles are valued for more than mere transportation; they also provide a number of comforts, conveniences, privacies, and other utilities which have positive value to the household.

It would also be reasonable to expect mean automobile ownership to increase with family size. Traveling by bus or other forms of transit is more bothersome, tiring, and inconvenient for adults when they have to take children along. The desire to own automobiles is thus likely to be stronger in families with one or more children regardless of their consumption of residential space. Furthermore, the cost of automobile transportation rapidly becomes competitive with that of public transportation as passengers are added to the vehicle. The author would therefore expect a family-size effect in addition to a space consumption and income effect.

The Estimating Equation for Mean Automobile Ownership

The estimating equation for mean automobile ownership succeeds in explaining just under half of the total variance in the dependent variable. (See Table 5.) Four of the five variables are significant at the one-percent level. The single variable that fails to be statistically significant at that level is the male percentage of the zone's workers. Apparently,

the cultural factor inhibiting automobile ownership by females, stated above as probably becoming less important, has in fact already become so.

The contribution of the remaining four variables to the explanation of total variance appears to be approximately equal. As postulated above, mean automobile ownership is higher for those workplace zones which possess a higher proportion of workers residing in single-family dwelling units, a higher proportion belonging to families having more than two members, a higher mean family income, and a higher proportion of male workers. It should be pointed out that the income variable is highly

Table 5

EQUATION (2): MEAN AUTOMOBILE OWNERSHIP

Variable	F_j	R^s_j	B_j	S_j	Y_j
Regression Coeff.	.004	.004	-.031	.0007	.004
Std. Error	.0008	.0009	.007	.0006	.001
Partial Corr. Coeff.	.31	.25	-.28	.08	.22
Coeff. of Det.	.49	Inter-cept	.466	Std Er-ror Est.	.12

significant in this equation; its regression coefficient is four times its standard error.

The level of transit service provided at the workplace also has the expected effect on the level of automobile ownership. The mean level of automobile ownership is inversely related to the number of coach miles of transit service provided to the workplace. This suggests that there are perhaps substantial numbers of captive automobile owners employed at workplaces having very low levels of transit service or none at all.

The automobile ownership function thus explains an acceptable proportion of the total variance in automobile ownership of workers employed in the 254 workplace zones and contains few surprises in the sense of exhibiting statistical results unexpected a priori. It therefore seems to support the appropriateness of the consumer-choice hypotheses underlying this research.

THE MODE CHOICE FUNCTIONS

From the discussions and results presented in previous sections, it should be apparent that the choice of mode by a household, and thus the proportion of each zone's workers using a given mode, are related to the residential space consumption of the individual worker or the average residential space consumption of the zone's workers; the worker's income or the mean income of the zone's workers; the sex of the worker or the male proportion of the zone's labor force; whether the worker has an automobile at his disposal or, in the case of the workplace zone, the mean automobile ownership of the zone; and finally, the level of service provided by the alternate transportation modes.

Like the residential space consumption variable, mode choice is an attribute variable, and again requires the use of more than a single estimating equation. For the mode choice portion of the model, the author has decided on three estimating equations. The dependent variables are the proportion of zone j's workers who are auto drivers, the percentage who are public transit passengers, and the percentage using all other modes. As in the previous examples, the first two estimates are linear regression equations. The third is obtained by subtracting the first two

equations from 1.0. There are some good reasons for using, as the dependent variables, the percentage of automobile drivers and the percentage using public transit. The automobile driver variable largely determines the highway capacity required to handle the journey-to-work travel. In a large proportion of instances, journey-to-work automobile riders belong to car pools, or are members of the same family who share an automobile. For this reason these trips require less highway capacity. The proportion of transit riders is of substantial interest because of the contribution it makes to the current policy controversy over the appropriate roles of public mass and private automobile transportation.

Equations (3a) through (3c) represent the equations estimated by least squares.

The Mode Choice Equations:

(3a) $$M_j^a = \lambda + \lambda_1 A_j + \lambda_2 R_j^s + \lambda_3 B_j + \lambda_4 Y_j + \lambda_5 S_j + \lambda_6 N_j \ .$$

(3b) $$M_j^b = \lambda' + \lambda_1' A_j + \lambda_2' R_j^s + \lambda_3' B_j + \lambda_4' Y_j + \lambda_5' S_j + \lambda_6' N_j \ .$$

(3c) $$M_j^o = 1.0 - M_j^a - M_j^b \ .$$

Dependent Variables:

M_j^a = percentage of zone j's workers who are auto drivers;

M_j^b = percentage of zone j's workers who use public transit;

M_j^o = percentage of zone j's workers using other modes.

Independent Variables:

A_j = mean automobile ownership of zone j's workers;

R_j^s = percentage of zone j's workers residing in single-family dwelling units;

B_j = coach miles of transit service in zone j;

Y_j = the mean family income of zone j's workers;

S_j = the male proportion of zone j's workers;

N_j = proportion of zone j's workers belonging to families with a single wage earner.

