smaller areas, updated for current years. The transportation demand compilations of the Urban Mass Transportation Administration mentioned earlier are also a better basis for estimation. Even where these are lacking, choosing comparable survey data and adjusting them by the methods presented here would be preferable to accepting the probable inflation of the ITE data. (Use of the ITE data also assumes a transferability of its sources to areas for which they may not have been collected.)

In times of major fuel price increases and shortages, even people in exclusively suburban settings may not continue to greatly exceed average regional travel. As shown above, people's trip rates have been coming down since the ITE data were compiled. If we do not want excessive expenditures for transportation or unnecessary encouragement of travel by overcapacity, we should not be sizing our roads from traffic generation rates taken from pre-fuel-crisis suburbs.

The lower traffic estimate here suggests that road building for a new area based on the more traditional data would be an excessive use of resources--capital, energy, and land. It would produce a road system compatible with a much more intensive land use than intended by the plan. If uses were held at the intended plan maximums, the excess road capacity would give an over-automobile-oriented character to the area that encourages excessive automobile use and defeats other aspects of the plan to encourage transportation alternatives and stop the propagation of the old syndrome of more roads, more travel, more congestion, and more energy consumption.

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Effect of Urban Character on Transferability of Travel Demand Models

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The effect of urban character on travel demand model transferability is investigated. Urban character was described by urban area size, type of activity concentration, and geographic characteristics, while travel demand measures consisted of trip frequency, trip length, and mode choice and were grouped by work and nonwork trip purposes and by metropolitan and nonmetropolitan areas. A generalized regression dummy variable approach was used for the analysis. The study results show that urban character bears significant influence on travel demand, and the model transferability varies with demand measures and model specification. The specific findings include (a) the type of activity concentration has a significant impact on trip frequency for nonmetropolitan areas and trip length for both metropolitan and nonmetropolitan areas; (b) the influence of urban area size on mode choice and trip length is significant for metropolitan areas; (c) the impact of geographic characteristics on travel demand can be ranked in order of trip length, trip frequency, and mode choice; (d) metropolitan trip frequency models are more transferable than their nonmetropolitan area counterparts, while the transferability of trip length models of both metropolitan and nonmetropolitan areas is very low; and (e) in nonmetropolitan areas, nonwork trip frequency models are more transferable than work trip models.

Experience in modeling indicates that a powerful organizing paradigm seems to generate its own problems. This is particularly true when dealing with such a complex reality as travel behavior in which influential elements observed may be merely partial and distorted. Some of the perceived elements are rigorously analyzed while others may have been completely overlooked. For instance, in the conventional method of trip generation analysis, land use variables have been used to determine trip production and attraction. However, these variables should not be considered as all-inclusive parameters that affect travel behavior. To illustrate, if the values of significant land use variables were identical for different urban areas, habitual travel behavior would indicate that each urban area would always remain different from that of every other. This implies that some other uncertainties must exist that also influence the desire for travel.

Each urban area has its own character, which may be typified by urban area size, activity concentration, geographic characteristics, etc. The urban character can be considered as the base conditions of a given urban area that dictate the activity system, the transportation system, and the traffic flow pattern.

If a demand model is developed for an area and is intended to be used for predicting travel demand in that area only, the effects of urban character may be neglected from analysis without jeopardizing the predictive accuracy. However, if a transferable model is desired for application of travel prediction in different areas, the distinction of urban character should become a significant factor in influencing travel behavior. The reason is that the observed travel demand patterns inherit the nature of urban character that is obviously different from one area to another.

The primary objective of this study was to identify urban character in terms of urban size, activity concentration, and geographic characteristics that affect the transferability of work and nonwork travel demand models. The significance of urban character was determined by the first set of data and then validated by a second set of data. In addition, the influence of model specification on transferability was also investigated. Travel demand measures include trip frequency, trip length, and mode choice. The main reason for choosing these measures is that composite demand measures, such as person miles of travel (PMT), person hours of travel (PHT), vehicle miles of travel (VMT), and vehicle hours of travel (VHT) can be derived. These composite demand measures have been applied as indicators of areawide transportation system performance and resource allocation.

