NATIONAL STUDIES OF URBAN ARTERIAL TRANSPORTATION: A RESEARCH FRAMEWORK

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A research framework is presented for the estimation of the national markets and the social, economic, and environmental impacts of new systems of urban arterial transportation, such as automated guideway and rail and bus rapid transit systems. A statistical step-wise procedure, based on the extrapolation of results from a limited number of analytical case studies to the set of all candidate metropolitan areas, is specified. Results are provided for the application of all steps in the procedure before the conducting of actual case studies: 80 candidate metropolitan areas are classified into 9 relatively homogeneous groups with respect to their arterial transportation needs; the most representative areas within each group are identified as preferred case study locales; and guidelines are developed for the extrapolation of system costs, benefits, and market estimates from the case studies to the remaining areas within the groups through sensitivity analyses. In addition, intermediate multivariate statistical results are interpreted as inputs to the development of hypotheses describing relationships between transportation and urban structure.

•THE INTENT of this research is to improve the processes of planning and implementing new transportation systems designed to meet the arterial transportation needs of metropolitan areas through the development and application of a statistical procedure to estimate the national markets and the total social, economic, and environmental impacts of such proposed new systems. Such estimations of the potential range and consequences of implementation are important to considerations of product markets and returns on capital investments when private funds are employed in research and development and are also important to considerations of the distributions of costs and benefits when public funds are so employed.

The diverse needs and requirements of the hundreds of metropolitan areas in the United States create substantial difficulties in generating such estimates. In light of the infeasibility of conducting analytical case studies of a new system in each area, the procedure developed involves the extrapolation of the results from a minimum number of selected case studies to the total set of candidate metropolitan areas. The viability of this approach was recognized by the Urban Mass Transportation Administration of the U. S. Department of Transportation in the definition of requirements analysis (61):

> New Systems Requirements Analysis comprises three essential objectives. The first is the design and development of a set of public transportation demand analysis techniques and associated computer programs that will facilitate the evaluation of proposed public transportation implementations. The second is the application of the techniques to a sample set of urban areas to determine the requirements of new systems of public transportation in these areas. The third is an estimation of national requirements for new systems by extrapolating needs detected in the sample urban areas to other areas having similar socio-economic and other characteristics.

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Specifically, the procedure structures the relationships between characteristics of the social and physical spaces of metropolitan areas and characteristics of transportation systems perceived of being imbedded in the metropolitan area environments through a series of sequential steps. These steps are methodologically described in Canty and Golob (18) and involve the classification of metropolitan areas into relatively homogeneous groups with respect to their arterial transportation needs, the selection of preferred case study locales from the areas within each group, and the extrapolation of the results of case studies conducted within the selected locales to the remaining areas within each group by means of sensitivity analyses and statistical relationships.

This paper documents the application of the procedure through all phases prior to the initiation of individual case studies of a particular new arterial transportation system under investigation. This system, called the Metro Guideway, is described in Canty (17) and is an integrated urban facility for dual-mode private automobiles and buses, personal rapid transit vehicles, and freight movement vehicles. The system is designed to serve commuter and cross-town arterial transportation needs now being provided by limited-access facilities such as freeways and rapid transit lines.

Because metropolitan area aggregations of people, institutions, and activities are appropriate for many proposed types of rail rapid transit, bus rapid transit, automated highway, or area-wide personal rapid transit systems as well as the Metro Guideway concept, the results of the application reported here are expected to be directly or indirectly of interest in a number of research studies. However, studies of other forms of urban transportation systems may require a different level of aggregation, such as major activity centers [see Canty (16) for discussions of system forms and urban scale]. Caution must thus be observed in the extension of the results reported here to the study of other than arterial systems.

DATA SELECTION

The determination of a data base on which the classification of metropolitan areas, identification of case study locales, and establishment of guidelines for case study sensitivity analyses were to be based was accomplished by first selecting a set of metropolitan areas and then selecting a set of variables measured on these areas. The metropolitan areas considered as candidate locations for the new system of urban arterial transportation under study are a subset of all standard metropolitan statistical areas and associated urbanized areas and standard consolidated areas in the United States defined by the Bureau of the Census. Such a pre-selection of a subset of areas is desirable (whenever possible) because inclusions of metropolitan areas for which the probabilities of implementation of a new system are extremely small would dilute the estimations for the more probable areas while adding no significant statistical information.

A subset of 80 metropolitan areas was selected as meeting criteria of minimum population and minimum geographical size (both projected for 1985) to warrant consideration as locations for limited-access arterial transportation systems. The minimum populations and area values were established by means of a simplified cost-benefit analysis based on intra-area as opposed to inter-area transportation needs. This analysis, which was biased toward the inclusion of all marginal cases, is reported in Golob et al. (27). The list of 80 candidate metropolitan areas is shown in Figure 1.

The set of 53 variables, on which the analyses of the similarities and differences between the 80 candidate metropolitan areas were based, was selected from the set of all compatibly defined measurements on social and physical spaces of the metropolitan areas. Each of the variables was judged by a multidisciplinary team of research economists, engineers, and urban planners to be related especially to arterial transportation needs or requirements. The list of the 53 variables is shown in Figure 2.

A CLASSIFICATION OF METROPOLITAN AREAS

The 80 candidate metropolitan areas were classified into relatively homogeneous groups on the basis of their observed values on the 53 variables selected as being related to arterial transportation needs and requirements. The objective of this classi-

Figure 1. Metropolitan areas selected.

STANDARD METROPOLITAN STATISTICAL AREA	ABBREVIATED TITLE
AKRON, OHIO	AKRON
ALBANY-SCHENECTADY-TROY, N.Y.	ALBANY
ALBUQUERQUE, N. MEX.	ALBUQUERQUE
ATLANTA, GA.	ATLANTA
BALTIMORE, MD.	BALTIMORE
BEAUMONT-PORT ARTHUR-ORANGE, TEX.	BEAUMONT
BIRMINGHAM, ALA.	BIRMINGHAM
BOSTON, MASS.	BOSTON
BRIDGEPORT, CONN.	BRIDGEPORT
BUFFALO, N.Y.	BUFFALO
CHARLOTTE, N.C.	CHARLOTTE
CHICAGO, ILL.-NORTH-WESTERN INDIANA**	CHICAGO
CINCINNATI, OHIO-KY.-IND.	CINCINNATI
CLEVELAND, OHIO	CLEVELAND
COLUMBUS, OHIO	COLUMBUS
DALLAS, TEX.	DALLAS
DAVENPORT-ROCK ISLAND-MOLINE, IOWA-ILL.	DAVENPORT
DAYTON, OHIO	DAYTON
DENVER, COLO.	DENVER
DETROIT, MICHIGAN	DETROIT
DULUTH-SUPERIOR, MINN.-WIS.	DULUTH
EL PASO, TEX.	EL PASO
FLINT, MICHIGAN	FLINT
FT. LAUDERDALE-HOLLYWOOD, FLA.	FT. LAUDERDALE
FORT WORTH, TEX.	FORT WORTH
GRAND RAPIDS, MICH.	GRAND RAPIDS
HARTFORD, CONN.	HARTFORD
HONOLULU, HAWAII	HONOLULU
HOUSTON, TEX.	HOUSTON
INDIANAPOLIS, IND.	INDIANAPOLIS
JACKSONVILLE, FLA.	JACKSONVILLE