As pointed out in previous sections, the author would expect the proportion of the zone's workers who are auto drivers to be directly related to the zone's mean automobile ownership. Conversely, the author would expect there to be an inverse relationship between the mean automobile ownership and the proportion of the zone's workers riding transit. It was also pointed out that auto usage is more frequent among workers who reside in single-family dwelling units. Automobile use should be inversely related to the level of transit service available at the workplace, and transit usage should be directly related to that level. Since higher-income workers would be expected to place higher value on their time, the author would expect to find a higher proportion of auto drivers in higher-income zones, even when automobile ownership and the level of transit service are held constant. This is because it nearly always takes

less time to travel a given distance by auto than by public transit, while the money costs per mile may be lower by public transit. Further, since females less often know how to drive, usually have lower incomes, and less often own automobiles, the author would expect the proportion of males employed in the zone to be positively correlated with a high proportion of auto drivers and negatively correlated with a high proportion of public transit usage, even with income and auto ownership held constant. Finally, the author would expect that the probability of a worker's being an automobile driver would be greater in households having a single wage earner than in those having two or more wage earners.

THE REGRESSION EQUATIONS FOR MODE CHOICE

Tables 6 and 7 give the multiple regression equations for the percentages of zone j's workers who are auto drivers and those who use public transit. Both equations explain more than eight-tenths of the total variance in the dependent variables. Two-thirds of the time, the predicted value lies within one-half of one per cent of the actual value. All of the regression coefficients are significant at the one-per-cent level under a two-tailed t ratio test and all have the signs expected *a priori*.

The most powerful explanatory variable seems to be that of family labor-force participation. This states that when there are two or more wage earners in the family, there is a very high probability that only one of them will be an automobile driver and one will be a public transit rider.

What appears to be the second most important explanatory variable is the zone's mean automobile ownership. Auto ownership thus seems to deserve some of the faith placed in it by the traffic analysts. More

Table 6

EQUATION (3a): PERCENTAGE OF WHITES WHO ARE AUTO DRIVERS, FOR 254 WORKPLACE ZONES

Variable	A_j	R_j^s	B_j	S_j	Y_j	N_j
Regression Coeff.	31.56	.087	-1.788	.229	.132	.337
Std. Error	3.51	.045	.413	.040	.059	.029
Partial Corr. Coeff.	.50	.12	-.26	.34	.14	.59
Coeff. of Det.	.82	Inter-cept	-18.49	Std Error Est.	6.93	

Table 7

EQUATION (3b): PERCENTAGE OF WHITES USING TRANSIT, FOR 254 WORKPLACE ZONES

Variable	A_j	R_j^s	B_j	S_j	Y_j	N_j
Regression Coeff.	-22.10	-.088	3.253	-.209	-.174	-.358
Std. Error	3.51	.044	.412	.040	.059	.029
Partial Corr. Coeff.	-.37	-.12	.45	-.32	-.18	-.61
Coeff. of Det.	.83	Inter-cept	86.06	Std Error Est.	6.92	

careful examination suggests that its net effect is probably less than is suggested in the equation, and illustrates the importance of considering it as endogenous rather than exogenous.

From Table 5, p. 34, we can see that the mean level of automobile ownership is itself a function of the level of transit service, the proportion of workers residing in single-family units, the mean income of

the zone's workers, and the male proportion of the zone's workers. These five variables explain 50 per cent of the variation in automobile ownership. There is evidence that the automobile ownership variable in this equation incorporates part of this effect. Tables 8 and 9 give the same equations with the automobile ownership variable omitted. Omission of mean automobile ownership reduces the explained variance by only 6 per cent for the percentage of the zone's workers who are auto drivers, and by only 3 per cent for the percentage of j's workers who are transit users.

As might be expected, the remaining difference is taken up by the variables of income, transit service, and percentage residing in single-family units. It should be noted that these are independent variables in the auto ownership equation.

The regression equations for mode choice explained an unusually high proportion of the total variance for this type of a model, especially considering the low level of aggregation. It too was largely consistent with our <u>a priori</u> formulation of the problem, and supports the appropriateness of the underlying mode.

THE JOURNEY-TO-WORK-LENGTH FUNCTION

The journey-to-work may be measured in a number of ways; in this model it is measured by elapsed time. The estimate of mean elapsed time was obtained from the home interview, in which the household member was asked to give the times of departure and arrival for each trip. Since, for the worktrip at least, the person interviewed was not the person making the trip, this elapsed-time estimate may contain a substantial error. There is no apparent reason, however, for there being any

Table 8

REGRESSION EQUATION FOR PERCENTAGE WHO ARE AUTO DRIVERS, WITH AUTOMOBILE OWNERSHIP OMITTED

Variable	R^s_j	B_j	S_j	Y_j	N_j
Regression Coeff.	.227	-2.83	.248	.280	.362
Std. Error	.048	.46	.046	.065	.034
Partial Corr. Coeff.	.29	-.37	.33	.26	.56
Coeff. of Det.	.76	Inter-cept	.607	Std Er-ror Est.	7.97

Table 9

REGRESSION EQUATION FOR PERCENTAGE WHO ARE TRANSIT USERS, WITH AUTOMOBILE OWNERSHIP OMITTED

Variable	R^s_j	B_j	S_j	Y_j	N_j
Regression Coeff.	-.186	3.98	-.222	-.278	-.375
Std. Error	.045	.42	.042	.061	.031
Partial Corr. Coeff.	-.26	.51	-.32	-.28	-.60
Coeff. of Det.	.80	Inter-cept	72.7	Std Er-ror Est.	7.44

particular bias in the responses, and much of the error may be self-cancelling when the aggregation by workplace zone is carried out.