Various approaches have been taken to identify urban character related to the transferability of travel demand models. The first approach is to classify urban areas based on the dominant economic activity (1-3). The second approach groups cities based on population and automobile availability (4). The third approach categorizes cities in accordance with their types of activity concentration (5). The fourth approach classifies cities by using factor and cluster analysis techniques (6,7). Although no study has yet been conducted for the use of all these notions in one context so that the joint effect of urban character can be investigated, this study was intended to do just that. In addition, there are obvious weaknesses in past studies to relate urban character to various types of models for transferability purposes. For instance, use of the relationship of automobile availability and trip frequency per person to urban areas may lead to the incorrect expectation that a greater automobile availability would yield a greater number of trips. As a matter of fact, cities that have higher automobile ownership rates often generated lower trip frequencies (8). Another example is that the classification based on the type of activity concentration may be more applicable to trip distribution than trip generation. The type of activity concentration has a better relationship with gravity-model friction factors than trip frequencies (9). Without the support of statistical evidence, however, these suggestions are not convincing. This study aimed to examine the applicability of the aforementioned urban classifications by using statistical analysis.

INITIAL SELECTION OF VARIABLES

A generalized regression dummy variable approach was used as the basic model form in this study. The proposed travel demand model consists of dependent and independent variables discussed in the following sections.

Dependent Variables

In this study, measures including travel demand necessary to estimate total person trips, PMT, and PHT were selected as the demand variables. They are trip generation, trip length, and mode choice in terms of trip frequency, trip duration, travel distance, percentage of travel by automobile, transit, and walk. In addition, automobile occupancy was considered because it would allow the estimation of modal-split between the automobile driver and the automobile passenger based on the percentage of travel by automobile.

In most urban transportation studies, travel demand was differentiated by work and nonwork trips. Thus person trips and trip length were categorized into work and nonwork trips. Because trip frequency is a common measure for both household models and zonal models, it was used as a measure of trip production. Mode choice models cover modes of automobile driver, automobile passenger, transit, walk, and other modes of transportation considered in this study.

Independent Variables

Conventional travel demand analysis assumes that the number of trips within an area depends on the land use of the area. Because the area's population, socioeconomic conditions, land use development, and employment reflect the land use, these activity system variables are usually used as the parameters for travel demand. In this study, relationships among land use indicators, urban character, and tripmaking activity were estimated so that the impact of changes in socioeconomic and physical environments on changes in travel demand could be statistically analyzed.

Urban Character Variables

Considerable theoretical analyses and empirical research efforts have been made to determine the factors that most influence travel behavior at the individual, zonal, and areawide levels (10-12). This study used the results of these efforts as the basic information for the selection of urban character variables.

The three independent variables considered to reflect the urban character are urban size class, activity concentration, and geographic cluster (i.e., groups of cities that share similar geographic characteristics). The urban size class contains five urban groups with a population of less than 50 000; 50 000 to 99 999; 100 000 to 249 999; 250 000 to 750 000; and more than 750 000. This classification scheme is consistent with the overall transportation policy framework of the nation. Section 134 of the Federal-Aid Highway Act of 1962, for example, specifies that urban areas with a population of 50 000 or more have comprehensive, cooperative, and continuing (3C) planning programs under way. In many local planning contexts, this legislative action draws a sharp distinction between cities of different sizes. Thus cities with population of 50 000 or more form a logical group because of their common planning guidelines, while those below 50 000 constitute a second grouping.

Next, in many demographic and economic studies, the population size of 100 000 has often been regarded as a benchmark for distinguishing urban areas with respect to social structure and economic performance. Because both factors have profound impact on travel demand, this study proposed that urban areas with a population of less than 100 000 and urban areas with a population of 100 000 or more should be divided into two different groups. Urban areas within each group share common economic characteristics.

The third distinction was made for urbanized areas with a population of 250 000 or more, most of which have performed multimodal planning programs including long-range transit planning. Thus, it would appear that urban areas with a population of 250 000 or more constitute one grouping, while those less than 250 000 are referred to as another.

Finally, a recent study indicated that a population of 750 000 is the minimum size for a city to provide certain types of transit service such as light rail (13). Urban areas falling into this category could generate enough activity to effectively use and financially support light rail facilities and service. Other studies also showed that travel behavior in large cities is significantly different from that in smaller urban areas (14). Large cities, for example, report a greater travel demand in terms of VMT on a per capita basis (15). In accordance with these research results, urban areas can be categorized into two groups--cities with population more than 750 000 and cities with 750 000 people or less.

The urban activity concentration includes the core-concentrated and the multinucleated (5,16). The reason for this distinction is that the distribution patterns of population and employment have significant bearing on travel demand. Obviously, the greater dispersion of population and employment, the higher the travel demand in terms of VMT. On the other hand, the type of activity concentration can be expressed by density. A high urban density tends to favor public transportation and depresses automobile use due to the limitation of parking space and higher operating costs.