STANDARD METROPOLITAN STATISTICAL AREA	ABBREVIATED TITLE
KANSAS CITY, MO.-KANS.	KANSAS CITY
KNOXVILLE, TENN.	KNOXVILLE
LANSING, MICHIGAN	LANSING
LOS ANGELES-LONG BEACH-ANAHEIM-SANTA ANA-GARDEN GROVE, CALIF.*	LOS ANGELES
LOUISVILLE, KY.-IND.	LOUISVILLE
MADISON, WIS.	MADISON
MEMPHIS, TENN.-ARK.	MEMPHIS
MIAMI, FLA.	MIAMI
MINNEAPOLIS-ST. PAUL MINN.	MINNEAPOLIS
MOBILE, ALA.	MOBILE
NASHVILLE, TENN.	NASHVILLE
NEW ORLEANS, LA.	NEW ORLEANS
NEW YORK, N.Y.-NORTHEASTERN N.J.***	NEW YORK
NEWPORT NEWS-HAMPTON, VA.	NEWPORT NEWS
NORFOLK-PORTSMOUTH, VA.	NORFOLK
OKLAHOMA CITY, OKLA.	OKLAHOMA CITY
OMAHA, NEBR.-IOWA	OMAHA
ORLANDO, FLA.	ORLANDO
PHILADELPHIA, PA.-N.J.	PHILADELPHIA
PHOENIX, ARIZ	PHOENIX
PITTSBURGH, PA.	PITTSBURGH
PORTLAND, OREG.-WASH.	PORTLAND
PROVIDENCE-PAWTUCKET-WARWICK, R.I.-MASS.	PROVIDENCE
RICHMOND, VA.	RICHMOND
ROCHESTER, N.Y.	ROCHESTER
SACRAMENTO, CALIF.	SACRAMENTO
ST. LOUIS, MO.-ILL.	ST. LOUIS
SALT LAKE CITY, UTAH	SALT LAKE CITY
SAN ANTONIO, TEX.	SAN ANTONIO
SAN BERNARDINO-RIVERSIDE-ONTARIO CALIF.	SAN BERNARDINO

STANDARD METROPOLITAN STATISTICAL AREA	ABBREVIATED TITLE
SAN DIEGO, CALIF.	SAN DIEGO
SAN FRANCISCO-OAKLAND, CALIF.	SAN FRANCISCO
SAN JOSE, CALIF.	SAN JOSE
SEATTLE-EVERETT, WASH.	SEATTLE
SPRINGFIELD-CHICOPEE-HOLYOKE, MASS.-CONN.	SPRINGFIELD
SYRACUSE, N.Y.	SYRACUSE
TACOMA, WASH.	TACOMA
TAMPA-ST. PETERSBURG, FLA.	TAMPA
TOLEDO, OHIO	TOLEDO
TUCSON, ARIZ.	TUCSON
TULSA, OKLA.	TULSA
UTICA-ROME, N.Y.	UTICA
WASHINGTON, D.C.-MD.-VA.	WASHINGTON
W. PALM BEACH, FLA.	W. PALM BEACH
WICHITA, KANS.	WICHITA
WILMINGTON, DEL.-N.J.-MD.	WILMINGTON
WORCESTER, MASS.	WORCESTER
YOUNGSTOWN-WARREN, OHIO	YOUNGSTOWN

*	INCORPORATES SMSA'S OF LOS ANGELES-LONG BEACH AND ANAHEIM-SANTA ANA-GARDEN GROVE, CALIFORNIA
**	STANDARD CONSOLIDATED AREA CONSISTS OF CHICAGO, ILL., AND GARY-HAMMOND-EAST CHICAGO, IND. STANDARD METROPOLITAN STATISTICAL AREAS
***	STANDARD CONSOLIDATED AREA CONSISTS OF THE FOLLOWING STANDARD METROPOLITAN STATISTICAL AREAS: NEW YORK,N.Y.; NEWARK, N.J.; JERSEY CITY, N.J.; PATERSON-CLIFTON-PASSAIC, N.J.; AND OF MIDDLESEX AND SOMERSET COUNTIES, N.J.

Figure 2. Variables selected.

