Land Use, Activity and Non-Residential Trip Generation

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THE planning of facilities to serve adequately the transportation needs of a community requires accurate forecasts of the amount of traffic which will be imposed upon these facilities. In recent years an orderly procedure for planning, designing, and evaluating systems of urban transportation has evolved. Often referred to as the urban transportation planning process, this procedure has as a fundamental requirement the estimation of the amount and characteristics of traffic which will be generated by the various uses of land in the community. These estimates must apply not only for conditions which pertain at the time which the traffic, land use, and other surveys are conducted, but also for periods 20 to 25 years or more in the future.

Much of the data upon which travel estimates are based are derived from detailed interviews conducted at a sample of dwelling places in the study area. In contrast to the wealth of data available from home interviews, a very limited amount of trip information is gathered directly at or for non-residential land uses. As a consequence, estimates of non-residential trip attractions are generally based on observed associations between measures of land use or site activities obtained from special surveys or public records and travel information obtained from interviews at the home.

The utility of transportation systems planning rests significantly upon the accuracy and functional validity of these associations. The problem of forecasting future non-residential attractions is particularly nettlesome. While estimates of household characteristics such as income and auto ownership can be used as fairly reliable indicators of future residential trip productions and, perhaps, of overall travel demands in an urban area, no such fundamental and clear-cut relationships between non-residential activities and trip attraction have been established. Thus, only the broadest of statements can presently be made regarding the effects which technological, marketing and other basic changes in the structure of non-residential activities will have upon future trips to non-residential land.

For these reasons, an exploratory study of the concepts and procedures used in recent urban transportation studies to derive non-residential trip attractions was undertaken (1). A large number of study reports as well as technical memoranda and other internal documents of a few of the larger studies were reviewed. In addition, extensive discussions and meetings were conducted with engineers and planners actively engaged in trip generation analysis. The material which follows represents the author's attempt to distill and interpret the wealth of information derived from these discussions and reviews. He alone is responsible for any errors of interpretation or fact.

GENERATION MODELS FOR NON-RESIDENTIAL TRIPS

If one is willing to emphasize (perhaps overemphasize) certain distinctive features, it is possible to identify several major approaches among the wide variety of methods

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used in urban transportation studies to estimate non-residential travel. As a basis for discussion, we have separated trip attraction models into three broad categories: Land-Use Based Models; Activity-Purpose Models; and an assortment of procedures gathered under the rubric of Other Methods. It should be clear from the discussion which follows that these distinctions are based more upon expository convenience than on fundamental differences among the three groups.

Land-Use Based Models

In one way or another, land use forms the basis for almost all current approaches to the estimation of non-residential trip attractions. The primary distinction between land-use based models in this paper and other models lies principally in the nature and extent to which various measures of the intensity of land use are employed and in the relative importance of trip purpose as a measure of use.

The underlying rationale in all transportation planning models is the functional relationship between land use and urban travel. Travel patterns are recognized to be a function of the locational distribution of various kinds of land uses in the urban region. Land-use based models carry this functional relationship one step further by tying the rate at which trips are generated by various land uses to the intensity and type of land use activity. In these models, trip generation is assumed to be related to the kinds, amounts, intensities and locations of a limited set of generalized land-use classes.

In an attempt to determine the general utility of land use as a measure of trip attraction, reports of approximately 150 metropolitan transportation studies were examined to ascertain the degree of comparability among communities in the rates at which trips were generated by various land-use classes. Of these reports, only ten were of such a nature as to permit city-to-city comparisons. The results of this effort, as well as some of the difficulties which were encountered, are summarized in Table 1.

It was desired to present trip-generation rates for as many metropolitan areas and for as many land-use categories within these areas as possible. Furthermore, we wished to present person trips as well as vehicle trips. It is obvious from Table 1 that these objectives were not completely fulfilled. If comparability of trip-generation rates from city to city is a worthy objective, then more highly coordinated efforts towards this goal will be required.

Problems of Summarization. — Each metropolitan area transportation study tends to prefer its own land-use breakdown; in all, trip generation rates were reported for 40 different categories of land use. Definitions of the various land-use categories were very often missing from the reports (although they may be available from the consultants or state highway departments who performed the studies). The consequence of such a conglomeration is a grouping of overlapping land uses whose generation rates are not comparable. For example, the category "public buildings" includes hospitals and schools in the Chicago Transportation Study but does not in the San Diego study. Even if the bases for categorization could be determined, most studies would not have generation rates for each of the smaller categories, and averages for the larger classes would not serve to differentiate among smaller classes.

This dilemma is related to the more general problem of categorizing land uses for purposes of trip generation analysis. Preliminary studies based upon data from the 1956 Chicago study indicate that even in a single urban area, variations in trip rates within generalized land use classes are far too large to permit what is essentially a definitional convenience to be effectively used as a measure of trip generation (1).

