Factors Influencing Transit and Automobile Use in Urban Areas

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●THE OBJECTIVE of this research is to develop a relationship between the use of public and private transportation on the one hand, and the principal factors influencing that use in urban areas on the other, in order to estimate what use will be made of each of these modes under each estimated set of influencing factors. If that can be satisfactorily done, an estimate can be made of the usage and the total construction and operating costs for such usage of any proposed transportation system, including terminal facilities for each mode. From this the next step is to estimate the benefits of each plan and program in relation to cost.

Within the next 20 to 25 years, there undoubtedly will be changes in modes of urban transportation. It is quite doubtful, however, that any drastic changes will take place so rapidly that the basis for planning will be wiped out over night. At least as far as can be foreseen, establishment of this relationship will permit preparation of transportation plans on a more realistic basis.

It is believed that a start, as reported in this preliminary paper, has been made in establishing this needed relationship. This investigation leads to the conclusion that this approach will yield relationships that will predict within a sufficient degree of accuracy for transportation planning the travel mode split for an estimated set of conditions. Future research may produce modifications in some of the factors and the estimating equations for the entire urban area, and especially in the relationships for subareas and for time periods.

Search for Relative Use Formula

In most urban areas since the late 1920's (except for the depression and war years) the automobile has been supplanting transit as the mass carrier of people. The rate of change, however, has not been uniform from city to city and from year to year. In a number of metropolitan areas, principally the larger ones to the east of the Mississippi River, the decline in transit riding apparently is tending to level off. In many cities, however, the trend from transit to automobile has been continuing at either an accelerated or a constant pace.

Transit, highway, planning, and municipal officials have long been seeking a means for determining the change in both relative use and total trips by transit and automobile. Transit and regulatory officials need this information to establish a fare structure and transit-service characteristics. Highway engineers have been faced with the necessity of determining whether the cost of street and parking facilities and of transit facilities on highways will be justified by future use. Planning and municipal agencies are concerned with the interrelated effect of land-use distribution and population on the one hand, and on the other hand the use of transit and automobile as well as the effect on other utilities. Municipal authorities must also weigh the effect on the tax structure of relative travel mode use, especially if transit operations should become the responsibility of an agency of the public. Primarily all of these are concerned with the factors and elements that cause variations in travel mode use and their relationships in the economic and political system.

PROCEDURE

Factors and Elements Studied

In previous attacks on this problem (1, 2, 3), attempts have been made to establish relationships between transit-riding habit and several factors. In most research these factors have been (a) population, (b) automobile registration, (c) transit service, (d) economic welfare, and (e) transportation costs. These studies, however, have not yielded