VARIABLE TITLE	ABBREVIATED TITLE
1. LAND AREA OF URBANIZED AREA, 1970	AREA
2. APPROXIMATE NUMBER OF 45° SECTORS OF URBAN DEVELOPMENT AROUND CBD	RADIUS OF DEVELOPMENT
3. NUMBER OF INCORPORATED CITIES WITHIN URBANIZED AREA, 1960	No. INC. CITIES
4. NUMBER OF CENTRAL CITIES DEFINED FOR SMSA, 1970	No. CENTRAL CITIES
5. TOTAL POPULATION OF URBANIZED AREA, 1970	POPULATION
6. APPROXIMATE YEAR IN WHICH CENTRAL CITY EXCEEDED 50,000 POPULATION	AGE OF CENTRAL CITY
7. POPULATION GROWTH FACTOR FOR SMSA, 1965-1985	POP. GROWTH FACTOR
8. PERCENT OF URBANIZED AREA POPULATION LOCATED IN CENTRAL CITY, 1970	% POP. IN CENTRAL CITY
9. POPULATION PER SQUARE MILE IN CENTRAL CITY, 1960	POP. DENSITY IN CENTRAL CITY
10. POPULATION PER SQUARE MILE IN URBAN FRINGE, 1960	POP. DENSITY IN FRINGE
11. PERCENT OF SMSA POPULATION NON-WHITE, 1970	% NON-WHITE
12. PERCENT OF SMSA POPULATION LESS THAN 18 YEARS OLD, 1970	% POP. < 18 YRS.
13. PERCENT OF SMSA POPULATION GREATER THAN 64 YEARS OLD, 1970	% POP. >64 YRS.
14. MEAN NUMBER OF PERSONS IN HOUSEHOLD IN SMSA, 1960	PERSONS/HOUSEHOLD
15. PERCENT OF SMSA HOUSING WHICH IS SOUND WITH ALL FACILITIES, 1960	% HOUSING SOUND
16. PERCENT OF SMSA HOUSEHOLDS IN ONE-UNIT STRUCTURES, 1960	% SINGLE-UNIT HOUSING
17. PERCENT OF SMSA POPULATION IN GROUP QUARTERS, 1960	% GROUP QUARTER HOUSING
18. MEDIAN VALUE OF ALL OWNER-OCCUPIED HOUSING IN SMSA, 1960	MEDIAN HOUSING VALUE
19. PER CAPITA INCOME, 1970	PER CAPITA INCOME
20. PROJECTED PER CAPITA INCOME GROWTH, 1970-1990	PER CAPITA INCOME GROWTH
21. PROJECTED MEAN HOUSEHOLD INCOME IN SMSA, 1985	PROJ. MEAN HOUSEHOLD INCOME
22. PROJECTED PERCENT OF SMSA HOUSEHOLDS WITH LESS THAN $ 4,000 INCOME, 1985	PROJ. % POOR HOUSEHOLDS
23. PROJECTED PERCENT OF SMSA HOUSEHOLDS WITH GREATER THAN $ 15,000 INCOME, 1985	PROJ. % AFFLUENT HOUSEHOLDS
24. RATIO OF NUMBER OF FAMILIES WITH LESS THAN $ 3,000 INCOME IN CENTRAL CITY TO THOSE IN URBANIZED AREA, 1960	CONCENTRATION OF POOR IN CENTRAL CITY
25. RATIO OF NONWORKER TO WORKER POPULATIONS IN URBANIZED AREA, 1960	NONWORKER-WORKER RATIO
26. PERCENT MARRIED WOMEN WITH HUSBAND PRESENT IN LABOR FORCE IN URBANIZED AREA, 1960	% MARRIED WOMEN WORKING
27. PERCENT WHITE COLLAR EMPLOYMENT IN SMSA, 1960	% WHITE COLLAR
28. MEAN NUMBER OF AUTOMOBILES AVAILABLE PER FAMILY IN SMSA, 1960	AUTOS/FAMILY
29. PROPORTION OF HOUSEHOLDS IN CENTRAL CITY WITH NO AUTOMOBILE AVAILABLE, 1960	% CENTRAL CITY HOUSEHOLDS WITH NO AUTO
30. PROPORTION OF HOUSEHOLDS IN URBAN FRINGE WITH NO AUTOMOBILE AVAILABLE, 1960	% FRINGE HOUSEHOLDS WITH NO AUTO
31. PERCENT OF WORKERS COMMUTING CENTRAL CITY TO URBAN FRINGE, 1960	% REVERSE COMMUTING
32. PERCENT OF WORKERS COMMUTING SMSA FRINGE TO CENTRAL CITY, 1960	% COMMUTING TO CENTRAL CITY
33. PERCENT OF WORKERS COMMUTING TOTALLY WITHIN SMSA FRINGE, 1960	% FRINGE COMMUTING
34. PERCENT CENTRAL CITY WORKERS USING PUBLIC TRANSIT, 1960	% CENTRAL CITY WORKERS USING TRANSIT
35. PERCENT URBAN FRINGE WORKERS USING PUBLIC TRANSIT, 1960	% FRINGE WORKERS USING TRANSIT
36. PROPORTION OF WORKERS WALKING TO WORK IN SMSA, 1960	% WORKERS WALKING
37. PROPORTION OF WORKERS USING RAIL TRANSIT IN SMSA, 1960	% WORKERS USING RAIL
38. TOTAL OF ALL PUBLIC TRANSIT VEHICLES IN SMSA, 1966	TOTAL TRANSIT VEHICLES
39. PERCENT OF SMSA RETAIL SALES IN CENTRAL BUSINESS DISTRICT, 1967	% SALES IN CBD
40. PERCENT CHANGE IN CBD RETAIL SALES, 1963-1967	% CHANGE IN CBD SALES
41. NUMBER OF SMSA RETAIL ESTABLISHMENTS PER 1000 POPULATION, 1967	RETAIL STORES/CAPITA
42. AVERAGE NUMBER OF EMPLOYEES PER MANUFACTURING ESTABLISHMENT IN SMSA, 1967	EMPLOYEES/MFG. ESTABL.
43. RECEIPTS OF SMSA SELECTED SERVICE ESTABLISHMENTS PER CAPITA, 1967	SERVICE RECEIPTS/CAPITA
44. MEAN JANUARY TEMPERATURE IN DEGREES FAHRENHEIT	MEAN JAN. TEMP.
45. TOTAL DAILY VEHICLE MILES OF TRAVEL ON PRINCIPAL ARTERIAL ROADWAYS IN URBAN AREA, PROJECTED 1990	PROJ. PRINCIPAL ARTERIAL DVMT
46. PERCENT CHANGE IN PRINCIPAL ARTERIAL DAILY VEHICLE MILES OF TRAVEL, 1968-1990	% CHANGE-PRINCIPAL ARTERIAL DVMT
47. PERCENT OF TOTAL ALL ROADWAY DAILY VEHICLE MILES OF TRAVEL ON PRINCIPAL ARTERIALS, PROJECTED 1990	PROJ. % DVMT ON PRINCIPAL ARTERIALS
48. PERCENT OF TOTAL ALL ROADWAY DAILY VEHICLE MILES OF TRAVEL ON FREEWAYS, PROJECTED 1990	PROJ. % DVMT ON FWYS.
49. PRINCIPAL ARTERIAL DAILY VEHICLE MILES OF TRAVEL PER CAPITA, PROJECTED 1990	PROJ. PRINCIPAL ARTERIAL DVMT/CAPITA
50. TOTAL ROUTE MILES OF FREEWAYS PROPOSED FOR 1990	PROJ. RT. MI.-FWYS.
51. TOTAL INCREASE IN PRINCIPAL ARTERIAL ROUTE MILES PROPOSED FOR 1968-1990	PROJ. INCREASE IN PRINCIPAL ARTERIAL RT. MI.
52. RATIO OF PROJECTED 1990 PRINCIPAL ARTERIAL DVMT PER ROUTE MILE TO 1968 PRINCIPAL ARTERIAL DVMT PER ROUTE MILE	GROWTH FACTOR: PRINC. ART DVMT/RT. MI.
53. PRINCIPAL ARTERIAL DAILY VEHICLE MILES OF TRAVEL PER ROUTE MILE, PROJECTED 1990	PROJ. PRINCIPAL ARTERIAL DVMT/ROUTE MILE

fication is to permit more valid extrapolation of case study results by restricting that process to the range of variation between a chosen representative area and the other areas within the same relatively homogeneous group. Berry (13) defines this objective as "improved modes of prediction" in his comprehensive list of purposes of city classification. In addition, the analytical attributes of the classification technique allowed the explicit isolation of important latent dimensions of differentiation between the metropolitan areas, an input to further research concerning the formulation and testing of hypotheses linking transportation and urban form.