A second problem which hinders the comparability of transportation studies with respect to generation rates is the variety of ways in which rates are expressed. For example, trips are reported as person trips or vehicle trips, and often there is no way to convert one into the other. Furthermore, the bases on which generation rates are calculated vary from study to study and often within a given study. For example, trips per acre and trips per 1,000 square feet of floor area are not comparable due to the wide range of building size (and thus floor areas) on any given acre of land, not to mention the fact that even the term "acre" is not the same from study to study—

TABLE 1

SUMMARY OF TRIP GENERATION RATES FOR TEN METROPOLITAN AREAS[a]

Metropolitan Area	Residential		Commercial		Industrial		Pub. & Quasi Pub.		Transportation		Pub. Bldg.		Pub. Open Space	
	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre	Tp/Acre	Tv/Acre
Tucson	18.2	13.0	134.3	112.6	3.9	4.3	14.3	8.8	—	—	—	—	—	—
Twin Cities	26.5	15.2	187.9	118.7	12.6	9.3	17.4	7.5	—	—	60.1	27.5	3.5	1.5
Corpus Christi	30.5	19.7	174.4	127.7	10.6	8.6	35.3	22.0	—	—	—	—	—	—
Pittsburgh	23.9	14.6	157.8	110.6	24.6	21.7	15.9	6.8	21.3	35.0	46.1	18.5	2.3	1.3
Chicago	48.5	26.1	181.4	144.6	22.0	16.0	12.4	6.0	8.6	10.2	52.8	24.2	4.2	3.1
Detroit	29.1	—	271.2	—	37.2	—	16.5	—	—	—	32.8	—	3.4	—
Hutchinson	—	13.3	—	63.3	—	2.5	—	9.8	—	0.9[b]	—	—	—	—
Ann Arbor	—	12.1	—	75.6	—	5.9	—	28.1	—	—	—	—	—	—
Flint	—	11.8	—	16.1[b]	—	20.1	—	1.6[b]	—	—	—	—	—	—
Baltimore	18.7	—	121.4	—	8.2	—	9.4	—	—	—	—	—	—	—
Range	18.2-48.5	11.8-26.1	121.4-271.2	63.3-144.6	3.9-37.2	2.5-21.7	9.4-35.3	6.0-28.1	8.6-21.3	10.2-35.0	32.8-60.1	18.5-27.5	2.3-4.2	1.3-3.1
Ratio, high/low	2.7	2.2	2.2	2.3	9.5	8.7	3.8	4.7	2.5	3.4	1.8	1.5	1.8	2.4

Sources: The Ann Arbor Metropolitan Area Traffic Study (1963), Baltimore Metropolitan Area Transportation Study (1964), Chicago Area Transportation Study (1959-62), Corpus Christi Transportation Study (1961), Report on the Detroit Metropolitan Area Traffic Study (1955), The Flint Metropolitan Area Traffic Study (1959), Hutchinson [Kansas] Transportation Study (1962), Pittsburgh Area Transportation Study (1961), Tucson Area Transportation Study (1960), Twin Cities Area Transportation Study (1962).

[a]Tp = person trips; Tv = vehicle trips.

[b]Not used in computation of range or ratio.

some using gross acre and some net acre as their base. Even the trip itself is defined differently for different studies. A trip may be a one-way or a two-way journey; it may involve several modes of transportation or only one. Some studies include trucks in their vehicle calculations, and others consider them separately. Still others weight truck trips and add them to auto trips on the basis that the larger vehicles cause a proportionately larger capacity requirement on the future road system. The difficulties involved in comparison of rates calculated on varying definitional bases are obvious.

Finally, and perhaps most important as far as prediction of future trips is concerned, there is the inevitability of change. All present rates are not fixed and immutable. Rather, they are based on a certain structure of land uses and land-use competition which is constantly changing. Agglomeration, competition, and new transportation all affect the generation of a given attractor. For example, the gathering of stores into shopping centers as opposed to dispersed locations seems to be producing fewer trips per store due to exclusion of walking trips in the analysis. No models to our knowledge have been constructed to account for this, and certainly it is impossible to depict such an occurrence as a constant generation rate. The rates reported in the various studies represent only one point in time, and since none of the studies were performed concurrently, that point is different for each study.

Floor Area as a Measure of Trip Attraction.—As an alternative to gross acreage, a number of studies have attempted to express trip attractions in terms of the number of square feet of floor space devoted to various land uses. A sought-for advantage in this approach is that floor area provides a measure of the intensity of use. For example, an acre of outlying single-story office buildings would be expected to generate far fewer trips than an acre of multi-story office buildings in the central area. The number of trips per square foot of floor area would be much more comparable in the two instances.

Despite its obvious appeal, floor area has not been used extensively, mainly because of the difficulty and expense of obtaining measures of floor area. Limited tests of the utility of floor area as an estimator of trip attraction have generally been inconclusive. In one such study, the relative effectiveness of floor area, land area, and employment (as determined from first work trips) was measured for approximately 40 non-CBD districts in the Chicago area. In each case, rate of generation was related to net residential density in each district. The following conclusions were made:

> No one of the three types of trip rates appears to be consistently superior. As measured by the variation coefficients, land area rates are best for two land uses, floor area rates for one, and first work trip rates for two. In three cases the land area rate has the highest correlation; in two cases, the floor area rate. (2).