The geographic cluster consists of nine different urban groups classified by Golob and others (6). The area characteristics used for the classification of 80 metropolitan areas included 53 variables related to arterial transportation requirements such as population, demographics, and socioeconomic measures, land use and economic activity measures, geographic factors, and travel mobility and accessibility measures. A principal components factor analysis was performed on the correlation matrix of the 53 variables (17). Based on eigenvalues, 15 orthogonal latent factors were derived. Because the 15 latent factors include most aspects of urban environment and particularly reflect geographic influence, the urban classification based on these factors was selected as representative of the geographic variables in this study.

The city grouping shows that the first two of nine homogeneous groups reflect the uniqueness and dominance in the urban hierarchy of first, New York, and second, Chicago and Los Angeles. The third group consists of large northeastern cities characterized by high residential density and transit orientation, such as Baltimore, Boston, Pittsburgh, etc. The fourth group consists of southern cities including Atlanta, Charlotte, Memphis, etc. The cities in this group have high residential density and low income. The fifth group contains midwestern cities such as Denver, Indianapolis, Oklahoma City, etc. The cities in this group are characterized by average industrialization and personal income, and older families. The sixth group consists of mideastern industrial cities including Akron, Cincinnati, Buffalo, etc. The cities in this group have high personal income and high residential density, and are oriented toward public transit. The seventh group includes young southwestern areas such as Dallas, Houston, Phoenix, etc. They are characterized by the lowest residential density and public transit orientation. The eighth group consists of Florida cities such as Miami, Tampa, Orlando, etc. These cities have a significant retired population and low residential density. The ninth group contains young northern industrial areas of Davenport, Dayton, Omaha, etc., which have high personal income. Because the nine homogeneous groups were classified according to their arterial transportation needs and requirements, each group (except the first two groups that have only one and two cities, respectively) can be used as an independent dummy variable to account for the spatial variation of geographic characteristics among urban areas.

As indicated previously, little work has been done to incorporate all aforementioned urban characters (except for the urban activity concentration and part of urban size class) into a single urban character relative to travel demand. This research is the first to take such a comprehensive approach for examining the spatial transferability of demand models.

Activity and Transportation System Variables

Six activity system variables most commonly used in the zonal travel demand analysis are population, land area, household size, income, automobile ownership, and activity density. The literature review of other studies has indicated that the relationships of travel demand with these variables are consistently stable, thus they were selected for model formulation (18).

Better transportation systems encourage people to use transportation facilities more often. Thus, the selection of transportation system variables was based on the representativeness of variables to the system's level of service. This study considered the linear feet per capita of the arterial freeway, as well as commuter rail and bus service routes, to reflect transportation system supplies. The supply of roads was estimated by the sum of arterial linear feet per capita plus 2.7 times the number of freeway linear feet-per capita (19). On the other hand, the supply of transit was estimated by an assumption that the service efficiency for commuter rail and rapid transit is four times that for bus. Therefore, 1 mile of commuter rail or rapid transit is equivalent to 4 miles of bus service route.

Note that the U.S. Department of Transportation directly or indirectly uses many of the aforementioned activity and transportation system variables as factors for the distribution of federal funds. According to the urban transit formula program of the 1978 Surface Transportation Act, the factors for grant allocation are population, population weighted by a factor of density, commuter rail miles, fixed guideway system route miles, and bus seat miles.

DATA COLLECTION

Despite the massive acquisition of travel data in urban areas during the period 1940-1970, little has been done to develop a consistent set of data in different areas that could be used to define a set of relationships between travel demand and urban character for evaluating urban travel demand models.

The data used in this study were collected from a variety of sources (20-23). Most of them were results of individual area transportation studies and are considered reliable. These data provide socioeconomic, demographic, and travel information for 212 urban areas in the United States including 43 nonmetropolitan areas and 169 metropolitan areas. The body of this information affords the possibility to examine factors determining aggregate travel behavior and the transferability of travel demand models. The 1960s data were used for model calibration, while data collected prior to 1960 and after 1970 were used for model validation. The notations

Table 1. List of variables and notations used.

