METHOD FOR PREDICTING THE EFFECT OF LONG-RANGE TRANSPORTATION PLANS ON RESIDENTIAL LAND USE ACTIVITIES

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A long-range predictive model is described for estimating the number of households that would be displaced by planned transportation systems for a metropolitan area. The model consists of 2 linked submodels: a basic model whose output is the number of household units displaced per acre of right-of-way and a right-of-way model whose output is total acres of right-of-way required by the proposed system. The method involved generating, calibrating, and testing several basic models by means of regression analysis and used real-world historical data for 105 sections (later aggregated into 65 sections) of recently constructed freeways. The case study area was classified into 4 categories: central city, suburbs, standard metropolitan statistical area, and urbanized. Each basic model was tested with observations of freeway sections in each category, and the "best" of the basic models was selected for linkage with a right-of-way model. The predictive capability of the household displacement model was tested on 12 miles of recently constructed freeways not included in the calibration of the model. The estimates were found to be within 4 percent of the actual displacements.

•SOCIAL and environmental effects of alternative transportation plans are rapidly becoming important considerations in the planning process. Traditional economic analyses of proposed systems, in terms of construction and right-of-way costs and user costs-benefits, no longer suffice. Increasingly, decisions to select and implement future transportation systems will be based on comprehensive evaluations that include social and environmental effects.

The Metro Guideway System study program of the Transportation and Urban Analysis Department includes a comparative evaluation of a planned freeway and transit system in a case study area and an investigation of a concept of an automated highway (automobile and transit) system. One set of inputs to the evaluation model is the social and environmental impacts of the 2 systems. One of these impacts is the displacement of households.

This paper describes a model developed for the long-range prediction of the number of households that will be displaced by a planned system. The method has application to any transportation system if the design characteristics and forecast data are known for the affected travel zones in each corridor for the time period of expected implementation.

The rest of this paper describes the model developed for predicting household displacement by planned transportation facilities and the procedure followed in developing the model. The method uses a multiple regression technique on historical freeway data

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in testing the stability of resulting relations, in solving for the regression coefficients, and in selecting the key variables and the "best" of 8 basic models generated for predicting the displacement of households.

RATIONALE FOR HOUSEHOLD DISPLACEMENT MODEL

It was postulated that the number of households displaced by a proposed freeway is a function of the location of the freeway, the land requirements of the freeway, and the characteristics of the land use activities on the required land. Briefly, household displacement = f (location, land requirements, development characteristics).

Location

The spatial location of a proposed freeway across the surface of a metropolitan area can help determine the number of households that will be displaced. Because development characteristics vary across a metropolitan area and, quite often, across a community within a metropolitan area, the location of a freeway in relation to the spatial arrangement of land use activities is an important consideration in estimating the displacement impact. The method described here is spatially oriented in that it considers the subareas (zones) of the local communities in the metropolitan area through which the future freeway will run.

Land Requirements

The amount of land required by a freeway is another determinant of household displacement. Because approximately 40 to 50 percent of an urban community's total developed land area is in residential use, generally the greater the amount of land is that an urban freeway requires, the greater the probability is that households will be displaced. The displacement model is concerned with net right-of-way and takes into account existing right-of-way of affected public streets and reservations in each affected zone. Net right-of-way is defined as the total right-of-way required for a freeway less existing right-of-way within the path of the freeway.

Development Characteristics

Development characteristics of an area through which a freeway will be constructed can also play a significant role in determining the number of households that will be displaced. For the displacement model, the 3 determinants selected were extent of urban development, level of residential development in relation to urban development, level of residential development in relation to developed land area and total land area, and density of residential development.

With reference to extent of development, it was reasoned that, the higher the percentage of developed land is that an affected zone contains, the greater the probability is that households will be displaced. Concerning level of residential development, the 2 variables selected were percentage of developed land area in residential use and percentage of total land area in residential use. It was reasoned that, the higher the level of residential development is in a given zone, the greater the probability is of displacement of households. On the other hand, a freeway running through a nonresidential area, such as an agricultural area or a park area, will displace few, if any, households.

With reference to density of residential development, the reasoning was that, the greater the number is of households per unit (acre) of residential land, the greater the probability is of displacing a relatively high number of households. Displacement is higher in and around a central business district where densities may run as high as 30 or more units per acre of land than in the suburb where perhaps 6 units exist on an acre of residential land.