Land-Use Activity—Trip Purpose Models

In the discussion of land-use based models it was stated that the primary distinction between the land-use and activity based models rests mainly on the nature and extent to which various indicators of the intensity of land use are employed, and in the role which trip purpose plays in the model. In evaluating the relative applicability of either of these two models, cognizance must be taken of the characteristics of the trip distribution model to be used in the analysis. For example, the opportunity model used in the CATS study required the separation of trips into three categories: (a) short trips; (b) home-based long trips; and (c) non-home-based long trips. The trip generation model used in the CATS study provided the basis for differentiating trips into these three groups.

In contrast to the CATS opportunity model, most gravity distribution models require separation of trips into three to six trip purpose categories depending upon the size of the study area and the degree of detail desired. In these cases, a trip generation model which provides generation by trip purpose is called for. Once trip making is differentiated on a trip purpose basis, relatively less reliance is placed upon land use per se as the basis for trip generation and more use is made of employment, retail sales and other measures of land-use activity which are more directly related to trip purpose. It should not be assumed, however, that the particular distribution model selected is the only basis upon which to choose a generation model or that the land-use and activity-purpose generation models represent pure forms of completely different approaches to estimating trip generation. The distribution model is only one factor in the selection of generation models, and the two generation models referred to here (in fact, all generation models in common use) represent different emphases, not essentially different bases, for trip generation. It should also be understood that there is a strong and logical relationship between the proportion of trips made for different purposes and the proportion of trips made to different land-use types.

Table 2 summarizes the land-use activity factors employed in estimating trip generation by several purposes for cities ranging in size from 55,000 to 2,900,000. The number of trip purposes used in these studies ranges from three to six (including commercial vehicle trips as a separate category) with the more elaborate models generally being limited to the larger studies. The various factors used to estimate trip attractions for the several purposes are shown in abbreviated form (Table 2).

Grouping of Trip Purposes. — Data obtained from the standard BPR-type of home interview survey permit identification of all sampled trips according to the purpose of each trip at both the origin and destination ends. Given these data, trip purpose types are then generally combined on the basis of the similarity of the land use at the non-home end and the trip length characteristic evidenced by each trip type (this method of grouping is similar to the CATS opportunity model grouping on the basis of "1" values). In most instances, an initial split is made between home-based trips, that is, trips with either origin or destination at home, and trips which are non-home-based. The following indicates the grouping of trip purposes used in the 1964 Fort Worth study (3).

TABLE 2

FACTORS USED TO ESTIMATE TRIP ATTRACTIONS

Study	Trip Purpose Category						
	Home-Based					Non-Home Based	Trucks
Year-Pop.	Work	Shop	Soc.-Rec.	Other	Special		
Washington, D.C. 1963-2,900,000	E	S_R	S_R, DU	E, S_R, DU	[1]A_{SC}, DU	E, S_RDU	
New Orleans	NRD, DU, S_R	NRD, DU, C	DU, P, C	[2]C, E	[3]NRD, P/C, S_R	NRD, DU, C	DU, D, E
1960-645,000	E, A_C, I, DRD	S_R, DRD	P_5, S_R	DRD	E, I, H, DRD	S_R, E, A_C, SC	A_C, SC
Kansas City, Kan.-Mo. 1959-643,000	[4]E, D	[4]S_R, D	[5]P, DU		[5,6]P	[5]D	
Ft. Worth, Tex.	E	[7,8]E_C		P, E_C		P, E_C	P, E_C
1964-540,000				E_M, E_O		E_M, E_O	E_M, E_O
Charleston, W. Va.	[9]E, E_V	E_R, S_C, S_P		[9]S_V, E_V, DU	[10]SC_V	[9]E, E_V, SC_V	[9]E_V, T
1965-250,000				A_R, SC_V, I		S_C, DU, A_R, I	S_V, I
Nashville, Tenn. 1961-250,000	[11]E, E_W, E_B	[11]A_C, D	[11,12]P, I	[13]A_C	[14]SC, I	A_C, D	
Chattanooga, Tenn. 1962-240,000	E	[15]A_C	[15,16]P, I	[15,17]A_C	[15,18]SC, I	A_C	
Waterbury, Conn.	E	E_R		P, E_C		P, E_C	P, E_C
1963-190,000				E_M, E_O		E_M, E_O	E_M, E_O
Erie, Pa.	E	[19]E_R	P, E_R, E_O			P, E_R	[20]P, E_R
1963-140,000						E_M, E_O	E_M, E_O
Greensboro, N.C.	E	E_R		P, E_C		P, E_C	P, E_C
1964-130,000				E_M, E_O		E_M, E_O	E_M, E_O
Fargo, N.D.	E, E_R	[21]P, E_R, E_O		P, DU	[22]DU, E_R, E_O	DU, E, E_R	C, E, E_R
1965-70,000				C, E			
Appleton, Wis.	[23]E, D			[23]DU, A_{PU}, A_I		D, E, A_C	DU, E
1965-55,000	A_{PU}, A_I			A_C, E		A_I, A_{PU}, DU	A_C, A_I