The classification was accomplished through the sequential application of two multivariate statistical methods: factor analysis and cluster analysis. Factor analysis was used to simplify the multivariate data structure by identifying the predominant interrelationships between the variables and removing redundancy due to intercorrelations that might attribute an implicit weighting to strongly correlated variables in the grouping process [see Green et al. (29) for a discussion of redundancy in classification]. This simplification is accomplished by formulating a smaller set (<53) of new latent factors that are linear combinations of the original 53 variables and are the best set of factors in the sense of describing as much of the original variance as possible within the limits of the decreased dimensionality. Factor analysis is described in general in texts on multivariate statistical methods [e.g., Anderson (3), Kendall (43), and Morrison (50)] and in considerable detail in specific expositions [Harman (32), Horst (36), and Mulaik (53)].

The factor analytic model can be written in matrix form as

$$X = A \cdot F + E \tag{1}$$

where X is the original (m by n) data matrix of the (m = 53) variables measured on the (n = 80) candidate metropolitan areas, A is the (m by p) matrix of factor coefficients or loadings relating the (m = 53) variables to the (p < 53) new latent factors, F is the (p by n) matrix of scores or evaluations of the (n = 80) metropolitan areas on the new (p) factors, and E is the (m by n) data matrix of observations on the composite of the (m) unique and error components for each variable. Following the establishment of certain plausible assumptions regarding the mutual independent of common, unique, and error components of each original variable (see previously cited references), the factor analytic model can be specified in statistical variance terms as

$$\Sigma = A\,\Phi A' + \psi \tag{2}$$

where Σ is the (m by m) matrix representing either the correlations, covariances, or cross-products of the original (m = 53) variables, A is the (m by p) matrix defined in Eq. 1, Φ is the (p by p) matrix of either correlations, covariances, or cross-products of the new latent factors, and ψ is the (m by m) composite matrix of the unique and error variances associated with the (m = 53) variables.

In the factor analytic model employed in this research, the new latent factors are specified as orthogonal or mutually independent, and Φ becomes a diagonal matrix. Moreover, because of the diverse nature of the measurement scales of the 53 variables (e.g., absolute numbers of persons and percentages of the populations using public transit), the correlation matrix was chosen to portray the variable variance interrelationships. Thus Φ is the identity matrix (each diagonal element being the correlation of a factor with itself), and

$$\Sigma = AA' + \psi \tag{3}$$

Equation 3 was solved for the loadings matrix A through a determination of the latent roots (eigenvalues) and latent vectors (eigenvectors) of the correlation matrix Σ. The scores matrix F in Eq. 1 is then found through a least-squares estimation

$$\hat{F} = (A'A)^{-1} A'X \tag{4}$$

such that the contribution of the unique and error composite matrix E (the information to be discarded in favor of the simplified data structure) is minimized [see Johnston (40) and texts on regression analysis for a discussion of this estimation technique].

The eigenvalues defining the new latent factors are extracted sequentially, in order of the proportion of the original variance in Σ accounted for by each factor. Through subjective judgment, in which reduction in dimensionality was compared to sufficiency of explanation, this extraction process was terminated at $p = 15$; the new 15 latent factors together accounted for over 86 percent of the original variance of the 53 manifest variables. The resulting (53 by 15) loadings matrix A was then rotated through application of the varimax procedure developed by Kaiser (41) and discussed in the previously cited references on factor analytic methods. This was done in order to simplify the interpretation of the latent factors in terms of the original variables by creating as many coefficients of very large and very small absolute value as possible (i.e., approaching 1.0, -1.0, or 0.0 in magnitude, or expressing very strong positive, very strong negative, or very weak correlation between a variable and a factor) while preserving the important properties of the solution. The rotated A matrix is shown in Figure 3.

Interpretation of the 15 latent factors in terms of the original 53 manifest variables is useful in improving understanding of the complex interrelationships between aggregate urban structure and needs and requirements for arterial transportation systems. As stated by Janson (37) and Palm and Caruso (56) in discussions of the applications of factor analytic models to ecological data, these types of interpretations are necessary if latent factors are to have anything more than a purely mathematical meaning. In the research described here, such interpretations are only a first step in the determination of such interrelationships; further steps are explicitly incorporated within the procedure to estimate national markets and total social, economic, and environmental impacts of new systems of arterial transportation.

A brief interpretation of the 15 latent factors is shown in Figure 4; the most significant factor-variable correlations are identified, as well as the metropolitan areas that have extremely high or low scores on each factor (i.e., outstanding elements in the F matrix). Such an interpretation of latent dimensions of differentiation between metropolitan areas is consistent with studies known as factorial ecology conducted by urban geographers and sociologists. These studies, in which the spatial units of analysis range from urban neighborhoods to nation states, have their genesis in a study of cities by Price (57) and the social area analysis of metropolitan census tracts by Shevky and his colleagues (65, 66).

Social area analysis, in which latent factors of differentiation are linked to broad postulates concerning dynamics of industrialization and urbanization, has been verified and extended through studies in numerous metropolitan areas [e.g., see Tryon (72, 73), Van Arsdol et al. (76), Bell (5, 6), McElrath (46), Sweetzer (70), Uldry (75), and Salins (64)], but the sociological hypotheses have been the subject of much debate [see Hawley and Duncan (34) and Bell and Greer (7)]. Other applications of factor analytic and related multivariate methods to spatial data are found, for example, in Berry (8, 9, 10, 11), Stone (69), and Ray and Berry (58). Integration of the basic concepts of social space and urban ecological space to be found in the foregoing works is pursued in Greer (30), Orleans (55), Clarkson (21), and Johnson (39), and a typology of factorial ecology methods and application is given in Berry (12) and Rees (59).

Cluster analysis, the second multivariate statistical method employed in the classification process, was used to determine optimal groupings of the 80 candidate metropolitan areas on the basis of their values on the 15 latent factors. A variety of cluster analysis techniques is available for the purpose of classifying objects into relatively homogeneous groups, and the choice among these techniques depends on the selection of a criterion for optimality, characteristics of the solution algorithm, and summary statistic options. Sokal and Sneath (68) and Frank and Green (24) describe a number of taxonomic techniques, and Taylor (71) provides a typology [reprinted in Rees (60)] of techniques applied to spatial data. Specific techniques of note are given in Rohlf and Sokal (62), Ward (77), McQuitty (47), Cattell and Coulter (19), Tryon and Bailey (74), Friedman and Rubin (25), and Johnson (38).

Figure 3. Rotated factor loadings matrix (only loadings with absolute value > 0.40 shown).