The Equations

Equation (4) gives the elapsed time equation estimated in this section.

(4) $$T_j = \mu + \mu_1 R^s_j + \mu_2 S_j + \mu_3 Y_j + \mu_4 P_j + \mu_5 N_j + \mu_6 M^b_j .$$

Dependent variable:

T_j = mean elapsed time in hours and tenths spent by j's workers in reaching work.

Independent Variables:

R^s_j = percentage of j's workers residing in single-family units;

Y_j = mean income of j's workers in hundreds of dollars;

P_j = 11.5 minus the airline distance from the Central Business District, where 11.0 = the maximum distance -- the proxy variable for the price of residential space for workers employed in each of the workplace zones;

S_j = male percentage of the zone's workers;

N_j = percentage of j's workers belonging to families having a single wage earner; and

M^b_j = the percentage of j's workers using public transit.

Expected Relationships

In the elapsed time equation the author would expect the mean elapsed time spent by the zone's workers in reaching work to be positively correlated with the proportion of its workers residing in single-family dwelling units. In the section on residential space consumption it was suggested that, for households employed in large urban areas, the payment

of location rents and transportation expenditures for the journey-to-work are substitutable or alternative means of gaining access to the workplace. It is hypothesized that the worker makes marginal decisions between higher expenditures for his residential site per unit of residential space, and higher transportation expenditures, until his savings in location rents are less than the increase in his commuting cost measured in both money and time. Given a schedule of location rents and of transportation alternatives, the length of the journey-to-work he is willing to make thus depends on his potential savings in location rents. The magnitude of these savings, and thus the length of his journey-to-work, largely depend on his consumption of residential space.

We would expect the length of time the worker spends in his journey-to-work to be directly related to the price of residential space. The higher the location rent function, the longer the journey-to-work should be at every level of residential space consumption. For this reason, the author would expect the proxy variable to be negatively correlated with journey-to-work length.

Because the labor force attachment of women is generally weaker than that of men, because they more often belong to families having low space preference, and because they often belong to families having more than a single wage earner, the author would expect them, on the average, to make shorter journeys-to-work than males; consequently, the average length of the journey-to-work, in both time and distance, should be greater for those zones with high proportions of male workers.

In zones with large proportions of workers belonging to families having a single wage earner, we would expect to find longer journeys-to-work than in zones where the proportion is lower.

In zones with high proportions of transit riders, we would expect to find higher mean elapsed times for the journey-to-work than in zones with low proportions of transit usage, if the effects of residential space consumption, income, etc., are held constant.

The elapsed time variable is a complex index, measuring both the spatial separation of the household's workplace and residence and the worker's decision about the relative value of his time and his money income. Underlying it is a substitution relationship between a mode usually having higher average cost, but higher speed -- the automobile -- and a mode having lower speed, but lower cost -- the bus or transit mode. In addition, because of differences in the levels of transit service available from zone to zone, various alternatives are available to the various workers.

If the effects of residential space consumption, the price of residential space, etc. are held constant, the author would expect that higher income households would make shorter journeys-to-work in terms of elapsed time. Zones with higher income households would, on the average, be marked by shorter mean elapsed times.

The Regressions on Elapsed Time

Table 10 gives the coefficient of multiple determination, the standard error of estimate, the regression coefficients, and the standard errors of the regression coefficients upon mean elapsed time. The regression equation explains 65 per cent of the total variance in the dependent variable: mean elapsed time.

The signs for the proportion using transit, the proportion male, and the location rent proxy are all positive. The first variable states that

the mean elapsed time spent by a zone's workers in reaching work tends to increase as the proportion of its workers using public transit increases. Underlying this are a number of substitution relationships which have been partially but not completely spelled out in the previous equations for mode choice. Mean elapsed time is also higher for those zones with higher proportions of male workers, if income, transit usage, and the remaining variables in the equation are held constant. There are a number of possible explanations for this. Perhaps the most probable is that most women are secondary wage earners and therefore tend to seek employment close to home. By and large, their jobs are also less specialized, less attractive, and usually less remunerative than those of men. For these reasons women have even more incentive for finding work conveniently close to home, rather than going far afield to find genuinely attractive positions. Even when these conditions do not prevail, women usually belong to households with rather minimal residential space requirements, in which case it is again to their advantage to reside near their workplaces.

The final variable having a positive regression coefficient states that the length of the journey-to-work increases as the price of residential space increases. This conforms to what the author postulated from the consumer choice model. It was hypothesized that workers would make longer journeys-to-work at every level of space consumption as the price of residential space increased, since the savings in location rents would be great enough to make longer journeys-to-work economically rational.