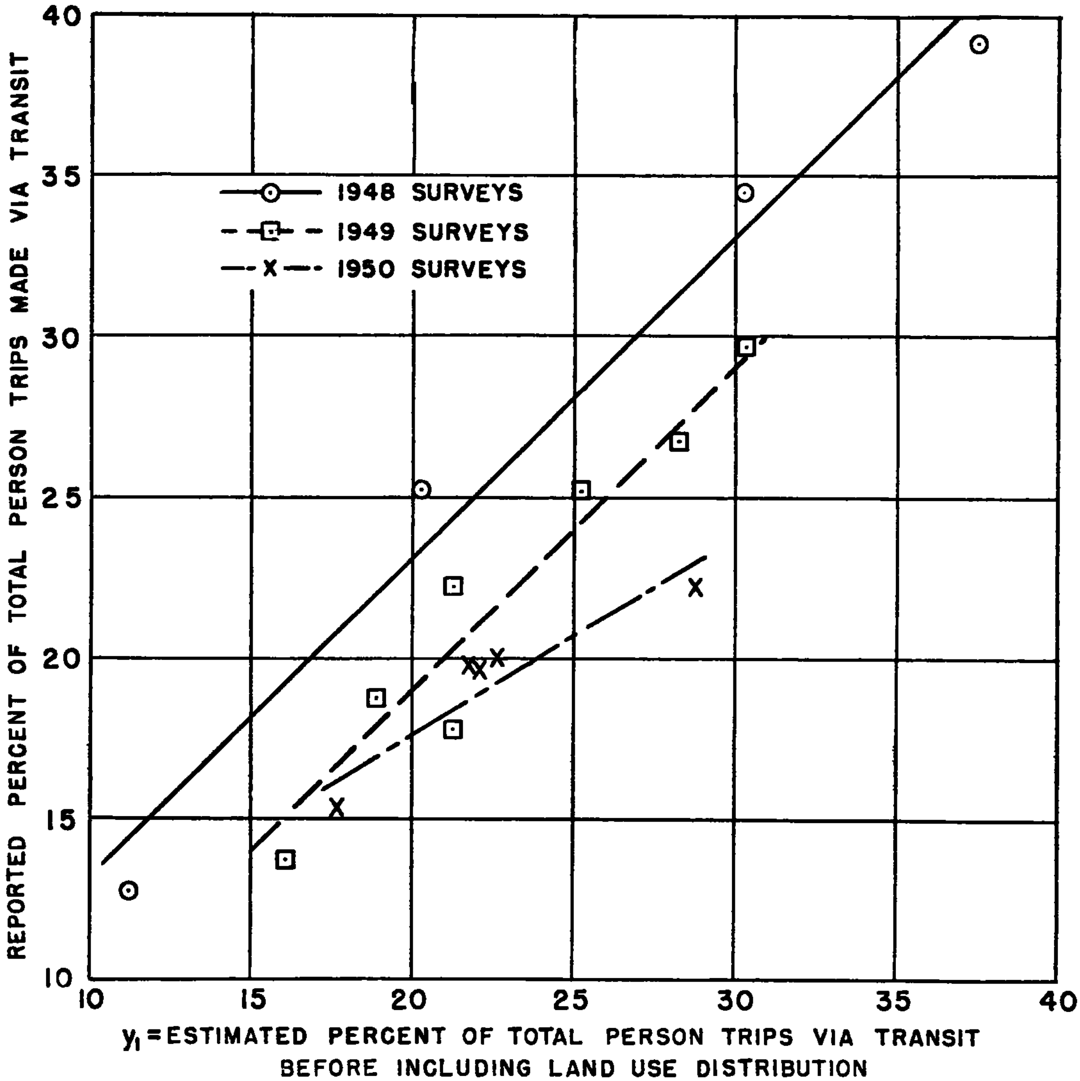

Figure 1. Relationship of reported relative transit use to that derived from estimating equation before including land use distribution factor.

conclusive results. They did not develop relationships that would forecast relative mode use within an acceptable degree of accuracy for the anticipated influencing factors.

In the last few years, more attention has been given to land use as one of the principal factors affecting urban transportation. These studies (4, 5, 6, 7, 8, 9, 10, 11) have indicated that an appreciable degree of correlation exists between travel mode on the one hand and residential, commercial, and industrial land use on the other.

In this project, a land-use distribution factor has been combined with factors relating to population, automobile ownership, employment, dwelling units, transit-service ratio, and urbanized area to attempt to develop a basis for forecasting mode use.

Source of Data

Because of the wealth of information gathered in the home-interview origin-destination surveys, the reports for all cities in which such surveys have been completed since

January 1948 were reviewed. Cities in which surveys were made prior to 1948 were not considered, principally because war-caused distortions still exerted a major influence through 1947 and the quality of many of the early surveys was questionable. Of course, the cities in which there was no transit operation could not be used. Initially, this left 30 cities to be studied. Of these, 8 had surveys in 1948, 7 in 1949, 6 in 1950, and 6 in 1953. There were only 3 in the 2-yr period of 1951-52. The 3 in this last period were at first disregarded because it appeared advisable to test within each year the development of a relationship that might hold from year to year, and for this test 3 cities were insufficient.

Through the cooperation of the American Transit Association, information on transit service at the time of the origin-destination survey was obtained from the transit companies in 22 of the 30 cities. As previous studies had indicated that one of the key factors in any developed relationship might be land-use distribution, land-use information corresponding to the origin-destination survey period was also requested from the planning agencies of each city.

Investigation of Relationships

By means of accepted simple and multiple regression analysis methods, travel mode use was studied in relation to the single and multiple, simple and compound dependent variable factors on which information had been gathered in each origin-destination survey. Among the simple factors examined were those of population, automobile ownership, trips to work, and total survey area. Among the compound factors investigated were population density, automobile ownership per capita, and employment per capita. Also tested was the relationship between travel mode split and combinations, within a minimum-maximum range of more complex, compound factors, such as employment and automobile ownership per capita, in single and multiple linear and curvilinear equations. None of these tests yielded either an acceptable standard error of estimate or a high degree of correlation.