VARIABLE	FACTOR 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. AREA	.87														
2. RADIUS OF DEVELOPMENT							-.89								
3. No. INC. CITIES	.65														
4. No. CENTRAL CITIES	.74														
5. POPULATION	.95														
6. AGE OF CENTRAL CITY														.75	
7. POP. GROWTH FACTOR											-.80				
8. % POP. IN CENTRAL CITY		.47				-.52									
9. POP. DENSITY IN CENTRAL CITY	.55													.64	
10. POP. DENSITY IN FRINGE						.40								.51	
11. % NON-WHITE									-.64						
12. % POP. < 18 YRS.				.87											
13. % POP. > 64 YRS.				-.83											
14. PERSONS/HOUSEHOLD				.85											
15. % HOUSING SOUND		-.81													
16. % SINGLE-UNIT HOUSING	-.41								-.40					-.55	
17. % GROUP QUARTER HOUSING										-.84					
18. MEDIAN HOUSING VALUE		-.63													
19. PER CAPITA INCOME		-.82													
20. PER CAPITA INCOME GROWTH		.83													
21. PROJ. MEAN HOUSEHOLD INCOME		-.68		.45											
22. PROJ. % POOR HOUSEHOLDS		.80		-.41											
23. PROJ. % AFFLUENT HOUSEHOLDS		-.71		.45											
24. CONCENTRATION OF POOR IN CENTRAL CITY														.74	
25. NONWORKER-WORKER RATIO					.72										
26. % MARRIED WOMEN WORKING					-.84										
27. % WHITE COLLAR			-.81												
28. AUTOS/FAMILY						.43								-.67	
29. % CENTRAL CITY HOUSEHOLDS WITH NO AUTO														.84	
30. % FRINGE HOUSEHOLDS WITH NO AUTO		.61					.42								
31. % REVERSE COMMUTING															.62
32. % COMMUTING TO CENTRAL CITY						.40									
33. % FRINGE COMMUTING						.90									
34. % CENTRAL CITY WORKERS USING TRANSIT	.53													.78	
35. % FRINGE WORKERS USING TRANSIT	.48													.71	
36. % WORKERS WALKING									.88						
37. % WORKERS USING RAIL	.89														
38. TOTAL TRANSIT VEHICLES	.94														
39. % SALES IN CBD						-.47									
40. % CHANGE IN CBD SALES															-.60
41. RETAIL STORES/CAPITA				-.61											
42. EMPLOYEES/MFG. ESTABL.			.68												
43. SERVICE RECEIPTS/CAPITA	.54		-.52												
44. MEAN JAN. TEMP.									-.61						
45. PROJ. PRINC. ART. DVMT	.84														
46. % CHANGE-PRINCIPAL ARTERIAL DVMT								.80							
47. PROJ. % DVMT-PRINCIPAL ARTERIAL												.84			
48. PROJ. % DVMT-FWYS.												.69			
49. PROJ. PRINCIPAL ARTERIALS DVMT/CAPITA								.56	-.41						
50. PROJ. ROUTE MILES-FWYS.															
51. PROJ. INCREASE-PRINC. ART. RT. MI.	.91														
52. GROWTH FACTOR; PRINC. ART. DVMT/RT. MI.	.83												-.81		
53. PROJ. PRINC. ART. DVMT/RT. MI.												.48			
PERCENT VARIANCE ACCOUNTED FOR:	16.9	11.4	4.1	7.0	4.2	4.6	3.2	3.2	5.3	2.7	2.7	4.1	2.7	11.3	2.8
RANK	1	2	8	4	7	6	10	11	5	13	14	9	15	3	12

Figure 4. Factor interpretation.

RANK ORDER	EIGENVECTOR NUMBER	% OF ORIGINAL VARIANCE ACCOUNTED FOR	FACTOR INTERPRETATION	AREAS WITH HIGHEST SCORES	AREAS WITH LOWEST SCORES
1	1	16.9	SIZE OF POPULATION AND AREA; CENTRAL CITY DENSITY; PUBLIC TRANSIT USAGE; SERVICE SECTOR ACTIVITY.	NEW YORK CHICAGO LOS ANGELES PHILADELPHIA	WILMINGTON ROCHESTER BRIDGEPORT SALT LAKE CITY
2	2	11.4	INCOME LEVEL; VALUE AND SOUNDNESS OF HOUSING; CONCENTRATION OF POPULATION IN SUBURBS; AUTO AVAILABILITY IN SUBURBS.	SAN JOSE BRIDGEPORT	MOBILE BIRMINGHAM KNOXVILLE MEMPHIS
3	14	11.3	POPULATION DENSITY; PUBLIC TRANSIT USAGE; UNAVAILABILITY OF AUTOS; AGE OF CITY; CONCENTRATION OF AREA POOR IN CENTRAL CITY.	WASHINGTON BOSTON NEW ORLEANS BUFFALO	SAN BERNARDINO LOS ANGELES PHOENIX
4	4	7.0	INCOME LEVEL; YOUTHFULNESS OF POPULATION; FAMILY SIZE; LOW LEVEL OF RETAIL SALES ACTIVITY.	WASHINGTON EL PASO HONOLULU	TAMPA W. PALM BEACH FT. LAUDERDALE PORTLAND
5	9	5.3	WHITE POPULATION IN MULTIPLE-UNIT HOUSING; HIGH PROPORTION OF WORK TRIPS ON FOOT; FEW PRINCIPLE ARTERIAL ROADS; COLDER CLIMATE.	DULUTH EL PASO MADISON WORCESTER UTICA	HONOLULU FT. LAUDERDALE
6	6	4.6	POPULATION CONCENTRATION AND DENSITY IN SUBURBS; WORKERS COMMUTING WITHIN SUBURBS AND TO CENTRAL CITY; AUTO AVAILABILITY; LOW CBD RETAIL ACTIVITY.	PITTSBURGH LOS ANGELES SAN BERNARDINO ORLANDO W.PALM BEACH	TOLEDO INDIANAPOLIS NEWPORT NEWS NEW YORK CHARLOTTE
7	5	4.2	LABOR FORCE PARTICIPATION RATE.	HONOLULU DALLAS CHARLOTTE HARTFORD	DETROIT PITTSBURGH TAMPA TUCSON
8	3	4.1	CONCENTRATION OF EMPLOYMENT IN BLUE COLLAR JOBS AND IN LARGE MANUFACTURING PLANTS; LOW SERVICE SECTOR ACTIVITY.	FLINT YOUNGSTOWN BEAUMONT NEWPORT NEWS DAVENPORT	ALBUQUERQUE WASHINGTON SALT LAKE CITY
9	12	4.1	CONCENTRATION OF PROJECTED ROADWAY USAGE ON FREEWAYS AND OTHER PRINCIPAL ARTERIALS.	LOS ANGELES EL PASO DALLAS SAN ANTONIO SAN FRANCISCO	YOUNGSTOWN ORLANDO DAYTON
10	7	3.2	HIGH PROPORTION OF HOUSEHOLDS IN SUBURBS WITH NO AUTO; LAND DEVELOPMENT RESTRICTED BY PHYSICAL FEATURES.	SAN FRANCISCO	LANSING FLINT RICHMOND NASHVILLE
11	8	3.2	PROJECTED RATE OF INCREASE IN PRINCIPAL ARTERIAL ROADWAY USAGE; LEVEL OF ARTERIAL USAGE PER CAPITA.	W.PALM BEACH SAN BERNARDINO ORLANDO WORCESTER	LOS ANGELES
12	15	2.8	PROPORTION OF WORKERS REVERSE COMMUTING; PROPORTIONAL DECREASE IN CBD RETAIL SALES ACTIVITY.	HONOLULU WICHITA ALBANY TUCSON	DALLAS MINNEAPOLIS
13	10	2.7	PROPORTION OF POPULATION LIVING IN GROUP QUARTERS.	NORFOLK TACOMA SAN DIEGO	TULSA DALLAS
14	11	2.7	RATE OF POPULATION GROWTH	TAMPA MIAMI	OKLAHOMA CITY MOBILE AKRON KANSAS CITY
15	13	2.7	PROJECTED RATE OF INCREASE IN PRINCIPAL ARTERIAL USAGE PER MILE OF ROADWAY	ALBUQUERQUE	BEAUMONT JACKSONVILLE WASHINGTON