Three of the equation's variables also have negative signs. These are the percentage residing in single-family units, the mean household

income, and the percentage of workers belonging to families having more than a single wage earner. It is surprising that the sign is negative for the first of these variables; the author would have expected the mean journey-to-work of a zone's workers to increase in length as the proportion of workers residing in single-family dwelling units increased. The

Table 10

EQUATION (4): REGRESSION EQUATION FOR THE MEAN ELAPSED TIME SPENT IN THE JOURNEY-TO-WORK

Variable	R^s_j	S_j	Y_j	P_j	N_j	M^b_j
Regression Coeff.	-.0006	.002	-.0010	.006	-.0006	.004
Std. Error	.0004	.0004	.0005	.002	.0003	.0005
Partial Corr. Coeff.	-.09	.31	-.12	.17	-.12	.43
Coeff. of Det.	.65	Inter-cept	.302	Std Error Est.	.06	

effect is a very weak one, and the coefficient is not significantly different from zero even at the five-per-cent level. Thus it is not necessary to put too much reliance on the sign of the regression coefficient upon the present single family, and our disappointment may be limited to the fact that we failed to obtain a strong relationship between residential space consumption and elapsed time. In part, the negative sign may result from the complex nature of the dependent variable. Trips to single-family dwelling units are more often made by automobile than by bus; they may extend over longer distances and cost a higher average of combined money and time, but may take less elapsed time.

In addition, the failure of the residential space consumption variable to measure differences in lot size may mean that it is relatively insensitive to variations in the length of the journey-to-work. Really long trips from a given workplace are likely to be made to very low density residential areas.

The signs for the last two variables are as expected. As the zone's mean family income increases, the length of the journey-to-work decreases, if the proportion using transit, the proportion residing in single-family dwelling units, and the price of residential space are held constant. Time is a valuable commodity and, ceteris paribus, we would expect its value to increase as a function of income. Households would thus be expected to substitute dollars for travel-time savings, and the mean elapsed time should be less for higher income households.

The coefficient upon income is relatively small in this equation; however, this does not mean that differences in income have an insignificant effect on mean elapsed time. On the contrary, its effect is probably substantial, since differences in income affect a number of the other independent variables used in the equation.

Finally, it is also a reasonable result to find that zones with large proportions of multiple-wage-earner families have lower mean elapsed journey-to-work times.

This is the last of the estimating equations for the household locational and tripmaking model. All of the equations have had good explanatory power. Section V examines the interdependencies in the model as whole.

V. USE OF THE MODEL FOR ANALYZING LOCATIONAL AND TRIPMAKING BEHAVIOR

It is now possible for us to use the model to analyze the effects of changes in various of our endogenous and exogenous variables on workers' locational and tripmaking behavior. There are a number of valid concerns about using the model in this way, many of which are not inconsequential questions concerning the statistical properties of the data upon which the estimates are based, and the statistical technique itself. Recognizing that there are limitations and problems inherent in the model and the estimation technique, let us in an exploratory and tentative way use the model to evaluate the probable effects of changes in the values of a number of its variables.

The estimating equations presented in previous sections are reproduced here in standardized form. The regression coefficients obtained from the original estimating equations have been transformed to beta coefficients, which in effect are regression coefficients transposed to standard comparable units. The great value of the beta coefficients is that unlike regression coefficients in actual units, the relative effect of each independent variable on the dependent variable is indicated by the relative magnitude of its beta coefficient. Because the data probably fail to meet the stringent tests of multivariate normality, although they are probably better in this regard than are most survey data used by social scientists in their analyses, it will be necessary to use caution in interpreting these beta coefficients.

THE REGRESSION EQUATIONS IN STANDARDIZED FORM

(1a) $$R^s_j = .190F_j + .145S_j + .014Y_j - .771P_j - .286N_j \, .$$

(1b) $$R^2_j = .095F_j - .107S_j + .016Y_j + .635P_j + .331N_j \, .$$

(1c) $$R^m_j = -.262F_j - .200S_j + .016Y_j + .593P_j + .251N_j \, .$$

(1d) $$R^o_j = 1.0 - R^s_j - R^2_j - R^m_j \, .$$

(2) $$A_j = .295F_j + .364R^s_j - .274B_j + .060S_j + .169Y_j \, .$$

(3a) $$M^a_j = .333A_j + .070R^s_j - .165B_j + .197S_j + .066Y_j + .423N_j \, .$$

(3b) $$M^b_j = -.224A_j - .068R^s_j + .288B_j - .173S_j - .084Y_j - .432N_j \, .$$

(3c) $$M^o_j = 1.0 - M^a_j - M^b_j \, .$$

(4) $$T_j = .605M^b_j - .079R^s_j + .271S_j - .076Y_j + .207P_j - .126N_j \, .$$

THE EFFECT OF AN INCREASE IN INCOME ON LOCATIONAL AND TRIPMAKING BEHAVIOR

The model suggests that an exogenous increase in the level of income would have a number of both direct and indirect effects on the locational and tripmaking behavior of households. It is possibly of some interest to examine these effects on the mean elapsed time spent by workers in the journey-to-work. If we followed the usual approach of examining only the direct effects as indicated by the income variable's regression coefficient in Eq. (4), it would appear that a rise in the level of income would only slightly reduce the mean elapsed time spent by workers in the journey-to-work. The manner in which these relationships are expressed in Eqs. (1)-(4) makes it evident that we must also consider the indirect income effects.