Comments

[1]School trips
[2]Personal business
[3]School trips
[4]Different procedures used for stable and unstable zones
[5]Different procedures used depending on type of zone
[6]School trips
[7]Includes related business, eat, and convenience and shopping goods
[8]Gross sales and floor area suggested as possible alternatives
[9]Different factors used to estimate AM and PM peaks
[10]School trips
[11]Different procedures used for stable and unstable zones
[12]Recreation trips computed by uniform factor expansion
[13]Business trips
[14]School trips
[15]Different procedures used for stable and unstable zones
[16]Recreation trips distributed in proportion to surveyed recreation trips.
[17]Business trips
[18]School trips
[19]Special adjustments made for shopping centers
[20]Special adjustments made for areas adjacent to major railroads
[21]Retail employment alone used for CBD and outlying areas
[22]Personal business trips
[23]Different factors used to estimate origins and destinations

Key to Entries

Employment: E = Total employment; E_R = Retail employment; E_M = Manufacturing employment; E_C = Commercial employment; E_O = Employment other than retail and manufacturing; E_W = White collar employment; E_B = Blue collar employment; E_V = Various specialized employment.

Sales: S_R = Retail sales; S_C = Convenience goods retail sales; S_P = Personal service sales; S_V = Retail sales by various specialized categories.

Area: A_{PU} = Acres of public and semipublic land; A_I = Acres of industrial land; A_C = Acres of commercial land; A_R = Acres of residential land; A_{SC} = Acres of school land.

School Enrollment: SC = Total school enrollment; SC_V = School enrollment by various grade levels.

Household Characteristics: P = Population; P_5 = Persons five years of age or older; H = Persons per dwelling unit; DU = Number of dwelling units; NRD = Persons per net residential acre; DRD = Dwelling units per net residential acre; I = Income; C = Number of automobiles.

Miscellaneous: D = Distance from CBD; T = Truck ownership.

General Purpose (Used in Distribution Model)		Specific Purpose (From O-D Study)	
Home-Based Work Trips	Home to -	Work	- to Home
Home-Based Commercial Trips	Home to -	Related Business Eat Meal Shop (Convenience Goods) Shop (Shopping Goods)	- to Home
Home-Based Other Trips	Home to -	Personal Medical and Dental Education Civic and Religious Recreation Other	- to Home
Non-Home-Based Trips	All trips with neither origin nor destination at the home.		
Truck Trips	All truck trips.		

The specific number of general purpose categories used in the analysis will depend on the size and type of community being studied, the size of the home interview sample, budget, and other factors. Considering their distinct characteristics, home-based work, home-based non-work, and non-home-based trips should probably be analyzed separately in all but perhaps the very smallest communities.

Trip Attraction Factors. —The selection of trip attraction factors appears to be based on three broad criteria:

1. Logical relationship between a given variable, either singly or in combination with other variables, and attraction of trips for the particular purpose or purposes being considered;
2. The degree of association evidenced through statistical analysis of a given variable, either singly or in combination with other variables, with attraction of trips for the particular purpose or purposes being considered;
3. The availability, accuracy and expense of obtaining data regarding a given variable for both the study year and for the design year.

Generally, it is not possible to satisfy completely all three requirements simultaneously, and some compromise is necessary. Data availability appears to be the controlling factor in the selection of generation variables, with statistical association being used to select among the set of available data types.

Recent studies have relied heavily upon employment in different categories as a basis for estimation of trip attractions to non-residential land (Table 2). Zonal population is also used as an estimator of trip attractions as evidenced in the following equations from the 1964 Erie study (4).

Zonal Trips by Purpose	Zonal Estimates of Relative Attractiveness
Work trips	Total employment
Shop trips	Retail employment
Social-recreational trips	Population + 2.2 (retail emp. + other emp.)
Other home-based-trips	Population + 2.6 (retail emp. + other emp.)
Non-home-based trips	Population + 7.1 (retail emp. + other emp.) + 0.9 (manufacturing emp.)
Truck trips	Population + 2.4 (retail emp. + other emp.) + 1.5 (manufacturing emp.)

These data are shown as an indication of the various factors which may be used to estimate trip attractions to non-residential land. The exact form of the equation and the coefficients used will vary from study to study.

Other Methods

The land-use and activity purpose models previously described are representative of the basic approach taken by almost all current transportation studies to the estimation of non-residential trip attraction. There are, however, a number of significant variations to these basic models, both conceptual and computational, which warrant review in their own right.

Step-Wise Multiple Regression Analysis. —The advent of large capacity, high-speed computers has made feasible the application of a number of sophisticated statistical techniques to the analysis of wide varieties of factors potentially related to trip attraction. Of most direct use is multiple regression analysis, particularly a current variation which automatically reviews each potential factor, selects those which are most closely associated with trip attraction, and computes an estimating equation relating trips to the selected independent variables. The computer is programmed to proceed step-by-step through the several variables, determining the degree of correlation of each variable with trip attraction while accounting for the interrelated effects of all other variables which were reviewed previously. Variables are permitted to enter and remain in the regression only if they contribute beyond a preselected level of significance to the explanatory power of the equation.

The number of variables used and the complexity of the estimating equations which are derived are practically unlimited, since powers and combinations of variables can be handled in the analysis. However, it is generally found that a relatively few variables are most useful in any given equation, with little or no increase in accuracy being obtained through the introduction of additional variables.