Notation	Variable	Notation	Variable
$T'_{w,d}$	Logarithmic value of average number of person trips per dwelling unit (work)	H	Average number of persons per dwelling unit
		H′	Logarithmic value of H
$T'_{n,d}$	Logarithmic value of average number of person trips per dwelling unit (nonwork)	D_p	Population density (persons per mile^2)
		I'_f	Logarithmic value of median family income ($)
$T_{w,p}$	Average number of person trips per capita (work)	V	Supply of transit (linear feet per capita)
$T_{n,p}$	Average number of person trips per capita (nonwork)	K	1 for multinucleated urban areas and 0 for core-concentrated cities
$L_{w,t}$	Average work trip duration (min)	S_1	1 for urban size class group with population of 100 000 to 249 999 and 0, otherwise
$L_{n,t}$	Average nonwork trip duration (min)		
M_a	Percentage of automobile travel	S_3	1 for urban size class group with population of more than 750 000 and 0, otherwise
M_t	Percentage of transit travel		
P′	Logarithmic value of population (number of persons)	G_3	1 for large northeastern cities and 0, otherwise
B	Land area (miles^2)	G_4	1 for southern cities and 0, otherwise
A'_d	Logarithmic value of the average number of automobiles per dwelling unit	G_5	1 for midwestern cities and 0, otherwise
		G_6	1 for mideastern cities and 0, otherwise
A_p	Average number of automobiles per capita	G_7	1 for young southwestern cities and 0, otherwise
A'_p	Logarithmic value of A_p		

of variables selected from the model calibration are listed in Table 1. The statistical significance of the data sample is described below.

As indicated previously, there are more data available for metropolitan areas than for nonmetropolitan areas. For the metropolitan area trip frequency model estimation, the sample contains 169 observations that account for 69.5 percent of U.S. metropolitan areas, or 49.2 percent of the U.S. metropolitan population. For the metropolitan area trip duration model estimation, the sample consists of 111 observations that have 46.9 percent of U.S. metropolitan areas, or 43.5 percent of the U.S. metropolitan population. There are only 35 observations available for estimating travel distance equations. However, the size of this sample is still statistically significant (14.4 percent of U.S. metropolitan areas, or 22.4 percent of the U.S. metropolitan population). Some 67 metropolitan areas were selected for mode choice model estimation. This data set accounts for 27.6 percent of U.S. metropolitan areas, or 43.2 percent of the U.S. metropolitan population. For nonmetropolitan areas, the sample contains 43 observations for trip frequency model estimation and 22 observations for trip length modeling.

ANALYSIS METHOD

A number of techniques may be used to examine the impact of urban character on travel demand. Some of these techniques such as automatic interaction detection (24) and contingency table analysis (25) have been widely applied to social science for determining classification schemes. This study selected Gujarati's generalized regression dummy variable approach as an analytical tool for several reasons (26). First, this study not only observes the relationship between urban character and travel demand but also tells how strong the relationship is. Next, the relationship between the two can be verified by data other than those used in the model calibration. Finally, the impact of urban character on the relationship between travel demand and a particular independent variable is shown in a constant term or a variable coefficient, or both. Gujarati's technique is capable of accomplishing these objectives.

The intent of Gujarati's generalized regression dummy variable technique is to portion the sample of nonoverlapping subgroups and to detect whether a subgroup can explain more of the variation in the dependent variable than any other such set of subgroups. By using the stepwise regression procedure it would allow differential intercept and slope for each group of study areas entering the model. Assume the selected model structure includes N explanatory variables and M area characters, the generalized dummy variable equation can be expressed by

$$Y = \alpha_o + \Sigma\alpha_j D_j + \Sigma\beta_i X_i + \Sigma\beta_{ij}(D_j X_{ij}) + U_{ij} \quad \begin{matrix} i = 1, 2, \ldots, N \\ j = 1, 2, \ldots, M \end{matrix} \tag{1}$$

where

Y = dependent variable (demand measure),
X_i = independent variables (activity and transportation system characteristics),
D_j = 1 if the observation lies in group j (urban character) or 0 otherwise,
α_o = intercept for all subgroups,
α_j = differential intercept for group j,
β_i = slope coefficient of Y with respect to X_i for all subgroups,
β_{ij} = differential coefficient of Y with respect to $D_j X_{ij}$, and
U = stochastic error term.

Among various forms of the regression model, linear, product, exponential, logarithmic, and combination forms were all used for appropriate travel demand measures. These forms were chosen in order to keep the statistical estimation problem tractable and to account for possible nonlinearities:

Linear	$Y = a + bX$
Product	$Y = aX^b$ or $\ln Y = a + b\ln X$
Exponential	$Y = ab^X$ or $\ln Y = a + bX$
Logarithmic	$Y = a + b\ln X$

where

Y = dependent variable,
X = independent variable, and
a,b = parameters to be estimated.