First we may note a slight income effect in the first equation upon the consumption of residential space. From Eq. (2) we may note that a rise in income will tend to increase automobile ownership. The induced increase in residential space consumption has a like effect. In considering the effect of income on the third equation, we must consider the fact that rising income decreases transit usage not only directly but also indirectly through increased automobile ownership and increased consumption of residential space.

Therefore, finally evaluating the effect of an increase in income on elapsed time, we must include the direct income effect, which tends to reduce travel time; a secondary income effect which reduces transit usage -- an indirect space consumption effect -- and a still further reduction in transit usage and elapsed time resulting from increased automobile ownership.

Since the direct and indirect effects on the dependent variables have been examined above for the other three equations, they will only be summarized at this point. Residential space consumption, as measured here, seems to be income inelastic, so that an increase in income would apparently have little effect. In terms of the model presented here, there is only a direct effect to consider for automobile ownership. This effect is one of increased automobile ownership with increased income. The percentage of workers using public transit would be affected both by the direct effect of income on transit usage and the indirect effect through increased automobile ownership. Both tend to reduce transit usage.

These direct and indirect effects of an exogenous change in the level of income may be seen more clearly by solving the normalized regression

equations for changes in Y_j; the same procedure may be followed by using the equations in actual units. The beta forms are presented here because it is felt they better facilitate comparison. The equations will be solved sequentially since it will then be easier to substitute the values in later equations.

(1a) $$dY_j^s = .014dY_j$$

(1b) $$dY_j^2 = .016dY_j$$

(1c) $$dY_j^m = .016dY_j$$

The solution of the residential space consumption equations for changes in the consumption of residential space resulting from exogenous change in income is readily obtained. The beta coefficients give the effect of a change in the normalized value of the independent variable on the dependent variable, net of the effects of any of the other independent variables. The remaining variables drop out, since a change is assumed only in the income variable. Equations (1a) through (1c) show that an exogenous change in income would have only a slight effect on the proportion residing in any of the three types of dwelling units. A ten-percent increase in income, for example, would cause only four-tenths of one per cent of Detroit's workers to shift from the various forms of non-dwelling-unit quarters to the three types of dwelling units in Eqs. (1a) through (1c). This is not an unreasonable estimate for this type of a shift. The surprising thing in this instance is that there are no shifts from multiple dwelling units toward the other two types of units and/or from two-family to one-family units.

In estimating the effect of a change in income on automobile ownership it is necessary for us to consider both a direct income effect and the very small indirect income effect on the percentage of single family units exhibited in the previous equation. Equation (2) gives the effect of the income variable and the endogenous space consumption variable.

(2) $$dA_j = .364dR_j^s + .169dY_j \ .$$

Substituting Eq. (1a) into Eq. (2) yields:

(2a.1) $$dA_j = .364\ (.014dY_j) + .169dY_j$$

(2a.2) $$dA_j = .174dY_j$$

In Equation (2a.1), the small coefficient for the income effect upon residential space consumption is weighted by a large coefficient upon the variable of the percentage residing in single-family dwelling units, to provide an indirect income effect upon mean automobile ownership of approximately .005. If both the direct and indirect effects are included, a ten-per-cent increase in income would be expected to lead to a two-per-cent increase in the mean number of automobiles owned.

The effect of changes in income on the proportion of workers driving automobiles and the proportion using transit is, as might be expected, more complex than that for residential space consumption or mean automobile ownership. Equations (3a) and (3b) are the statistical equations for choice of mode.

(3a) $$dM_j^a = .333dA_j + .070dR_j^s + .066dY_j \ .$$

(3b) $$dM_j^b = -.224dA_j - .068dR_j^s - .084dY_j \ .$$

Substitution of Eqs. (2a.2) and (1a) gives the following results:

(3a.1) $$dM_j^a = .333dA_j + .070dR_j^s + .066dY_j \ ,$$

(3a.2) $$= .333(.174dY_j) + .070(.014dY_j) + .066dY_j \ ,$$

(3a.3) $$= .125dY_j \ .$$

For the percentage using transit:

(3b.1) $$dM_j^b = - .224dA_j - .068dR_j^s - .084dY_j \ ,$$

(3b.2) $$= - .224(.174dY_j) - .068(.014dY_j) - .084dY_j \ ,$$

(3b.3) $$= - .124dY_j \ .$$

The results again are reasonable and quite interesting. As might be expected, the two equations are symmetrical-- that for the percentage who are auto drivers and that for the percentage who are transit users. A ten-per-cent increase in income would increase the proportion of Detroit's workers using automobiles by about 1.2 per cent, and would decrease the percentage using transit by about the same proportion. Of considerable interest in these equations is the fact that the indirect income effects, operating through changes in the percentage residing in low-density single-family dwelling units and changes in automobile ownership, are almost as great as the direct effects. This strongly reinforces and supports our basic premise that to understand the urban transportation problem and to formulate appropriate policies it is essential to consider the entire complex of land use and transportation relationships.