Sample equations from two recent transportation studies will illustrate the nature of the regression equations developed by the step-wise program.

In the first example, 27 independent variables were reviewed in the development of peak hour generation equations for 332 zones in the city of Charleston and Kanawha County, W. Va. (5). The following equation for home-based social, recreational and miscellaneous trips is a somewhat extreme example of the relationships which were derived. (A particularly complex equation has been selected in order to illustrate clearly the point in question.)

$$Y = 0.5 + 1.173\sqrt{S_P} + 12.175\sqrt{E_R} + 0.031\,A_S + 0.050\,A_E$$
$$+ 0.811\sqrt{S_S} + 1.662\sqrt{A_C} + 0.011\,S_C m + 0.232\sqrt{ID/10}$$

where for each zone

Y = Total P.M. peak home-based school, visiting, social, religious, recreational and miscellaneous trip attractions.

S_P = Dollar volume of personal service sales.

E_R = Number of employees in recreation.

A_S = Senior high school attendance.

A_E = Elementary school attendance.

S_S = Dollar volume of shopping goods retail sales.

A_C = Attendance at colleges, adult education programs and business schools.

S_C = Dollar volume of convenience goods retail sales.

ID = Total income.

Presumably the order in which the variables appear in the equation is representative of their relative association with Y. The multiple coefficient of determination (R^2) is 0.78, and the standard error of estimate as a percent of the mean, $(S_Y / \bar{Y}) \times 100$ percent, is 78 percent.

In a recent study for the Fargo metropolitan area, the following equation for home-based miscellaneous trip attractions was developed (6).

$$Y = 47.19883 + 2.00901\ DU - 0.30248\ C - 0.30790\ P + 0.44575\ E$$

where for each zone

- Y = total home-based auto driver trip attractions for purposes other than work, shop, and personal business;
- DU = dwelling units;
- C = cars;
- P = population; and
- E = total employment.

The multiple coefficient of determination is 0.531, and the standard error of estimate is 104.3 percent of the mean.

The major strengths and weaknesses of the step-wise multiple regression technique are indicated by these examples. The procedure permits an objective and efficient review of a large number of variables, and the incorporation of those which are most highly correlated with trip attraction into an estimating equation. These features, when properly used, represent the primary advantages of the multiple regression approach. However, when misused, these same features can lead to apparently precise, but misleading or even meaningless equations of relationship.

This caveat applies to all regression analysis, but most strongly to its use in the formulation of complex, multiple factor equations, particularly where the computer is interposed between the researcher and the raw data. In these instances it is essential that careful attention be paid to the reasonableness and theoretical validity of the equations and to the extent to which the several variables in the equation are subject to prediction for application of the equation to the design year.

Further, the researcher should not rely solely upon F ratios and the coefficient of determination as measures of the statistical validity of derived relationships. It is entirely possible (and is often the case) that the statistical significance of several of the regression coefficients may be very low, although the coefficient of multiple determination is beguilingly high. Computation and reporting of standard errors of the regression coefficients is essential to guard against unwarranted reliance on essentially uncertain relationships. The rounding off of equation parameters to two or three significant figures to be more in keeping with the quality of the input data would also serve to avoid the appearance of excessively precise regression equations.

Analogy Expansions.—In direct contrast to regression analyses which attempt to isolate the contributory effects of a relatively large number of explanatory variables to trip generation, the analogy technique is based upon a much more pragmatic and expedient view of the world. Essentially, this procedure uses observed trip rates which reflect all causative factors without seeking to identify them. Separate rates by trip purpose are computed for each traffic zone on the basis of survey data. If little change is anticipated in zonal activity during the projection period, the observed rates for that zone are used for the design year. If significant changes in any use are forecasted, land use or activity factors are employed to estimate trip attractions. An example of the analogy technique as applied to work and shopping trips in the Nashville transportation study is as follows (7):

Work Trips

$$T_W^{1980} = T_W^{1959} \times \frac{E^{1980}}{E^{1959}} \quad \text{(for zones where } E^{1959} \geq 100)$$

$$T_W^{1980} = 1.53\ E_{WC}^{1980} + 1.73\ E_{BC}^{1980} \quad \text{(for zones where } E^{1959} < 100)$$

Shopping Trips

$$T_S^{1980} = T_S^{1959} \times \frac{A_C^{1980}}{A_C^{1959}} \quad \text{(for "stable" zones)}$$

$$\left.\begin{array}{l} T_{SG}^{1980} = 6.3 \times A_C^{1980} \\ T_{SC}^{1980} = f\ (\text{CBD Distance}) \end{array}\right\} \text{(for zones with "considerable new commercial development")}$$

where for each zone

T_W = home-based work trip attractions;
T_S = home-based shopping trip attractions;
T_{SG} = home-based shopping goods trip attractions;
T_{SC} = home-based convenience goods trip attractions;
E = total number of employees;
E_{WC} = white collar employees;
E_{BC} = blue collar employees; and
A_C = acreage of commercial land.