As transit-service information was received, tests were made to determine if there might be any significant relationship between the service data and mode split. As the lone independent variable, transit service did not produce a satisfactory estimating equation. Using a transit-service ratio factor in conjuction with a population factor, a combination automobile and employment factor, and an urbanized land-use factor, semilog multiple variable equations of the form,

$$y_1 = A + b_1 \log P + b_2 \log E + b_3 \log T + b_4 \log M \qquad (1)$$

were developed that gave the results shown in Figure 1 for the cities with available data for 1948, 1949, and 1950.

These results indicated that there might be at least one other factor which, if included, would produce the relationship sought regardless of the year. From previous studies, it was believed that this factor might be largely based on land-use distribution, for with each succeeding year since 1948 there has been an increasing decentralization of residential, commercial, and industrial land use with respect to the central business district (CBD). Tests were made of ranges of various ratios and combinations of ratios involving, (a) distribution of land used commercially and industrially within and about the CBD, (b) population distribution with respect to the center of urbanized land area, and (c) population distribtuion with respect to employment location. Although differing in amount of variation explained, nearly all combinations tended to reduce the year-to-year variations. Using the semilog equation,

$$y_1 = A + b_1 \log P + b_2 \log E + b_3 \log T + b_4 \log U + b_5 \log M \qquad (2)$$

the land-use distribution factor brought all 16 cities into a straight line relationship, as shown in Figure 2.

Neither the land-use distribution factor nor some of the other factors now being used may prove to be the best ones as additional information is obtained. Variations in these have been investigated. Several satisfactory estimating equations with only minor variations have been developed. All have yielded a standard error of estimate of less than

1.5 percentage points and several of less than 1.0 percentage point of the reported transit use in percent of total person trips for the entire urbanized areas of the 16 cities. Transit usage in these cities ranged from 8 percent to 40 percent of the total person trips, with a mean of approximately 20 percent. Thus a standard error of 1.5 percentage points is equivalent to 7.5 percent of the mean revenue total transit trips per weekday for the 16 cities.

Of the semilog multiple regression equations developed, the following equation has been used in this paper:

$$y_1 = -2.6466 + 3.7084 \log P + 0.3912 \log E + 2.3757 \log T + 0.4918 \log U - 0.9708 \log M \quad (3)$$

The basic data used in developing Eq. 3 are found in Table 1. In Eq. 3,

y_1 = Percent of total person trips made via transit;
P = Population over 5 years of age in the survey urbanized area, in 10,000;