DETERMINATION OF TRANSFERABLE VARIABLES

Explanatory variables included in trip frequency equations for nonmetropolitan areas are household automobile ownership and household size variables; for metropolitan areas, automobile ownership per capita, household size, and population variables. The transferability of these variables and the estimated models are summarized in Table 2. Comparison of the estimated models for both types of urban areas reveals that trip frequency equations for metropolitan areas are more transferable than their nonmetropolitan counterparts.

The type of urban activity concentration (core-

Table 2. Significance of urban character influencing trip frequency.

Trip Purpose	Explanatory Variable	Coefficient	Size Class	Activity Concentration	Geographic Cluster
Nonmetropolitan area					
Work trips	$\underline{A'_d}$	Intercept	NA		G_5^*
	$\underline{A'_d}$	Slope	NA		G_5^{***}, G_6^*
	$\underline{H'}$	Intercept	NA	K^*	
	$\underline{H'}$	Slope	NA	K^{**}	G_5^{**}
	$\underline{A'_d}$, $\underline{H'}$				
	H'	Slope	NA	K^{***}	
Nonwork trips	$\underline{A'_d}$	Intercept	NA	K^{***}	
	$\underline{H'}$	Slope	NA	K^{***}	
	$\underline{A'_d}$, $\underline{H'}$				
	H'	Slope	NA	K^{***}	
Metropolitan area					
Work trips	$\underline{A'_p}$, $\underline{P'}$				
	$\underline{A'_p}$, $\underline{P'}$, $\underline{H}$				
	H	Slope			G_7^{***}
Nonwork trips	$\underline{A'_p}$, $\underline{P'}$				
	$\underline{A'_p}$, $\underline{P'}$, $\underline{H}$				
	H	Slope			G_7^{***}

Notes: NA = not applicable.
Total explanatory variables included in a model are underlined.
Statistical significance is defined by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.

concentrated versus multinucleated) appears to be a crucial element in determining the difference of both work and nonwork household trip frequency among nonmetropolitan areas, while its impact on the metropolitan area trip frequency per capita is statistically insignificant. The work household trip frequency in nonmetropolitan areas of geographic cluster 5 (midwestern cities) is significantly different from that of other U.S. nonmetropolitan areas if the household trip frequency is explained either by household automobile ownership or by household size, respectively. On the other hand, the influence of activity concentration on metropolitan area trip frequency per capita is not significant. However, the relationship between trip frequency per capita and household size in metropolitan areas of geographic cluster 7 (young southwestern areas) is significantly different from that of the rest of U.S. metropolitan areas.

Investigating the performance of each explanatory variable reveals that the relationship between household trip frequency and household size is not transferable between certain subgroups of nonmetropolitan areas, i.e., nonmetropolitan areas of geographic cluster 5 versus the rest of U.S. nonmetropolitan areas and the core-concentrated versus multinucleated nonmetropolitan areas. For metropolitan areas, the trip frequency model with household size as the independent variable is not transferable between metropolitan areas of geographic cluster 7 and the rest of U.S. metropolitan areas. The relationship between trip frequency per capita and automobile ownership per capita is spatially transferable for metropolitan areas. Such a transferability is applicable to both trip purposes. However, the spatial transferability of the nonmetropolitan area household trip frequency model with household automobile ownership as the independent variable is only limited to work trips.

Table 3 suggests that the spatial transferability of mode choice model is fairly high. Both percentage of travel by transit and automobile occupancy equations are independent of the influence of geographic factors, while the percentage of travel by automobile and the percentage of walking equations are influenced only by the urban character of geographic cluster 3 (large northeastern cities) and geographic cluster 7 (young southwestern cities), respectively. The most important urban size class variable is urban size class 3 (cities with a population of more than 750 000), which indicates the divergency of mode choice models between metropolitan areas with a population of more than 750 000 and metropolitan areas of 750 000 people or less. The comparison between explanatory variables shows that automobile ownership per capita is a transferable variable whereas the transferability of population density, the supply of public transit service, and the income variables are limited to a certain degree.