The cluster analysis technique chosen was a version of a method developed by Friedman and Rubin (25) in which an approximation of the Wilks' λ-statistic is optimized through use of a hill-climbing partitioning algorithm due to Rubin (63). The algorithm features heuristic object reassignments and restarts in order to dislodge from local optima, and the relatively homogeneous groups found are mutually exclusive and exhaustive of the set of metropolitan areas. The criterion function is derived from the basic matrix identity relating variance or scatter in grouped data (79):

$$T = W + B \tag{5}$$

where T is the total data scatter matrix, W is the pooled within-group scatter matrix, and B is the between-group scatter matrix. Since the clustering of the 80 metropolitan areas was based on the distribution of the areas in the space of the 15 latent factors, given by the (15 by 80) factor scores matrix F,

$$T = FF' \tag{6}$$

which remains constant throughout the clustering process. A clear objective is then to minimize W (i.e., make the individual groups, taken together, as compact as possible) or, equivalently, maximize B (i.e., make the groups as far removed from each other as possible).

The scalar function chosen to represent this objective is the ratio of the determinants of T and W:

$$\frac{|T|}{|W|} = |I + W^{-1}B| \tag{7}$$

where I is the identity matrix. This function, due to Wilks (78), exhibits the important property of being invariant under non-singular linear transformations of the factor scores matrix, thus addressing the problem of circular indeterminancy between metric and group formulation discussed in Friedman and Rubin (25). In the degenerate case of one-dimensional data (p = number of latent factors = 1), maximization of the Wilks' λ-statistic is equivalent to maximization of a quantity (B/W) proportional to the familiar F-statistic.

Eight applications of the clustering program, each application complete with a series of restarts from random group partitions to help avoid termination on local maxima (which is never completely assured), were used to classify the 80 metropolitan areas into 5, 6, 7, 8, 9, 10, 11, and 12 groups. From these clusterings the 9-group level was selected through subjective judgment in which increases in homogeneity were weighted against numbers of potential case studies as the classification scheme for empirical elaboration of the further steps in the procedure to estimate national markets and total social, economic, and environmental impacts of new systems of arterial transportation. This classification is shown in Figure 5. The pronounced geographical distributions of the groups are shown in Figure 6. The salient features of the 9 groups, as reflected in their outstanding mean values on the 15 latent factors, are summarized in Figure 7. Two-dimensional plots of the metropolitan areas by group in the spaces formed by pairs of the most important latent factors (i. e., factors associated with eigenvectors 1, 2, 4, and 14) are given in the expanded version of Golob et al. (27).

Two additional multivariate statistical methods were applied to the data in order to provide information about the classification scheme complementary to that obtained in the cluster analysis: A hierarchical grouping analysis based on the diameter method evaluations of Euclidean distances [due to Johnson (38)] supplied information concerning outlying (i.e., difficult to classify) metropolitan areas, and a step-wise multiple linear discriminant analysis [see previously cited references on multivariate methods and Morrison (51)] supplied information concerning the replication of groups through the use of hyperplanes in the spaces of particular subsets of the original manifest variables. Results from these applications are detailed in Golob et al. (27).

Figure 5. Nine-group level clustering (Wilks' λ criterion value = 8.23).

9-GROUP LEVEL CLUSTERING

(WILKS'-LAMBDA CRITERION VALUE = 8.23)

GROUP 1	GROUP 4	GROUP 6	GROUP 7	GROUP 9
NEW YORK	ATLANTA	AKRON	BEAUMONT	ALBUQUERQUE
	BIRMINGHAM	ALBANY	DALLAS	DAVENPORT
	CHARLOTTE	BRIDGEPORT	EL PASO	DAYTON
	HONOLULU	BUFFALO	FORT WORTH	DULUTH
	JACKSONVILLE	CINCINNATI	HOUSTON	FLINT
GROUP 2	KNOXVILLE	CLEVELAND	PHOENIX	LANSING
	LOUISVILLE	COLUMBUS	SAN ANTONIO	MADISON
LOS ANGELES	MEMPHIS	GRAND RAPIDS	SAN BERNARDINO	MINNEAPOLIS
CHICAGO	MOBILE	HARTFORD	SAN DIEGO	NEWPORT NEWS
	NASHVILLE	MILWAUKEE	SAN FRANCISCO	OMAHA
	NEW ORLEANS	RICHMOND	SAN JOSE	TUCSON
	NORFOLK	ROCHESTER		UTICA
GROUP 3	GROUP 5	SACRAMENTO	GROUP 8	WICHITA
		SALT LAKE CITY		YOUNGSTOWN
BALTIMORE	DENVER	SYRACUSE	FORT LAUDERDALE	
BOSTON	INDIANAPOLIS	TOLEDO	MIAMI	
DETROIT	KANSAS CITY	WILMINGTON	ORLANDO	
PHILADELPHIA	OKLAHOMA CITY	WORCESTER	TAMPA	
PITTSBURGH	PORTLAND		WEST PALM BEACH	
ST. LOUIS	PROVIDENCE			
WASHINGTON	SEATTLE			
	SPRINGFIELD			
	TACOMA			
	TULSA			

Figure 6. Geographical distribution of the groups.