MODEL DEVELOPMENT

The approach to predicting the household (HH) displacement impact of a case study area's freeway program was to obtain historical input data and known impacts of recently constructed freeways, establish relations between independent and dependent variables by means of regression analysis, and apply these relations to forecast data for the independent variables to give an estimate of the number of households that will be displaced by a post-1980 freeway system. The concept is shown in Figure 1. The major steps taken in the development of the forecast model may be outlined as follows:

1. Define the causal factors, input data requirements, and quantitative output measures;
2. Generate several different basic displacement models;
3. Obtain the historical input data for the independent and dependent variables from highway and urban planning agencies;
4. Calibrate the models;
5. Apply the models to observations on selected freeway sections in 4 area types and select the most valid basic model for the area type that provides the most valid results; and
6. Convert the best basic model to the household displacement model to be applied to the forecast data for the affected zones of future freeways.

Estimation of Model Parameters

Eight basic models were postulated, each to be tested with observations in 4 area categories. The models included additive and multiplicative functions and various combinations of independent variables. The model formulations are as follows:

$$Y = K_1 + K_2(A) + K_3(B) + K_4(R) \quad (1)$$

$$Y = K_1 + K_2(A) + K_3(C) + K_4(R) \quad (2)$$

$$Y = K_1 + K_3(B) + K_4(R) \quad (3)$$

$$Y = K_1 + K_3(C) + K_4(R) \quad (4)$$

$$Y = K_1(A)^{K_2}(B)^{K_3}(R)^{K_4} \quad (5)$$

$$Y = K_1(A)^{K_2}(C)^{K_3}(R)^{K_4} \quad (6)$$

$$Y = K_1(B)^{K_3}(R)^{K_4} \quad (7)$$

$$Y = K_1(C)^{K_3}(R)^{K_4} \quad (8)$$

where, for a given zone,

Y = number of households displaced per acre of right-of-way acquired,
A = percentage of developed land,
B = percentage of developed land in residential use,
C = percentage of total land in residential use,
R = net residential density,
K_1 = constant of regression, and
K_2, K_3, K_4 = regression coefficients.

The rationale for the basic models is that the number of households displaced per unit (acre) of freeway right-of-way depends on the state of future conditions in each subarea (zone) through which the freeway will run. These conditions may be described by the following independent variables: developed land, developed land in residential use, total land in residential use, and net residential density.

Model Calibration

The coefficient values of K_1, K_2, K_3, and K_4 were determined by performing regression analysis on historical data on household displacement by sections of freeways recently constructed or under construction for 4 area categories. The necessary data for calibrating the models were obtained from the state highway department and local urban planning documents.

Data for the dependent variable, number of households displaced by 3 selected freeways, and for the independent variable, land required for freeway right-of-way, were obtained from the state highway department. Data for the remaining independent variables were obtained from local land use studies.

Historical data were obtained for 3 freeways. Criteria used in their selection were recent construction, location within the counties of the case study standard metropolitan statistical area (SMSA), diversity of urban area types traversed, representation of the 2 basic freeway corridor types (i.e., radial and circumferential), and availability of suitable data.

Data from the state highway department were available for freeway sections ranging from 0.1 to 1.0 mile in length. Total data points were 105. Short freeway sections in similar urban area categories were aggregated into 1-mile sections, resulting in 65 data points or observations for analysis.

Because area characteristics within the SMSA varied across the metropolitan area, the basic models were tested on observations in each of the 4 area types in a search for the best results. The area types and the number of observations or freeway sections analyzed within each area category were as follows:

Area	Observations
Central city	32
Suburbs	33
SMSA	65
Urbanized	53

Historical data were tabulated for each freeway section for each area type. An example for freeway sections in the central city is given in Table 1. The obtained data were coded and keypunched for the regression analysis. The stepwise multiple regression analysis (STEP) program of the IBM System 360 scientific subroutine package (PL/I) was used for the analysis. This procedure was repeated for each model for each area category.

Calibration Results and Selection of Best Model

A number of the 8 models performed well, and the outputs were analyzed for their validity. Percentage of total land in residential use and net residential density were the 2 most significant independent variables in estimating household displacement per acre of right-of-way.

The results of the model applications to the city and suburb categories differed to the extent that net residential density was more significant in the city than in the suburbs. This may be due to densities generally being more uniform in the suburbs than in central cities where densities may vary from 30 or more household units per acre of land in and around central business districts to 6 or fewer units per acre in the city's fringe areas. Also, observations in the suburb category included some of the rural freeway sections that may have resulted in a biased sample.