By using population, land area, and population density as variables to explain trip length, the transferability of the model is relatively low when compared with that of trip frequency and mode choice models. As indicated in Table 4, the slope of the population variable in trip duration for both trip purposes and for both types of urban areas is significantly affected by the type of urban activity concentration. The slope of the population density variable differs among urban area groups as defined by urban size class, while the slope of the land area variable is significantly different between metropolitan areas of geographic cluster 4 (southern cities) and the rest of U.S. metropolitan areas. Because the transferability of explanatory variables is low, the estimated trip length models have less transferability than trip frequency and mode choice models.

In general, the results of the above analyses indicate that the transferability of models depends on the type of demand measure and explanatory variable as well as the number of explanatory variables included in the model. The combination of two or more explanatory variables in a model tends to enhance transferability.

MODEL VERIFICATION

Verification of the findings presented here can be accomplished by the traditional case-study approach or the validation of the developed models on which the preceding analysis was based. However, in order to exhaustively examine the validity of the findings the traditional approach would require 4x30 (120) case studies for nonmetropolitan areas and 6x90 (540) case studies for metropolitan areas. Thus the second method of verification was selected in this study. The developed models were applied to real-life situations. The validity of these models was evaluated by comparing the estimated and actual travel demand. The results of applications are presented below. Note that the selection of study areas was based on data availability, and the data for use in validation were collected either before 1960 or after 1970.

Demand Models for Nonmetropolitan Areas

Trip Frequency Models

The trip frequency equations contained in Table 5 were applied to five U.S. nonmetropolitan areas to forecast the total person trips per dwelling unit. The forecast years (forward and backward) range from 1947 to 1948 and from 1972 to 1973. The areas, which were selected in accordance with the diversity of urban character, include Nashaua, New Hampshire; Tri-cities, Virginia; Rapid City, South Dakota; Tucson, Arizona; and Pontiac, Michigan. The prediction error ranges from 2 to 13.7 percent. The result of this application indicates that the predictive ability of trip frequency models is satisfactory.

Trip Length Models

The equations for applying trip length models to forecast the average trip duration for U.S. nonmetropolitan areas are shown in Table 5. The study areas are Tri-Cities; Beloit, Wisconsin; Hutchinson, Kansas; and Tallahassee, Florida. The forecast years range from 1971 to 1973. Comparison of the estimated and actual trip durations shows that the forecast error falls into a range of 3.1-10.4 percent. The accuracy of these estimations is considered acceptable.

As to mode choice models, nonmetropolitan areas generally have a limited choice of travel modes. The data limitation and necessity precluded verification of mode choice models for nonmetropolitan areas.

Demand Models for Metropolitan Areas

Trip Frequency Models

Two trip frequency equations as shown in Table 6 were applied to forecast the average work and nonwork person trips per capita for seven U.S. metropolitan areas: Phoenix, Arizona; Wichita, Kansas; Huntington, West Virginia; Akron, Ohio; Anderson, Indiana; Denver, Colorado; and Duluth-Superior, Minnesota. The population of these metropolitan areas ranges from 90 000 (Anderson) to 1 220 000 (Phoenix), while the forecast years range from 1970 to 1976. The result indicates that the predictive ability of work trip frequency model is satisfactory, with an error ranging from 0 to 9.3 percent. The prediction error for the nonwork person trip frequency equation is varied. It ranges from 0.3 percent in Wichita to 22.8 percent in Denver, and to 39.5 percent in Phoenix. The main cause of the large discrepancy between the estimated and actual is the dramatic change of automobile ownership. For example, the automobile ownership for Phoenix was

Table 3. Significance of urban character influencing mode choice and automobile occupancy for metropolitan areas.

Transportation Mode	Explanatory Variable	Coefficient	Size Class	Activity Concentration	Geographic Cluster
Percentage of automobile travel	$\underline{A}_p$, $\underline{D}_p$				
	D_p	Slope			G_3^{***}
Percentage of transit travel	$\underline{A}_p$, $\underline{D}_p$, $\underline{P}'$				
	D_p	Slope	S_3^{***}		
	P'	Slope	S_1^{**}		
Percentage of walk	$\underline{A}_p$, $\underline{V}$				
	V	Slope	S_3^{***}		G_7^{***}
Automobile occupancy	$\underline{I}_f'$	Slope	S_3^{*}		

Notes: Total explanatory variables included in a model are underlined.
Statistical significance is defined by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.

Table 4. Significance of urban character influencing trip length.