The strengths and weaknesses of the analogy technique are, perhaps, best expressed in the words of F.H. Wynn, one of its most astute proponents:

> This is an expedient, and should be recognized as such, while constant effort is made to get at the underlying reasons [for trip generation]. Nevertheless, this approach will produce good short-term results—much better than many of the most sophisticated formulae. (8).

Competitive Models.—The use of competitive distribution models of the gravity type leads naturally to the introduction of interzonal competition into estimates of trip attraction. Rather than estimate the number of trips of a given type attracted to a zone, the model uses indices of attraction which apportion to each zone the total number of trips of that type which were derived from estimates of household trip production. Such a model would appear to be most suited for estimating strongly competitive trips, such as shopping goods trips, but its greatest use has been for estimating miscellaneous trips for which no single set of measures of attraction is available. Table 3 illustrates the set of attraction indices derived for the Fort Worth study (9).

The indices in Table 3 are weights which assign to each land-use factor its relative importance in the trip attraction model. Consider the "Other Home-Based" trip purpose category, for example:

Let

Y_i = the "basic attractiveness" of zone i for other home-based trips relative to all other zones—basic attractiveness is used here to designate the attractiveness of zone i without regard to its location or accessibility relative to all other zones;

TABLE 3

TRIP ATTRACTION INDICES

Land Use Factor at Zone of Attraction	Trip Purpose		
	Other Home-Based	Non-Homed-Based	Trucks
Population	0.115	0.013	0.002
Commercial employment	0.048	0.290	0.246
Industrial employment	0.025	0.080	0.088
Other employment	0.150	0.100	0.009

P_i = population in zone i.

C_i = commercial employment in zone i.

I_i = industrial employment in zone i.

O_i = other employment in zone i.

Then

$$Y_i = 0.115 (P_i) + 0.048 (C_i) + 0.025 (I_i) + 0.150 (O_i).$$

The Yi's are then combined with appropriate friction factors to distribute the total number of other home-based trips among the various zones by means of the gravity model.

Extensive use was made of the relative attractiveness concept by the Southeast Connecticut Area Transportation Study (SEATS) in developing attraction indices for all purposes but home-based work (10). The procedure may be described as follows. For each of eight non-residential land uses (industrial, personal service, business service, institutional, recreational, commercial amusements, retail, other) a single variable, employment in that particular use, was assumed to represent the level of activity. Thus, for example, in any zone, industrial employment was taken as the measure of industrial activity in that zone, retail employment as the measure of retail activity, etc. This measure is called the destination zone factor. The frequency of trips to the various land uses was then grouped into three classes, home-based long, home-based short and non-home-based. Trip type factors for each class of trips to each land use activity were then computed as the ratio of the total number of trips of a given class to a given land use divided by the total employment in that activity. The final step was to develop an attraction index for each zone for each class of trip as a function of the trip type factors and the destination zone factors.

The procedure is shown in more detail for a single class of trip in the following.

Let

k designate a particular land use activity, k = 1, . . ., 8,

and

i designate a particular zone, i = 1, . . . , 100.

A_{ki} = destination zone factor for k^{th} land use activity in i^{th} zone. For example, the amount of industrial employment in zone 5.

L_k = total number of long trips to k^{th} land use in all zones.

F_{Lk} = trip type factor for k^{th} land use, where

$$F_{Lk} = \frac{L_k}{\sum_{i=1}^{100} A_{ki}}$$

I_{Li} = attraction index for long trips to zone i, where

$$I_{Li} = \sum_{k=1}^{8} F_{Lk} A_{ki}$$

The attraction index so computed is used to distribute home-based long trips among the various zones. A basic assumption in the model is that a single rate of attractiveness for a given trip purpose exists for all zones.

The relative attractiveness of each traffic zone may also be related directly to system variables of several types. Two such variables, a transit service index and an accessibility index, were used in estimating trip attraction by mode in the Baltimore study (11). The transit service index for a given zone is related to the frequency of transit service to that zone. The accessibility index for a given zone is a function of the reciprocal of highway travel times from that zone to all other zones.

An example of the use of these indices for estimating trips by all modes to CBD and non-CBD zones follows (derived by step-wise regression technique).

$$T_C = 222.856 + 0.354\ TSI + 2.346\ HS + 1.969\ TE + 3.684\ RE$$

$$T_N = 3,300.635 + 1.394\ PS + 1.255\ HS + 4.426\ CS + 1.616\ E + 8.051\ RE - 367.120\ AI$$

where

T_C = CBD trip attractions, all modes;
T_N = non-CBD trip attractions, all modes;
TSI = transit service index;
AI = accessibility index;
PS = primary school students;
HS = high school students;
CS = college students;
TE = total employment; and
RE = retail employment.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations must be evaluated within the full context of the restrictions of this study. Based as they are upon a limited review of essentially secondary sources, these recommendations should be treated as hypotheses to be tested, rather than as prescriptions or standards to be followed.

Role of Land Use in Trip Generation

Land use plays a pervasive and often ambiguous role in trip generation analysis. It can never be ignored as an element in traffic and transportation planning, yet its uncritical use may often obscure rather than reveal functional relationships between patterns of travel and urban activity. In the language of the mathematician, land use is necessary—but not sufficient.