A test was made to check this by applying the SMSA equations to the freeway sections in the central city and the suburbs, including the rural sections of the suburbs. The difference was only 5 percent in the case of the central city, but 40 percent in the case of suburbs, perhaps because of the mixture of urban and rural freeway sections in the suburbs.

Rural sections were, therefore, removed from the collection of observations, and a model was developed for the urbanized area only. Again, estimated Y values with the urbanized area equations and the city and suburb equations were compared. The difference was less than 5 percent in both cases.

Among the 8 basic equations, Eqs. 5 and 6 had a high degree of correlation (R^2 = 0.903). However, the t value for variable A was less than 2, indicating the insignificance of this variable. Equations 7 and 8, without variable A, provided satisfactory results ($R^2 = 0.90$). Equation 8 and its application to observations for the urbanized portion of the metropolitan area, however, provided more satisfactory results than Eq. 7 in that its predictive capabilities would be enhanced because it reflects the undeveloped portions of an affected zone where the growth potential exists. Results of the urbanized-area tests are given in Tables 2 and 3.

A chi-square test was also made to further establish the selected goodness of fit of the selected model. The test revealed that the model fits at the 5 percent significance level.

Estimation of Household Displacement

The basic displacement model (Eq. 8) selected is described as follows:

$$Y = (0.61 \times 10^{-2})(C)^{0.85} \times R^{1.53} \tag{9}$$

After the number of households displaced per acre of freeway right-of-way is established by means of the basic model, the procedure then requires that the net right-of-way in acres be ascertained, which, when multiplied with the number of units displaced per acre of right-of-way, will provide an estimate of the total number of units that will be displaced in a given zone. In mathematical notation, we have

$$H = Y \times R_N \tag{10}$$

where, for a given zone,

H = number of household units displaced, and
R_N = net right-of-way, in acres.

For Eq. 10, the value of Y is provided by Eq. 9. To solve for H, however, requires that R_N be calculated. It was established that net right-of-way of a proposed freeway is a function of the length of the freeway, the design right-of-way, the number of interchanges, and the design and existing rights-of-way of each interchange.

It was reasoned that, if the number of displaced households were related to the amount of urban land that would have to be acquired for a freeway and if existing public right-of-way varied from community to community, depending on long-range planning policies, a straightforward measure of the design right-of-way would not suffice. A more realistic measure would be the design right-of-way less existing public right-of-way that would not have to be acquired in each zone. Therefore, Eq. 11 was formulated:

$$R_N = \frac{5{,}280L(R_D - R_E)}{43{,}560} + N_M(a_1) - e_1 + N_m(a_2) - e_2 \tag{11}$$

where, for each given zone,

L = length of freeway section not including interchanges, in miles;
R_D = design right-of-way, in feet;
R_E = existing right-of-way, in feet;
N_M = number of major interchanges;
N_m = number of minor interchanges;
a_1 = average right-of-way required for major interchange, in acres;
a_2 = average right-of-way required for minor interchange, in acres;
e_1 = existing right-of-way for major interchanges, in acres; and
e_2 = existing right-of-way for minor interchanges, in acres.

For case study area 1, the design right-of-way will be 350 ft for the conventional urban freeway and 450 ft for the multimodal urban freeway (e.g., a freeway with a transit system in its median). In addition, the major interchange, defined as an interchange between freeways, will require an average of 65 acres of land. The minor interchange, defined as an interchange between a freeway and a major divided arterial, will require

Figure 1. Model concept.

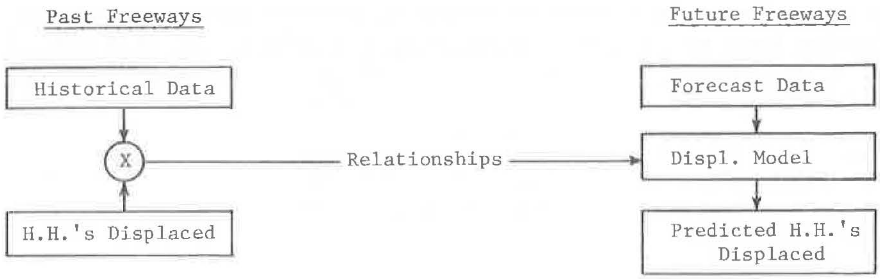

Table 1. Example of data for freeway sections in central city.