Trip Purpose	Explanatory Variable	Coefficient	Size Class	Activity Concentration	Geographic Cluster
Nonmetropolitan area					
Work trips					
Trip duration	$\underline{P}'$	Slope	NA	K**	G_5^{*}, G_6^{***}
Travel distance	$\underline{P}'$	Slope	NA		G_6^{***}
Nonwork trips					
Trip duration	$\underline{P}'$	Slope	NA	K*	G_5^{***}, G_6^{***}
Travel distance	$\underline{P}'$	Slope	NA		G_6^{***}
Metropolitan area					
Work trips					
Trip duration	$\underline{P}'$, $\underline{B}$, $\underline{D}_p$				
	P'	Slope		K***	G_7^{***}
	B	Slope			G_4^{***}
	D_p	Slope	S_1^{***}, S_3^{***}		
Travel distance	$\underline{P}'$, $\underline{B}$				
	B	Slope			G_4^{**}
Nonwork trips					
Trip duration	$\underline{P}'$, $\underline{B}$, $\underline{D}_p$	Intercept			G_3^{**}
	P'	Slope		K***	
	B	Slope			G_4^{***}
	D_p	Slope	S_1^{***}	K**	
Travel distance	$\underline{P}'$, $\underline{B}$				
	P'	Slope	S_1^{***}		
	B	Slope	S_2^{***}	K***	G_4^{***}

Notes: NA = not applicable.
Total explanatory variables included in a model are underlined.
Statistical significance is defined by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.

Table 5. Trip frequency and trip length models for nonmetropolitan areas.

Factor	Equation		
Work trip frequency	$T'_{w,d} = -0.702 + 1.026\,A'_d + 1.285\,H' - 0.105\,(KH')$ [29.0]*** [33.3]*** [4.3]***	$R^2 = 0.8013$	D.F. = 28
Nonwork trip frequency	$T'_{n,d} = 1.835 + 1.080\,A'_d - 0.251\,(KH')$ [10.2]*** [6.6]***	$R^2 = 0.3728$	D.F. = 29
Work trip duration	$L_{w,t} = -30.671 + 3.506\,P' + 0.181\,(G_5P') + 0.232\,(G_6P') - 0.168\,(kP')$ [34.3]*** [2.1]* [8.7]*** [4.2]**	$R^2 = 0.7821$	D.F. = 25
Nonwork trip duration	$L_{n,t} = -26.180 + 2.896\,P' - 0.131\,(KP') + 0.139\,(G_5P') + 0.248\,(G_6P')$ [27.2]*** [3.0]* [7.6]*** [11.6]***	$R^2 = 0.7618$	D.F. = 25

Notes: [ ] = F-value.
* Significant at the 10 percent level.
** Significant at the 5 percent level.
*** Significant at the 1 percent level.

Table 6. Trip frequency, trip length, and mode choice models for metropolitan areas.

Factor	Equation
Work trip frequency	$T_{w,p} = 0.708 + 0.939 A_p - 0.0316 P' - 0.0143 (G_7 H)$ [24.7]*** [16.6]*** [3.0]*** $R^2 = 0.2915$ D.F. = 110
Nonwork trip frequency	$T_{n,p} = 3.001 + 4.300 A_p - 0.193 P' - 0.056 (G_7 H)$ [37.9]*** [41.1]*** [3.0]*** $R^2 = 0.4121$ D.F. = 110
Work trip duration	$L_{w,t} = -17.288 + 2.472 P' - 0.183 (KP') - 0.153 (G_7 P') + 0.000\,331 B + 0.0016 (G_4 B) - 0.0086 (S_1 D_p) + 0.0038 (S_3 D_p)$ [11.7]*** [9.8]*** [3.2]*** [3.4]*** [13.4]*** [6.1]*** [7.9]*** $R^2 = 0.7702$ D.F. = 103
Nonwork trip duration	$L_{n,t} = -4.729 + 2.268 G_3 + 1.225 P' - 0.0227 (KP') + 0.0012 (G_4 B) + 0.0019 (KD_p) - 0.0087 (S_1 D_p)$ [2.6]** [5.4]*** [8.8]*** [8.9]*** [2.4]** [8.9]*** $R^2 = 0.5729$ D.F. = 104
Percentage of automobile travel	$M_a = 45.536 + 95.773 A_p - 0.0044 (G_3 D_p)$ [47.3]*** [9.3]*** $R^2 = 0.4821$ D.F. = 64
Percentage of transit travel	$M_t = 31.143 - 64.377 A_p + 0.491 (S_3 D_p') - 0.247 (S_1 P')$ [11.4]*** [12.8]*** [2.2]** $R^2 = 0.5795$ D.F. = 63

Notes: [] = F-value.
* Significant at the 10 percent level.
** Significant at the 5 percent level.
*** Significant at the 1 percent level.

near 0.6 cars per capita for the forecasting year, while the average automobile ownership of the 1960s sample was 0.37 cars per person with a range of 0.25-0.45 cars per capita. The forecast error for total person trips falls into a range of 0.4-31.9 percent. The accuracy of forecast is still comparable to that of zonal models.