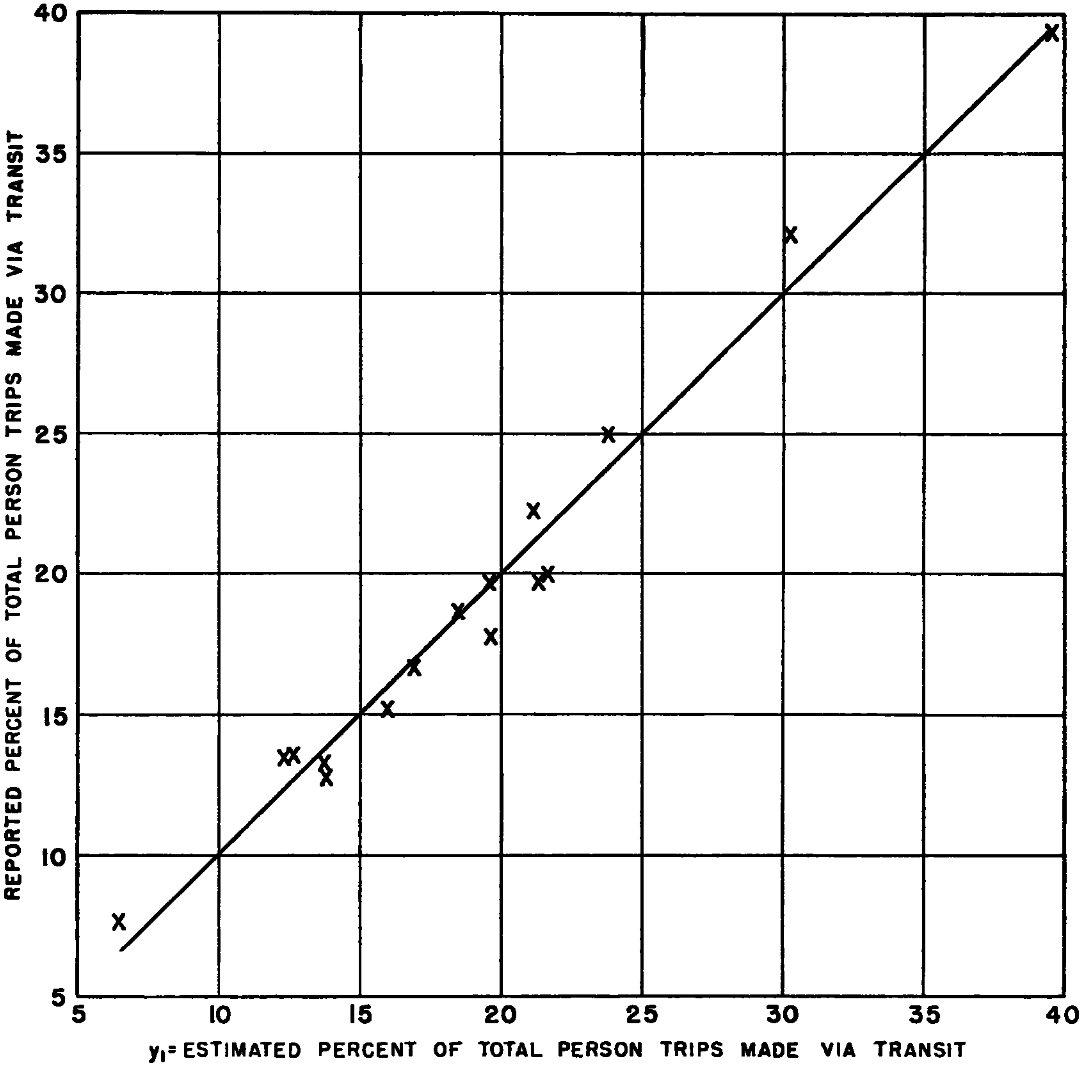

Figure 2. Relationship of reported relative transit use to that derived from estimating equation after including land use distribution factor (studies in 16 cities, 1948-1953).

TABLE 1

BASIC DATA FOR 16 CITIES USED IN DEVELOPING RELATIVE TRANSIT USE EQUATION FOR ENTIRE URBANIZED AREA

O-D Survey Year	City	Population Over 5 Years of Age P (1,000's)	Dwelling Units, H (1,000's)	Employees Going to Work per Average Weekday e (1,000's)	Automobiles Owned a (1,000's)	Equivalent Revenue Veh-Mi per Average Weekday, V (mi)	Urbanized Land Area, M (sq mi)	Land Use Distib. Factor, U	Reported Relative Transit Use, y (%)
1948	Washington, D.C	992 6	336 2	380 8	203.5	155,060	108.80	0.00456	39 3
	Tacoma, Wash.	125 0	48 0	36 1	35 2	11,960	45.80	0.03350	25 2
	Tuscon, Ariz.	113 7	38.7	29 6	32 9	3,610	41.00	0.07398	12.7
	Allentown - Bethlehem, Pa	156.4	48 8	61.6	28 6	12,490	18.95	0 00628	32.1
1949	Albuquerque, N Mex	100 8	34 9	30.4	27.5	4,510	38.93	0.02035	13 6
	Madison, Wis.	94.3	33.4	29.6	25 3	5,780	20 40	0.03034	22 4
	Racine, Wis	69 5	23.3	23.1	18 5	3,210	11.56	0.06204	17.8
	Sharon-Farrell, Pa	44.3	13.7	12 9	9 4	1,530	8.08	0.19520	18 5
1950	Dallas Tex.	471 1	168.1	182 5	153.8	57,900	173 20	0.00253	19 8
	Altoona, Pa.	77 5	24.1	17.1	16.8	3,680	15.82	0.03204	20 0
	Kenosha, Wis	50.2	17.3	21 7	13 4	2,580	8.32	0.19264	19 6
	Rockford, Ill	102.5	36.2	48.7	33.1	6,020	24.54	0 05248	15 1
1953	Houston, Tex.	765.9	272.7	278.8	256 3	48,020	244.50	0.00024	13 6
	Stockton, Calif	124.3	41.6	34 9	70 0	3,000	31.89	0.01109	7.8
	San Diego, Calif	513.0	175 0	152 1	250.5	36,170	152.01	0.00025	13.2
	Detroit, Mich	2,642.2	875.4	971 1	845 8	183,170	548.85	0.00004	16 7

T = Transit-service ratio factor as determined by

$$\frac{V^{1.0}}{P^{1.50}M^{0.25}} \; S_r \frac{F}{D} \qquad (4)$$

in which

V = Equivalent revenue-vehicle-miles operated per weekday during the survey (as explained in subsequent discussion of factors);

M = Urbanized land area, in square miles;

S_r = Ratio of the square root of the average vehicle speed of the different travel modes[1];

F = Terminal or parking facility factor[1]; and

D = Parking demand as related to volume of employment types[1].