The final equation in the model is Eq. (4), the elapsed time equation, which has the most complex effects of the four.

$$(4) \qquad dT_j = .605dM_j^b - .079dR_j^s - .079dY_j \ .$$

Equations (4.1) through (4.3) give the solution of the income effects.

$$(4.1) \qquad dT_j = .605dM_j^b - .079dR_j^s - .079dY_j \quad ,$$

$$(4.2) \qquad = .605(- .124dY_j) - .079(.014dY_j) - .079dY_j \ ,$$

$$(4.3) \qquad = -.155dY_j \ .$$

A 10-per-cent rise in income, if both the direct and indirect effects are considered, decreases the amount of elapsed time spent in the journey-to-work by about 2 per cent. About half of this is the result of a direct income effect and about half results from decreased transit usage, part of which is direct and part of which is induced by changes in automobile ownership, increased occupancy of single-family dwelling units, and changes in income. The indirect effects are again about equal to the direct effects upon income.

This example, the author feels, clearly exhibits the need to be explicit about these relationships in our prediction, planning, and research. The interdependencies have been traced out in the model; the importance of considering the indirect as well as the direct changes in any explanatory variable has been illustrated.

For a number of reasons, the effect of changes in income might be understated in this model. First, as has been pointed out, there might well be a positive relationship between income and the consumption of

residential space, if the measures of residential space were to include differences in lot size for single-family dwelling units. Secondly, the income variable is extremely crude and consequently may completely fail to measure income relationships throughout the model, or may at least underestimate them. Finally, it has been pointed out that the model includes at least two other exogenous variables, which may pick up part of the income effects and are in fact correlated with family income. These are the number of wage earners in the worker's family and the male percentage of the zone's workers.

THE EFFECT OF AN EXPANSION OF TRANSIT SERVICE

It has been hypothesized that an increase in the level and frequency of transit service would also have a number of interesting direct and indirect effects. The first is that an increase in the level of transit service would reduce automobile ownership. Secondly, it would tend to increase transit usage, both because of the direct transit service effects indicated in Eq. (3) and through the induced reduction in automobile ownership. Finally, there would probably be some increase in the amount of time spent on the journey-to-work as the transit mode became more competitive and workers switched from automobiles to public transit. Their reasons for doing so would probably be the lower money cost of transit usage and their escaping from high parking fees. As the level of service improved and terminal time went down, the time-money ratio would shift for many workers in favor of transit usage. Many two-car families would find it preferable to get rid of one car and use a transit vehicle for the journey-to-work, leaving the other car at home for the housewife's use

and for family trips. Some households would find it possible to give up automobiles altogether.

The following paragraphs examine the direct and indirect effect of changes in the level of transit service upon the model's dependent variables.

The effects of changes in the level of transit service at workplaces are derived below for the dependent variables: the mean automobile ownership, the percentage using transit and the percentage driving automobiles, and the mean elapsed time spent in reaching work from home.

Automobile Ownership

(2) $$dA_j = - .274dB_j \ .$$

Mode Choice - Auto Drivers

(3a.1) $$dM_j^a = .333dA_j - .165dB_j \ .$$

(3a.2) $$dM_j^a = + .333(-.274dB_j) - .165dB_j \ .$$

(3a.3) $$dM_j^a = -.256dB_j \ .$$

Mode Choice - Transit Users

(3b.1) $$dM_j^b = - .224dA_j + .288dB_j \ .$$

(3b.2) $$dM_j^b = - .224(-.274dB_j) + .288dB_j \ .$$

(3b.3) $$dM_j^b = .349dB_j$$

Elapsed Time

(4.1) $$dT_j = .605dM_j \quad .$$

(4.2) $$dT_j = .605(-.256dB_j) \quad .$$

(4.3) $$dT_j = - .155dB_j \quad .$$

From these equations it can be seen that a 10-per-cent improvement in transit service at Detroit workplaces would decrease automobile ownership by about 3 per cent, and a 10-per-cent decrease would increase automobile ownership by the same amount. It is of considerable interest to note, subject to the reservations noted about the estimates of the income effects, that a 10-per-cent increase in the level of transit service would decrease automobile ownership by a larger amount than a 10-per-cent increase in income would increase it.

The effects of a curtailment in transit service, as might be expected, would be somewhat more for the mode choice equations. A 10-per-cent decline in transit service would reduce the percentage using transit by about 2-1/2 per cent and increase the number of auto drivers by about 3-1/2 per cent. This suggests that more workers would switch from riding buses than would become auto drivers. This too is not an unreasonable result. A portion of the lost bus riders would probably become auto riders or would walk to work, since some may be unable or unwilling to drive.

The final equation states that as the level of transit service is curtailed, the mean elapsed time spent in the journey-to-work would decrease. This primarily results from the shift to the possibly more expensive, but private automobile.

Thus, as in the income change analysis, there are substantial and important interdependencies and indirect effects resulting from a change in the level of one of our explanatory variables. It is the purpose of this analysis to provide greater insights into these relationships.

THE EFFECT OF CHANGES IN LOCATION RENTS ON LOCATIONAL AND TRIPMAKING BEHAVIOR

From the standardized regression equations on p. 49 it is obvious that the location rent proxy is an important and powerful explanatory variable. Changes in the level or distribution of that variable have a considerable effect on all of the dependent variables included in the model. In the residential space consumption equation it is more than twice as important as any other variable. It is also highly important in the elapsed time equation and indirectly, through changes in residential space consumption, would have a substantial effect on the level of automobile ownership and on the utilization of alternative transportation modes.