Trip Length Models

Six U.S. metropolitan areas were selected to evaluate the predictive ability of trip length models for metropolitan areas: Phoenix; Lima, Ohio; Wichita; Akron; Denver; and Duluth-Superior. Two models for this evaluation are contained in Table 6. The forecast years range from 1970 to 1976. Comparison between the actual and estimated shows that both models perform fairly well. The discrepancy between them ranges from 2.2 to 10.0 percent for the work trip duration equation and from 2.0 to 12.0 percent for the nonwork trip duration model. The results indicate that the trip duration equations are capable of estimating trip duration for various metropolitan areas with a diversity of demographic and geographic characteristics.

Mode Choice Models

The developed mode choice models as shown in Table 6 were applied to forecast the modal-split between automobile driver, automobile passenger, and public transit for three U.S. metropolitan areas of Akron, Denver, and Duluth-Superior. The forecast year of the three applications is 1970. Comparison of the estimated and actual percent of each mode reveals that the developed models can predict the mode choice of the three metropolitan areas with a high degree of accuracy. The prediction errors are less than 5 percent.

The results of these model verifications indicate that the predictive ability of the models developed in this study is comparable to specific models developed for particular areas as shown in zonal experience. They also imply that the relationships between travel demand and urban character as identified in this study are stable over time.

CONCLUSIONS

The purpose of this paper has been to call attention to the consideration of certain types of urban character when the transfer of travel demand models is desired. A generalized regression dummy variable approach was used to identify the effects of urban character on travel demand. The results provide some guidelines for determining model transferability.

The effects of urban character on travel demand depend on the aspect of demand measure and the model specification. In accordance with the selected variables this study has found no models (including trip frequency models) that are perfectly transferable. However, with careful selection, the transfer of a model from one geographic areas to another is not impossible.

The reliability of these findings was verified by testing the models that were developed for examining the relationships between urban character and travel demand measures. These models were applied to several U.S. urban areas with satisfactory results. The findings of this study provide the following conclusions.

1. For nonmetropolitan area work trips, if the household trip frequency is explained by household automobile ownership, the model is not transferable between three urban classes: midwestern cities, mideastern cities, and the rest of U.S. cities. If the household trip frequency is explained by household size, both activity concentration (core-concentrated versus multinucleated) and geographic cluster (midwestern cities versus the rest of U.S. cities) become the dominant factors for determining model transferability. If both household automobile ownership and household size are included in the model, the model is not transferable between cities with different types of activity concentration.
2. For nonmetropolitan areas, the nonwork trip frequency model composed of household automobile ownership and/or household size variables is significantly affected by the type of activity concentration.
3. For metropolitan areas, both work and nonwork trip frequency models composed of automobile ownership per capita and household size are not transferable between young southwestern cities and the rest of U.S. cities.
4. For metropolitan area mode choice, if the percentage of automobile travel is explained by both automobile ownership per capita and population density, the model is not transferable between large northern cities and the rest of U.S. metropolitan areas. If the percentage of transit travel model is composed of automobile ownership per capita, population density, and population, the model is not transferable among cities with population 50 000 to

99 999; 100 000 to 249 999; 250 000 to 750 000; and more than 750 000. If the percentage of walk is explained by both automobile ownership per capita and transit system supply, the model is not transferable between cities with a population equal to, less than, or more than 750 000 and between young southwestern cities and the rest of U.S. cities. If automobile occupancy is explained by the median family income the urban size becomes a significant dummy variable.

5. For nonmetropolitan areas, the trip length is explained by population and the model is not transferable between different types of activity concentration and between geographic clusters of midwestern cities, mideastern cities, and the rest of U.S. cities for trip duration, nor between mideastern cities and the rest of U.S. cities for travel distance.

6. For metropolitan areas, the trip length is explained by population, land area, and population density. The model transferability is limited to urban groups defined by activity concentration, geographic cluster, and urban size class.

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