E = Economic factor of $(\frac{P}{e})^{3.5}\,(\frac{h}{e})^{1.5}\,(\frac{P}{a})^{1.0}\,(\frac{h}{a})^{1.5}$,

in which, for the urbanized area:

P = Population above 5 years of age, in 10,000;

h = Dwelling units, in 10,000;

e = Employees going to work per average weekday, in 10,000; and

a = Automobiles owned, in 10,000.

U = Land-use distribution factor based on $(r_1)(r_4)(r_5)$, in which

$r_1 = 1 - \frac{R_p}{R_u}$, in which

R_p = Mean distance (distance from area centroid to CBD center) of population, and

R_u = Mean distance of urbanized area.

$r_4 = \frac{A_{tc}}{A_{tc}R_{tc}} = \frac{1}{R_{tc}}$, in which

A_{tc} = Area of total commercial and industrial land within the entire urbanized area;

R_{tc} = Mean distance of total commercial and industrial area.

$r_5 = \frac{A_{1c}R_{1c}}{A_{tc}R_{tc}}$, in which

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[1]In the estimating equation used in this paper, these items have not been included due to their apparently small effect on the standard error of estimate and the limited amount of available data. Discussion of these items is included under "Discussion of Factors."

A_{1_c} = Area of commercial and industrial land within a 1-mi radius of the CBD center;
R_{1_c} = Mean distance of commercial and industrial land within a 1-mi radius of the CBD center; and

M = Urbanized land area in square miles.

Testing of Estimating Equation

Since developing this estimating equation, complete information has been obtained from additional cities. In applying this equation, estimated results for all have been within the previously stated standard error of estimate (Fig. 3). Among these recently tested cities, there have been several with surveys between 1955 and 1957.

The sample of cities studied is not a random one. The Geary test for normal distribution, however, indicates that the sample of 16 cities can be considered to have a normal distribution. In population, the survey areas have ranged from 48,000 to 3,000,000. All sections of the United States except the Southeast and New England are represented. Although some information has been received from the Chicago origin-destination survey, it is insufficient to include in the test. Unfortunately, of all the cities in which a survey has been made since 1948, Chicago is the only one having rapid transit.

DISCUSSION OF FACTORS

In this estimating equation, the three compound variables have been developed through testing each (and variations thereof) over a range that would determine the maximum effect of each in correlation with other potential variables. As more information is obtained from the present 22 and additional cities, and as this information is examined through an electronic computer program, it is anticipated that more precise parameters will be established.

Economic Factor, E

Apparently there is a high degree of correlation between relative use of each transportation mode and some economic factor. Many contend that this factor is either income or wealth. But what income or wealth? Is it gross or net? What should be included and what deducted? Moreover, how could accurate measurements of these income or wealth items be made? Correlating travel mode use and related O-D information with sufficiently accurate income and wealth data will be most difficult under present legal restrictions.

There may be other economic items that have a higher degree of correlation with mode use than the ones used in this study. The items investigated in this study seem to be the best available that can be accurately measured with the simple linear correlation coefficient between this and relative mode use varying from 0.40 to 0.60.

The use of both population and dwelling units in relation to automobiles owned and employees going to work per average weekday may be challenged. The correlation obtained by use of these in combination has been greater than when only one has been used. This may be due to compensating errors in the O-D surveys studied, and to the effect of differences in population per dwelling unit.

Transit-Service Ratio Factor, T

There is a significant degree of correlation between the developed transit service item and the dependent transit use variable. The two variables are not, however, perfectly correlated. The simple linear correlation coefficient for this item and relative transit use has ranged from 0.30 to 0.45. The degree of correlation varies not only from city to city, but also within many cities there is likely to be an even greater variation among subdivisions (sectors, districts, etc.) or transportation channels. Furthermore, the effect of each of this factor's components apparently varies among cities and their subdivisions.