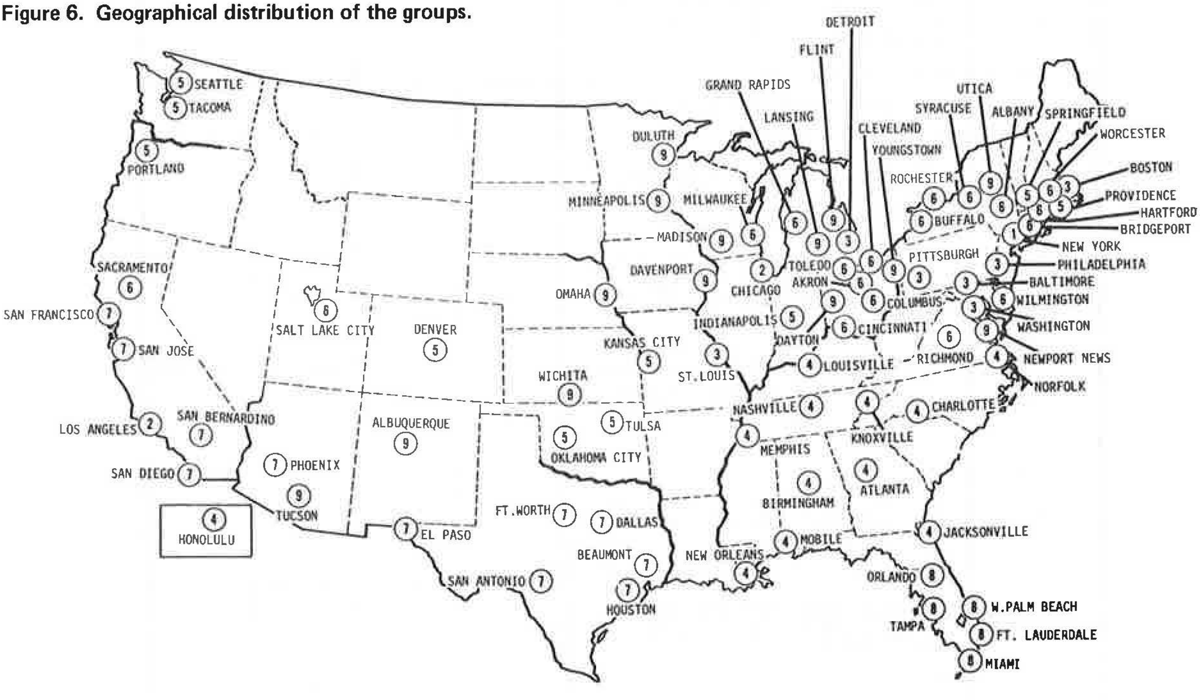

Figure 7. Factor interpretation for 9 groups.

EIGENVECTOR NUMBER	FACTOR INTERPRETATION	GROUPS WITH OUTSTANDING MEANS		GROUPS WITH OUTSTANDING STD. DEV.	
		HIGH	LOW	HIGH	LOW
1	SIZE OF POPULATION AND AREA; CENTRAL CITY DENSITY; PUBLIC TRANSIT USAGE; SERVICE SECTOR ACTIVITY.	--	6	3	--
2	INCOME LEVEL; VALUE AND SOUNDNESS OF HOUSING; CONCENTRATION OF POPULATION IN SUBURBS; AUTO AVAILABILITY IN SUBURBS.	6	4	7	--
14	POPULATION DENSITY; PUBLIC TRANSIT USAGE; UNAVAILABILITY OF AUTOS; AGE OF CITY; CONCENTRATION OF AREA POOR IN CENTRAL CITY.	3	7	--	--
4	INCOME LEVEL; YOUTHFULNESS OF POPULATION; FAMILY SIZE; LOW LEVEL OF RETAIL SALES ACTIVITY.	--	8	3,8	--
9	WHITE POPULATION IN MULTIPLE-UNIT HOUSING; HIGH PROPORTION OF WORK TRIPS ON FOOT; FEW PRINCIPLE ARTERIAL ROADS; COLDER CLIMATE.	9	8	9	4
6	POPULATION CONCENTRATION AND DENSITY IN SUBURBS; WORKERS COMMUTING WITHIN SUBURBS AND TO CENTRAL CITY; AUTO AVAILABILITY; LOW CBD RETAIL ACTIVITY.	3	6	--	--
5	LABOR FORCE PARTICIPATION RATE.	3	--	--	5
3	CONCENTRATION OF EMPLOYMENT IN BLUE COLLAR JOBS AND IN LARGE MANUFACTURING PLANTS; LOW SERVICE SECTOR ACTIVITY.	--	5,8	9	--
12	CONCENTRATION OF PROJECTED ROADWAY USAGE ON FREEWAYS AND OTHER PRINCIPAL ARTERIALS.	7	9	--	--
7	HIGH PROPORTION OF HOUSEHOLDS IN SUBURBS WITH NO AUTO; LAND DEVELOPMENT RESTRICTED BY PHYSICAL FEATURES.	8	--	--	3
8	PROJECTED RATE OF INCREASE IN PRINCIPAL ARTERIAL ROADWAY USAGE; LEVEL OF ARTERIAL USAGE PER CAPITA.	8	--	8	4,5
15	PROPORTION OF WORKERS REVERSE COMMUTING; PROPORTIONAL DECREASE IN CBD RETAIL SALES ACTIVITY.	8	--	9	--
10	PROPORTION OF POPULATION LIVING IN GROUP QUARTERS.	8	5	5,7	--
11	RATE OF POPULATION GROWTH	5	8	--	5,7
13	PROJECTED RATE OF INCREASE IN PRINCIPAL ARTERIAL USAGE PER MILE OF ROADWAY	5	--	--	5,8

Results of the 6, 7, 8, 10, and 11-group clusterings are also found in the expanded version of Golob et al. (27). The maximum value of the Wilks' λ-statistic was found to be approximately linear across this range, providing evidence that there exists no "natural" number of groups in the range and contributing assurance that no clustering was determined by local maxima significantly different from the global maxima.

While the factor and cluster analytic classification process described here is, to the knowledge of the authors, a unique approach in terms of its integration as one step in an estimation procedure and in terms of its methodologies and its data base, it is related in concept to functional city classification studies conducted by geographers and other social scientists. The first city classification related in terms of being based on empirically derived multivariate classification criteria was that of Ogburn (54). This non-factorial work was advanced by Harris (33) and Kneedler (45), among others, and has been expanded in a number of studies [particularly Forstall (22)].