The fact that the author has been unsuccessful in adequately explaining this function or in providing anything like positive empirical evidence of it does not mean that he has no ideas as to its determinants or as to its interpretation and meaning. It was stated above that although this function may be picking up a number of other effects as well, the author believes its primary explanation is as a price variable which rather grossly and crudely describes the price that households or other economic units must pay to utilize urban space for their activities. The analysis of the residuals from the percentage of workers residing in single-family dwelling units provides, the author believes, some evidence supporting this view.

Given this as a starting point and drawing upon some of the theoretical

work cited earlier, it is not too difficult to hypothesize about possible changes in the function. For example, technological improvements that reduce either the money costs or time costs of transportation services would tend to lower the surface absolutely, if unaccompanied by any other changes such as increases in population or greater concentration of existing employment. The model suggests that this lowering might be less than initially expected or that certain indirect effects would logically result from a fall in the surface which would feed back and affect the changes in the surface itself. The model suggests that one such feedback would be an increase in households' consumption of residential space, resulting in an expansion in the aggregate demand for residential space by households even if the population remained constant. This would certainly lessen the fall in these prices and would probably lead to changes in the configuration of the surface. One probable result would be that the surface would tend to flatten and the margin of the surface would certainly be extended. It is altogether possible that aggregate land values or location rents might even rise as a result, if the price elasticity of residential space consumption were high enough. The result in any case would be a larger metropolitan area, with a higher average consumption of residential space.

Just as certainly, an expansion of employment and population would cause the location rent surface to shift. The character of these shifts would largely depend on the location of the new employment opportunities. If they were near the center or near existing employment locations, thereby raising employment densities, the surface would probably shift predominantly upward. By way of contrast, if the new employment were on the periphery, the surface would probably shift upward more on the periphery and less near

the center. If no other change occurred, the surface would also probably be higher near the center. Most of the effects, however, would be in terms of raising peripheral location rents and in terms of increasing the size of the urban area.

If there were decreases in employment and population or a redistribution of employment that lessened densities near the center, the changes in the surface would probably be symmetrical.

Thus let us consider the effects of changes in the location rent proxy on the location and tripmaking variables included in the model. In the following paragraphs, the model's equations have been solved in terms of the location rent proxy. Equations (1a.1) through (1c.1) give the solutions for the residential space consumption equations. Equations (2.1) through (2.3) give its direct and indirect effects on automobile ownership. The solutions for mode choice are given in Eqs. (3a.1) through (3b.3), and those for the mean elapsed time spent in reaching work from home in Eqs. (4.1) through (4.3).

Residential Space Consumption

(1a.1) $$dR_j^s = -.771dP_j \, .$$

(1b.1) $$dR_j^2 = .635dP_j \, .$$

(1c.1) $$dR_j^m = .593dP_j \, .$$

Mean Automobile Ownership

(2.1) $$dA_j = .364dR_j^s \ .$$

(2.2) $$dA_j = .364(-.771dP_j) \ .$$

(2.3) $$dA_j = -\ .281dP_j \ .$$

Mode Choice - Auto Ownership

(3a.1) $$dM_j^a = .333dA_j + .070dR_j^s \ .$$

(3a.2) $$dM_j^a = .333(-.281dP_j) + .070(-.771dP_j) \ .$$

(3a.3) $$dM_j^a = -\ .147dP_j \ .$$

Mode Choice - Transit Usage

(3b.1) $$dM_j^b = -\ .224dA_j - .068dR_j^s \ .$$

(3b.2) $$dM_j^b = -\ .224(-.281dP_j) - .068(-.771dP_j) \ .$$

(3b.3) $$dM_j^b = .115dP_j \ .$$

Mean Elapsed Time

(4.1) $$dT_j = .605dM_j^b - .079dR_j^s + .207dP_j \ .$$

(4.2) $$dT_j = .605(.115dP_j) - .079(-.779dP_j) + .207dP_j \ .$$

(4.3) $$dT_j = .338dP_j \ .$$

The model states that an increase in the price of residential space (which might, as noted earlier, be caused by an increase in employment at existing workplaces located within the urban area) would have a substantial effect; a 10-per-cent increase in the proxy variable would result in nearly a 10-per-cent decrease in the proportion of a zone's workers residing in single-family units. The displaced workers would be rehoused by approximately a 6-per-cent increase in the proportions of both the percentage residing in single-family dwelling units and of the percentage residing in multiple dwelling units. The mean percentages by structure type for the 254 workplace zones are currently 67.7 per cent residing in single-family dwelling units, 16.8 residing in two-family dwelling units, and 11.9 residing in multiple dwelling units. If the increase were uniform for all areas, the equation would suggest that the proportions following a 10-percent rise in the proxy variable would be on the order of 52 per cent residing in single-family dwelling units, 27 in two-family dwelling units, and 19 in multiple dwelling units.

This, it should be noted, would lead to a substantial increase in residential densities. These higher residential densities and workplace densities would have a very important bearing on the types of transportation facilities that would be optimal for serving the journey-to-work.

Equations (2.1) through (2.3) indicate that these higher residential densities would probably result in reduced car ownership.