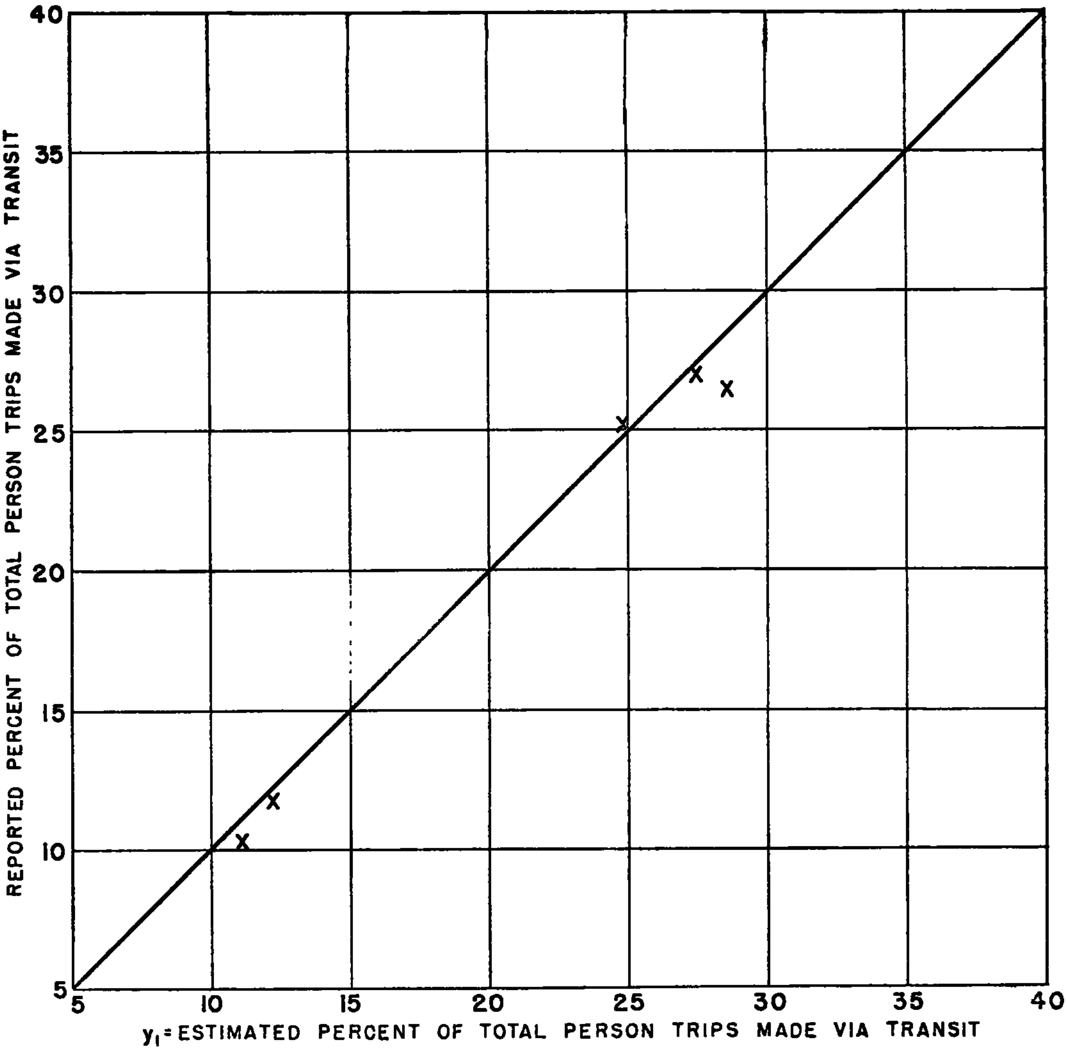

Figure 3. Relationship of reported relative transit use to estimated relative use in cities tested since deriving the equation in Figure 2.

The ratio of the square roots of the speeds of transit and of automobile vehicle travel is one of the components in this factor. There are few who do not consider this ratio as an influencing item. Nevertheless, based on the data available, the standard error is increased by only 0.1 when the speed ratio item is excluded. This would indicate that the variation in this ratio from city to city is not appreciable with respect to the over-all area for each city. Due to the limited amount of data so far available and the apparent relatively small effect on the standard error, this item has not been included in the estimating equation. Using the ratio of the square root of the speed of each mode would, of course, reduce the sensitivity of this item; but the investigation, so far, has borne out that each mode speed should be in proportion to this exponent.