As in most cases of this type, the problem is essentially one of definition—both of terms and of objectives. The results of our limited analyses, as well as the experience of almost all transportation studies, give ample evidence that, with few exceptions, generalized land use by itself is usually inadequate as a basis for estimating trip attraction. As we begin to subdivide these very broad categories into groups that are more identifiable with the nature of the activities which are performed in each group, a more rational and useful basis for trip estimation is created. It is not only that the major categories of land use are too general and include too many unrelated uses, but it is also that these broad designations are too far removed from the activities which take place upon them and which are the reasons for which trips to a given use are made. As finer groupings of land use are made, we move closer and closer to an identity with specific activity designations and farther away from the traditional concept of "land use." (Since our ability to predict the future location and level of land use activities tends to diminish rapidly as the detail of classification increases, there is an upper limit to the degree of detail which can be usefully employed.) Thus, the problem of definition of terms.

The problems of definition of objectives arise chiefly out of the extremely complex nature of the transportation planning process and its interrelation with land use planning and regulation. Trip generation is only one aspect of transportation planning. To be useful, it must relate on one hand with urban growth models or more traditional techniques of land-use projection, and on the other with the relatively precise demands of current techniques of trip distribution and traffic assignment. Standing, as it does, between land use and transportation planning, trip generation analysis has suffered with respect to each in trying to meet the requirements of the other. The recent collaboration of the Urban Renewal Administration and the Bureau of Public Roads in developing a multi-dimensional system of land-use coding based upon activities compatible with the Standard Industrial Classification should be of material help in resolving this dilemma (12).

Viewed from the perspective of transportation planning, land use must be considered essentially as a means for understanding travel characteristics, not as a device for estimating or forecasting trip attraction rates. This is not to say that land use, particularly as defined on the basis of travel-rated activities, can or should be completely laid aside in favor of more direct activity measures such as employment or retail sales. After all, urban travel is spatially as well as activity oriented, and the definition and physical location of activities on the land is essential for the planning of transportation systems and facilities. Clearly, the future distribution of spatially separated but functionally related activities will create the trips for which these facilities are to be built.

Without attempting to specify the exact form which land-use specification and classification should take in order to be useful for trip generation analysis, the following general principles have been suggested (13):

1. Land-use classes should relate to the purposes for which trips are made. More specifically, (a) activities which produce significantly different proportions of work trips, non-work trips, and non-home-based trips should be classified separately; (b) activities which produce significantly different proportions of trips by mode should be kept distinct; (c) activities which produce relatively large proportions of goods trips should be classified separately from those that produce predominantly person trips.
2. Land-use classes should be understandable to household survey respondents.
3. Land-use classes should be relatable to land-use models and economic theory.

Variables Used in Generation Analysis

Whatever the classification of land uses employed as a basis for interpreting and projecting travel at the spatial level, current practice tends to favor activity measures rather than area or space measures as a basis for analyzing and forecasting trip attraction. Measures of activity should be selected which have as many of the following characteristics as possible:

1. They should be functionally related to the purpose or purposes for which trips to a designated land use class are made. For example, employment is the primary (but not necessarily the only) factor attracting trips to industrial land, while school enrollment is the principal agent in the generation of trips to schools. Table 2 lists a number of activity measures which have been used in recent studies to estimate trips for various purposes.
2. They should be as directly and universally descriptive of the conditions in which the activity operates as is possible, so that relationships established in one community can be readily translated to other communities. For example, density would be preferable to distance from CBD as a predictive variable.
3. They should be subject to prediction or projection within the desired planning horizon. This applies not only to the location and level of the variable, but also to the relationship between it and trip generation. In this regard, employment in various major categories appears to be a particularly desirable measure since it forms an integral part of economic and regional growth models as well as being sensitive in a relatively predictable manner to the effects of automation and other technological and social changes.
4. They should be sensitive to the competition for trips among similar or related land uses. Retail sales, as a measure of the level of competitive activity of various commercial areas, would seem to satisfy this requirement best.
5. They should show a strong and direct statistical association with trip making. Logic and experience should not be disregarded, however, in the search for good statistical fits. Overly complex multi-dimensional, multi-factor equations are rarely justified, considering the lack of underlying theory and the questionable accuracy of some of the input data.
6. The complexity and degree of refinement of the measures used should be in keeping with the intensity of trip attraction to a particular land use and the relative importance of these trips in the total daily travel pattern. The analysis of work trips, for example, would warrant the development and use of highly specific measures of employment. In contrast, estimation of trips to parks and other urban open space might better be based upon gross acres or other fairly simple measures.
7. They should be relatively inexpensive to obtain in a uniform manner for the entire study area. Data which are collected, analyzed, and forecasted by other agencies as a regular part of their activities can be particularly valuable in this regard. Net or gross acres, broad categories of employment, school enrollment, and sales tax receipts are examples of measures which often meet these requirements. Floor space, particularly outside the central area, is, perhaps, the one single measure of trip-related activity which is generally not obtainable within these constraints.

Clearly, a number of the above requirements tend to be mutually exclusive, and it is unlikely that any single variable or set of variables will satisfy all of these conditions. The exact nature of the compromises with reality that will have to be made will depend strongly on the circumstances relevant to each study and the experience of those who are responsible for obtaining, analyzing, and using the data.