Both through lower car ownership and higher residential densities, the rise in location rents would lead to an increase in transit usage and a decrease in the proportion driving autos to and from work.

Finally, the increase in location rents would lead to a lengthening

of the journey-to-work. This is in part a result of greater transit usage. A greater part results from the higher transportation-cost/location-rent break-even point. About two-thirds of the total increase results from a direct effect on trip length exerted by the location rent increase. The remaining increase of one-third results primarily from the greater transit usage.

THE EFFECTS OF OTHER VARIABLES

It would be possible to trace the effects of a number of the other variables through the model; in fact the number of such exercises that could be carried out using even this very simple model is very large. These three specific examples are presented primarily as illustrations of the potential uses of such a model, if sufficient confidence can be acquired in its reliability. In addition, it was the author's objective to illustrate the complexities of the tripmaking/land-use relationships we are groping with; and to emphasize the importance of embracing as many as possible of their interdependencies. This model, although more complex and more explicit than those usually employed in traffic, transportation, and land use analysis, is still far from being an adequate or complete representation of these complex relationships.

The model has a number of obvious shortcomings. The shortcomings of the proxy variable used for the location rent function have already been mentioned specifically. We at RAND have considered the betterment of our understanding of the urban land market as essential to our efforts to construct a meaningful and reasonably useful model of an urban community for use in studying these critical transportation and land use relationships. As yet our efforts in this direction have been less than notable, although

we feel that by explicitly recognizing the importance of this factor in our research, we are somewhat better off than we would be if we ignored it. True, we may discover after considerable effort, soul-searching, and research that there is nothing to the idea, as many of our fellow researchers suggest; but this is a hazard we are willing to accept. If the outcome did indeed prove to be negative, however, we would still find it necessary to forge another explanation for what are apparently very useful proxy variables.

In the same vein, if our and other researchers' intuitions and hypotheses about the fundamental operation of the urban land market are correct, it will probably be necessary for us to trace out the effects of a number of our endogenous and exogenous variables on the location rent surface. Changes in the costs of transportation services, changes in the consumption of residential space, changes in the distribution of employment, and changes in the level of population or employment certainly affect -- and, we suspect, largely determine -- the location rent surface. These relationships must be explicitly treated and some way of stimulating them must be found for the overall model. That is, it is apparent that the location rent variable, which we treated as exogenous in this model, is in fact very much endogenous. Certainly, incomes, the level of transit services, etc., affect the location rent surface. It is probable that these are longer-run adjustments than are the others included in this model, but are all the same interdependent.

Similarly, over a longer adjustment period, there is evidently a functional relationship between transit usage and transit service. Some urban researchers have offered a kind of "vicious circle" theory to explain the decline in transit usage. They argue that reductions in service levels

lead to reductions in usage, reductions in usage lead to further curtailments in service, further curtailments in service lead to reductions in usage, and so on. As noted above, there is probably some validity to this observation; whether their conclusions and prescriptions logically follow from this observation is another issue. These researchers often then suggest that the appropriate short-run urban transportation policy is to grant a large subsidy to provide levels of transit service higher than have ever been experienced, until a service-usage equilibrium is reached at which this improved super transit system becomes self-sustaining or can operate with only a small subsidy.

As with the previous example, the bus service level may be considered as it is here, as exogenous for the individual worker or for the shorter-run adjustment and decision-making period implicit in this model.

It is probable that in future work the author will explicitly consider the functional relationship between transit service levels and transit usage, workplace and residence densities, and other such variables which probably affect transit service levels.

VI. CONCLUSION

This has been a progress report on research directed toward the eventual development of a residential location and tripmaking submodel for use in the projected RAND model of an urban community. (See Preface, p. iii.) The multiple equation recursive model reported here was estimated by using least squares regression techniques applied to cross-sectional data obtained from the Detroit Area Traffic Study's home-interview origin and destination study. The worktrips of more than 40,000 sampled workers were aggregated to 254 spatially separate workplace zones. The model explains four types of locational and tripmaking behavior for the white workers employed in these 254 zones: residential space consumption, automobile ownership, mode choice, and length of journey-to-work. The final model has, in all, seven statistical and two definitional equations. The dependent variables for these nine equations are the percentage of each zone's workers residing in single-family dwelling units, the percentage residing in two-family units, the percentage residing in multiple units, the percentage residing in non-dwelling-unit quarters, the mean automobile ownership of the zone's workers, the percentage of the zone's workers who are auto drivers, the percentage who are transit users, the percentage who are neither auto drivers nor transit users, and the mean elapsed time spent by the zone's workers in reaching work from their places of residence.

The proportion of explained variance for the seven statistical equations is uniformly high; the regression coefficients are generally significant at the one-per-cent level, and they have signs consistent with the underlying consumer-choice hypotheses upon which the statistical model is based.

The major directions in which improvement is currently being sought are: (1) efforts to explain additional aspects of household locational and tripmaking behavior and to improve on the explanation of the aspects considered in this model; (2) the provision of a more adequate explanation of the mechanisms and dynamics of the urban market for real property and for location; and (3) broadening of the range of experimentation and analysis to include more metropolitan areas, and thus to include a greater range of experience and of urban forms and structures.