The little work done to date by subdivision of urban areas has pointed to a much greater influence of this speed component for subdivisions and transportation channels. This is due to the greater spread of relative speeds within these subdivisions. It still indicates, however, that the ratio should be based on the square root of the respective speeds.

It is quite possible that additional data may establish that different ratios should be applied to the two principal components of over-all travel time for each mode, namely, vehicle speed and the terminal factor. The effect of these components must be more accurately determined, not only to be able to estimate the use of the two travel modes under specific conditions, but also to develop the required transit, parking, and highway capacity, with attendant capital and operating costs, for the estimated use of each mode.

Equivalent vehicle-revenue-miles operated per weekday are expressed in terms of a 50-seat bus revenue-mile. This includes all vehicle-revenue-miles operated per weekday regardless of the number of passengers carried on each vehicle trip. This item has been derived by applying a carrying capacity factor to the average weekday revenue-vehicle-miles operated during the survey. This factor has been developed through assignment of each vehicle size by time periods in proportion to the ages of the active vehicle groups. Inasmuch as it is impossible to obtain actual average carrying capacity during the survey without a prior uniform arrangement with the transit operators, this derivation gives an arbitrary, but uniform, estimate for all cities that most nearly approaches the actual average.

Land-Use Distribution Factor, U

The land-use distribution factor is a complex one that has been developed from a series of studies with the limitations of available material, time, and computing equipment. Its simple linear correlation coefficient has varied from 0.60 to 0.75. It appears likely that more effecient analysis of present and additional data by means of an electronic computer program will produce either more precise values for those factors now being used or more simple factors that may prove to be more satisfactory. For the entire urban area and for the subdivisions investigated, there appear to be 5 land-use-distribution ratios about the CBD center that should be taken into consideration. These are:

$$r_1 = \frac{1 - R_p}{R_u}$$

$$r_2 = \frac{R_p R_{tc}}{R_u}$$

$$r_3 = \frac{A_{1c}}{A_{tc}}$$

$$r_4 = \frac{A_{tc}}{(A_{tc} R_{tc})} = \frac{1}{R_{tc}}$$

$$r_5 = \frac{(A_{1c} R_{1c})}{(A_{tc} R_{tc})}$$

in which

R_p = Mean distance of center of population from CBD center;

R_u = Mean distance of urbanized area from CBD center;

R_{tc} = Mean distance of commercial and industrial land;

A_{1c} = Area of commercial and industrial land within a 1-mile radius;

A_{tc} = Area of commercial and industrial land within the entire urbanized area; and

R_{1c} = Mean distance of commercial and industrial land within a 1-mile radius.

Mean Distance Derivation. In arriving at the mean distance to the CBD center from the centroid of each of the items used in the land-use ratios, the same procedure has been used for each of these items. Therefore, a detailed description of the derivation of one (commercial and industrial land use) will suffice for all. Each city has been divided into 4 quadrants by rectangular coordinate axes passing through the CBD center. In each quadrant, the area of each industrial and commercial parcel (or each group of adjacent parcels) actually used for one of these purposes at the time of the O-D survey is multiplied by the distance from the CBD center to the centroid of the parcel or group of parcels. These products are then summed for the four quadrants and this summation divided by the summation of the areas of all the industrial and commercial parcels in the urbanized area.

In some instances it has been found more efficient to determine this distance through summing the products obtained by multiplying the areas by their distances to the 2 coordinate axes, and then extracting the square root of the sum of the squares of those 2 product summations.

In the estimating equation in this paper, ratios r_2 and r_3 have not been included in the land-use distribution factor. Studies not concluded indicate that the inclusion of ratios r_2 and r_3 with possible modification of the other ratios would reduce the standard error of estimate.

For the entire urban area, this study has shown that it is not necessary to differentiate between commercial and industrial land. This is apparently due to the balancing effect of the two over a complete urban area. Within highly specialized subdivisions or transportation channels serving predominantly one type of land use, the investigation shows that the two will have to be considered separately. It may even be necessary to subdivide these two classifications into four—industrial, office, shopping durable, and shopping service and convenience. Based on probable accuracy of land-use forecast, the studies make it questionable if a further breakdown can be justified for transportation channel subdivisions (even much less for subdivisions comparable to O-D districts). To justify more classifications of land use would require a much greater specialization of land use in a transportation channel subdivision than has been found or seems probable in the future.