Methodological Approach

We have found a wide variety of approaches used in the determination and forecasting of trip attractions to non-residential land. There is no one best way, although any particular technique can be made better by careful attention to the primary objectives of the analysis and to the basic principles of sound engineering practice. In this respect, the following points appear to be particularly relevant:

1. Trip generation is a manifestation of human activity. A high degree of variability is to be expected, particularly in those activities (such as recreation, social interaction, and shopping) which generally lie outside of formal social or economic systems.

2. Most, if not all, of the basic data used in trip generation analysis are subject to a greater or lesser degree of error. At best, such errors add to the variability of generation forecasts. More often they may lead to biased and unreliable forecasts.

3. A clear distinction must be made between trip generation analysis for systems planning on one hand and for traffic planning or project design on the other. The collection and forecasting of data for trip generation analysis within the context of urban transportation studies is directed toward the planning of areawide transportation systems. Estimates of trip attractions to particular generators or sites is not feasible from these data. Not only is the variability in generic estimates ordinarily far too great to permit meaningful application to a single generator, but also the precise location of a large generator will usually be of overwhelming importance with respect to the impact upon any given facility. Analysis at this scale requires data and knowledge not commonly available or needed at the systems planning level.

4. Estimates of generation using one source of data or one analytical technique should be cross-checked against as many other sources as budget and time permit. Of particular importance in this regard is the establishment of control totals and subtotals from household trip production and other independent sources.

5. Given the present state of the art, relatively simple methods which derive from a synthesis of logic and experience may often yield better results than complex, mechanistic analyses, particularly where data are poor or where change in the zone of analysis is expected to be slight. In any event, estimates obtained through statistical abstractions such as regression equations should be carefully checked for reasonableness against perhaps less precise, but more stable models.

6. Statistical analysis should be used as an aid in testing hypotheses and specifying numerical values for generation models based upon rational or logical relationships, and not as an end in itself. Regression models should be based more on the criteria of simplicity and validity and less on attempts to wring the last degree of variance from the data. Regression coefficients should be expressed to as many significant figures as are warranted by the precision of the source data and no more. Coefficients carried out to the fifth decimal place lend an air of precision to the equations of relationship which is unwarranted and may be misleading.

Further Study

In an exploratory study such as this, each finding raises its own host of new questions. Within our limited means of time, money and knowledge, we have tried to answer some of these questions, but most have had to be set aside as fit topics for future research. In selecting among the many topics for which understanding is presently lacking, we have tried to view trip generation in the general context of transportation planning. Those questions which appear to us to be most germane in this regard are considered in the following:

1. Although most workers in this field would agree that the precision with which we can estimate trip attractions to many types of non-residential land uses is too low, we have no objective measures of what an acceptable level of precision would be. There is an urgent need throughout the urban transportation planning process for measures of the sensitivity of one stage of the process to errors transmitted to it from other stages. Not only are measures of this type unavailable, but the methodology by which they might be obtained has not been formulated. With specific regard to trip generation, research should be initiated to determine: (a) the probable effects which errors in the forecasting of various types of trip ends have upon the nature and volumes of trips derived from models of trip distribution and assignment; and (b) the probable errors in forecasting the independent variables used in trip generation equations and the effects which such errors have upon forecasted trip ends.

2. Many of the land-use classification systems in current use were not derived with the needs of generation analysis and other phases of transportation planning in mind. Sets of land-use groupings based upon the highly flexible multi-dimensioned activity coding system developed by the Urban Renewal Administration and the Bureau of Public Roads should be derived and tested for applicability in the analyzing and forecasting of urban travel generation and trip structure.

3. Linkages between land uses should be more deeply explored, particularly those that occur on multipurpose trips and daily trip sets. The effect of walking trips, especially in the CBD, needs careful study. Also of importance in this regard is the effect of separation and contiguity of activities upon trip attractions and trip length characteristics.

4. The volume and nature of goods movements generated by commercial and industrial uses should be given more attention than they are at present.

5. A comparative analysis of existing techniques for forecasting non-residential attraction should be undertaken on a continuing basis to provide objective measures of cost and reliability over time. A moderate-sized urban area rather than a very large metropolitan area would appear to be more suitable for such a study.

6. The relative utility of floor space, sales and employment in forecasting trips to commercial land and other high-intensity urban uses, particularly in central areas, should be more fully studied. Consideration should be given to the predictability of the several measures for the design year as well as to their observed association with trip attraction.

7. Improved techniques are needed to estimate traffic impacts of large generators for use in traffic planning and facility design. As it now exists, generation analysis is directed toward the planning of transportation systems and is generally not appropriate for studies of specific sites or facilities. Current work under NCHRP Project 7-1, "The Influence of Land Use on Urban Travel Patterns," which is directed toward improving our capability to estimate the amount of traffic produced by major facilities such as large factories, shopping centers, and airports, is an example of the type of research needed.

8. Studies at selected non-residential sites should be conducted concurrently with home-interview surveys to attempt to establish the nature and extent of errors in estimating trip ends on non-residential land from residential interviews.

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