Freeway Section	Households Displaced/ Acre of Right-of-Way	Developed Land (percent)	Percentage of Land in Residential Use		Net Residential Density
			Developed	Total	
1	Y_1	A_1	B_1	C_1	R_1
2	Y_2	A_2	B_2	C_2	R_2
.	.	.	.	.	.
.	.	.	.	.	.
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n	Y_{32}	A_{32}	B_{32}	C_{32}	R_{32}

Table 2. Results of application of model to 53 freeway sections in urbanized area.

Model	Regression Coefficients				Multiple Correlation Coefficient	Standard Error of Estimate
	K_1	K_2	K_3	K_4		
1	-10.64413	0.05657	0.08165	0.77643	0.808	2.828
2	-6.35368	-0.00175	0.10601	0.79468	0.832	2.662
3	-8.72528		0.08424	1.06782	0.790	2.914
4	-6.40391		0.10546	0.78705	0.832	2.636
5	0.000287	0.38063	0.97684	1.85187	0.903	0.204
6	0.0258	-0.59621	0.97685	1.85188	0.903	0.204
7	0.000861		0.97600	2.11844	0.900	0.206
8	0.0061		0.85095	1.52849	0.896	0.207

Table 3. T values and β coefficients of regression coefficients.

Model	Item	K_2	K_3	K_4
1	T value	2.022	4.221	4.048
	β coefficient	0.25784	0.35611	0.51629
2	T value	-0.060	5.138	4.397
	β coefficient	-0.00797	0.48657	0.52843
3	T value		4.236	8.186
	β coefficient		0.36745	0.71005
4	T value		5.750	6.217
	β coefficient		0.48408	0.52335
5	T value	1.356	6.706	7.201
	β coefficient	0.12890	0.41117	0.68481
6	T value	-1.889	6.706	7.201
	β coefficient	-0.20191	0.53515	0.68481
7	T value		6.644	12.670
	β coefficient		0.46618	0.78389
8	T value		6.407	7.769
	β coefficient		0.46618	0.56523

Table 4. Actual and estimated households displaced.

Freeway	Actual	Estimated	Ratio
1	641	643	1.003
2	1,112	1,178	1.068
Total	1,753	1,821	1.039

40 acres. (The rights-of-way of various existing interchanges were computed, and the averages were developed for the case study area. The design right-of-way was provided by the state highway department.)

Substituting these values in Eq. 11, we now have

$$R_N = 0.121L(R_D - R_E) + (65N_M - e_1) + (40N_m - e_2) \quad (12)$$

Combining the 2 submodels (Eqs. 9 and 12), we have the following household displacement model:

$$H = [0.61 \times 10^{-2}(C)^{0.85} \times (R)^{1.53}]\,[0.121L(R_D - R_E) + (65N_M - e_1) + (40N_m - e_2)] \quad (13)$$

DISPLACEMENT MODEL TEST

A test of the model's predictive capability was undertaken on 2 recently constructed or about-to-be constructed freeways whose actual household impacts were known by the state highway department. Two test areas were established on the basis of availability of data. One involved a 6.20-mile segment of a radial Interstate freeway, the other, a 5.98-mile segment of a circumferential Interstate freeway. Neither had been included in the calibration of the model.

Input data, except percentage of residential development, were obtained from various urban planning agencies. Data on existing and design rights-of-way, the number of major and minor interchanges, and the count of households displaced were obtained from the highway department. The percentage of residential development in each affected zone was calculated from data obtained from the metropolitan area's council of governments. Net residential densities were obtained from zoning ordinances obtained from local urban planning agencies.

The model estimated 1,821 household units displaced, which was within 4 percent of the actual displacement of 1,753 units. The actual versus estimated displacements for each study area are given in Table 4.

The model was accepted as satisfactory by the authors as a long-range forecast tool capable of providing decision-makers with approximate estimates of household impacts of alternative transportation systems. The model is not intended to substitute for the traditional parcel-by-parcel right-of-way study that normally precedes right-of-way acquisition. Rather, it is intended to serve as a long-range tool for urban and transportation planners so that they can assist decision-makers to assess the consequences of a number of systems and system alignments and to adopt housing programs and possible joint development and multiple-use concepts that would minimize adverse effects of future transportation systems.

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