Urbanized Land Area Factor, M

The definition of an urbanized area is of utmost importance in determining the relative use of urban transportation mode. The urbanized area for present studies has been confined to contiguously developed land; future estimates, of course, must be based on anticipated contiguously developed land. Furthermore, to be included such land must have a minimum residential population per area unit—500 per square mile—or a minimum number of total trip ends—2,000 per square mile. Islands of vacant land should be included if the land outside is sufficiently developed to bring the combination of vacant land and adjacent outside developed land up to the minimum. Pockets of vacant land at the boundary not meeting these specifications should be excluded. Even many subdivisions with population or trip ends above the minimum cannot be served by transit without such service costs being partially defrayed by either the subdivision, the entire urban area, or the entire transit system. In border subareas where either the resident population or number of trip ends is less than the minimum, the only mode of urban transportation will be automobile unless transit service is furnished by an intercity carrier, or is almost entirely underwritten on a service charge basis due to relative low transit use. If border land with subminimum population or trip ends is included in an urban area study, the effect of the urbanized area is appreciably changed.

WORK IN PROGRESS

Expansion of Project

Of the factors investigated so far, the three that contribute the most in explaining the variance are those pertaining to: (a) transit-service ratio, (b) land-use distribution, and (c) the economic factor. Some of the factors are still being studied to determine if they should be modified or if they should be replaced by more satisfactory ones. It is possible that the estimating equation may be appreciably changed by these continued studies. However, if the work in the past is a criterion for the future, the estimating equation should not be significantly altered.

In addition to continuing research on the whole metropolitan area, this study is now being expanded in two directions. Generalizing, it can be stated that the developed estimating equation is an expression of the division of trips between transit and automobile in relation to factors pertaining to the home area (employment, automobile ownership, population distribution) and to factors applying to the entire metropolitan area, such as land-use distribution, transit-service ratio, total population, and urbanized land area. Now this equation is being tested to determine if it, or a modification of it, will apply to subdivisions of each metropolitan area. Up to the present, sufficient informaation has been obtained from only three origin-destination survey cities to ivestigate the application within these cities. The results so far indicate that this equation, after modifying the land-use and transit-service ratio factors for the relationship between each home subdivision and the CBD, will probably forecast with acceptable accuracy the split between transit and automobile trips for each subdivision. Two items that apparently have more influence on the mode use within each subdivision than for the whole urban area are (a) the average ratio of over-all trip time by the two transportation modes and (b) the ratio of commercial to industrial land use. Inasmuch as only 20 subdivisions have been investigated, a precise basis for modifying the transit-service ratios and land-use factors has not yet been developed.

The other extension of this project has been to determine the influence of other factors in destination areas on the estimating equation. In this subphase, even less information has been available. A limited amount of information on CBD destination factors has been gathered in several cities, and the relation between these factors and the travel mode split has been tested. Foremost among the items that apparently should be introduced into the equation is a parking facility factor. The equation, modified by this factor, appears to yield a low standard error of estimate in predicting mode split in destination areas. This factor, however, is not confined to total parking supply in each destination area. It also includes accessibility to demand as expressed by a relationship including parking charges and walking and parking time.

Work To Be Done

Much still remains to be done. Only the surface has been scratched in attempting to establish factors and estimating equations pertaining to split by home and destination subdivision. Relationships by subdivision should then be developed for the peak period. Work already is under way on this peak-period relationship for the entire metropolitan area.

From research done so far, it appears that the speed factor varies about as the ratio of the square root of trip speed. Convenience and irritation items, modified somewhat by cost, to the extent that it has been possible to measure them, are apparently as important, if not more so, than absolute vehicle speed. This observation, however, may not hold for freeway and rapid-transit operation. In fact, testing of additional data for vehicle operation on unrestricted rights-of-way may alter the findings in this field. The analysis begun on the Chicago origin-destination survey should yield much information on this phase; however, it is the only origin-destination survey city with both rapid transit and a limited amount of freeway traffic data now available for testing.

Data Needed for Carrying Out Project

To carry out this work, much additional information will be needed. Many cities and transit companies have cooperated. If the needed relationships are to be established, it will be necessary to call on these and other cities for more basic data from time to time. Many of these data should be gathered at the time of the origin-destination survey; in fact, made a part of it. It will take time and money to gather and assemble the information, but it should be to the advantage of both the cities and transit companies to do this.

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