Classifications based on latent structure derived through factor analytic or related methods began with Moser and Scott (52) in their study of British towns. Ahmad (1), Hadden and Borgatta (31), and King (44) have all contributed revealing analyses (of Indian cities, U.S. cities over 25,000 population, and Canadian cities respectively), and comprehensive classifications of all U.S. urban places have been recently reported by Forstall (23), Berry (14), and Meyer (49). Discussions of the methods, purposes, and limitations of such city classification schemes can be found in Smith (67), Berry (13, 14), Alford (2), Arnold (4), and Clark (20). Noteworthy transportation-related classifications (which have not, in general, reflected the state of the art as demonstrated in the above studies) are those of Bottiny and Goley (15), Ganz (26), Henderson et al. (35), Mendelson et al. (48), Graves and Rechel (28), and Kassoff and Gendell (42).

A SELECTION OF CASE STUDY LOCALES

The number of groups chosen to represent the similarities and differences between the 80 candidate metropolitan areas (in this application, 9) determines the necessary number of case studies of the proposed new transportation system. However, the intensity of the individual case studies might vary significantly, and, in the extreme, entire groups might be dismissed from consideration of the national markets and impacts on the basis of criteria external to the estimation procedure. For example, the group consisting of the New York Standard Consolidated Area, or even the group consisting of the Chicago and Los Angeles areas, might be a priori dismissed from considerations of certain classes of arterial systems.

The order of preference within each group for case study locales is identical to the order of representativeness of the metropolitan areas within that group. This is a basic postulate in the development of the statistical procedure to estimate national markets and total social, economic, and environmental impacts of new systems of urban transportation; it is conceptually discussed in the section of this paper on research objectives and is methodologically specified in Canty and Golob (18).

The representativeness rankings for groups 3 through 9 (the concept is not defined for groups made up of less than 3 metropolitan areas) were generated by subjectively combining for each group 3 distinct statistical criteria of representativeness for each of the metropolitan areas within that group. The first criterion was the generalized Mahalanobis distance from the metropolitan area to the center of its group in the space of the 15 orthogonal factors, which is simply the Euclidean distance between the points weighted in terms of the metric of the pooled within-group scatter matrix W [see Friedman and Rubin (25)]. The second criterion was the measurement of the decrease in the maximum value of the Wilks' λ-statistic resulting from movement of the area from its assigned group to the "next best" group. And the third criterion was the number of significant Q-type product-moment correlations between the area and the other areas within its group. This latter criterion, measuring the number of pair-wise significant associations, was employed in isolation by Zenk and Frost (80) to similarly identify case study locales.

The resultant representativeness rankings for the 9 groups are given in Figure 8. The representativeness rankings for the 6, 7, 8, 10, and 11-group clusterings, which

Figure 8. Areas ranked by representativeness in each group (9-group level).

GROUP 1	GROUP 4	GROUP 6	GROUP 7	GROUP 9
(1) NEW YORK	1. NASHVILLE	1. MILWAUKEE	1. SAN JOSE	1. OMAHA
	2. MEMPHIS	2. GRAND RAPIDS	2. FORT WORTH	2. DAVENPORT
GROUP 2	3. BIRMINGHAM	3. CINCINNATI	3. HOUSTON	3. UTICA
	4. JACKSONVILLE	4. SYRACUSE	4. PHOENIX	4. DULUTH
(1) CHICAGO	5. ATLANTA	5. COLUMBUS	5. SAN ANTONIO	5. LANSING
(1) LOS ANGELES	6. CHARLOTTE	6. AKRON	6. SAN BERNARDINO	6. DAYTON
	7. MOBILE	7. TOLEDO	7. SAN DIEGO	7. YOUNGSTOWN
GROUP 3	8. NEW ORLEANS	8. ROCHESTER	8. BEAUMONT	8. MINNEAPOLIS
	9. KNOXVILLE	9. CLEVELAND	9. DALLAS	9. TUCSON
1. ST. LOUIS	10. LOUISVILLE	10. HARTFORD	10. EL PASO	10. WICHITA
2. BOSTON	11. NORFOLK	11. ALBANY	11. SAN FRANCISCO	11. MADISON
3. DETROIT	12. HONOLULU	12. BRIDGEPORT		12. FLINT
4. PHILADELPHIA		13. SALT LAKE CITY	GROUP 8	13. ALBUQUERQUE
5. PITTSBURGH	GROUP 5	14. WILMINGTON		14. NEWPORT NEWS
6. BALTIMORE		15. SACRAMENTO	1. FORT LAUDERDALE	
7. WASHINGTON	1. KANSAS CITY	16. BUFFALO	2. WEST PALM BEACH	
	2. OKLAHOMA CITY	17. WORCESTER	3. MIAMI	
	3. DENVER	18. RICHMOND	4. TAMPA	
	4. PORTLAND		5. ORLANDO	
	5. SEATTLE			
	6. SPRINGFIELD			
	7. INDIANAPOLIS			
	8. PROVIDENCE			
	9. TULSA			
	10. TACOMA			

are different from the 9-group rankings because of the distinct shifts of group centers and area assignments encountered in clustering into varying numbers of groups, are provided in the expanded version of Golob et al. (27). Also given in this reference are summary tables of the 3 representativeness criteria measurements for the 8- and 9-group clusterings of the 80 metropolitan areas.

While the selection of case study locales should be highly influenced by the degree of representativeness of metropolitan areas relative to their groups, additional factors enter into the decision. These include the quality and quantity of available and relevant data on the metropolitan area and its projected needs for arterial transportation facilities. Inasmuch as local planning agencies should be involved in the conduct of the case studies and sensitivity analyses, either in a leading or technically supportive role, the qualifications and staffing of local land use and transportation planning agencies are also important, as is their evidenced interest in cooperative efforts with planning groups conducting parallel studies in other case study areas. Case study areas should also be selected where the community as a whole and its political leaders would likely be receptive to the implementation of the subject system, if and when the system could be shown to be cost-effective and socially and environmentally beneficial. Such reception enhances the likelihood of acquiring a more empirical data base on which system size, costs, and impacts can be estimated for other metropolitan areas. Clearly, the selection among metropolitan areas as case study locales must be based on such subjective judgments of sociopolitical factors as well as rank order of representativeness as determined by statistical analyses.

EXTENSION OF CASE STUDY RESULTS

The objective here is to estimate the overall market for, or the overall costs and benefits that would be incident to the implementation of, some specified urban system (e.g., the Metro Guideway arterial transportation system providing personal rapid transit and dual-mode functions). In this context, "overall" is for some totality of metropolitan areas to which the new system might initially be considered applicable.

Let it be assumed that case studies of the contemplated new system have been conducted in some limited number of metropolitan locales such that the remaining tasks are to estimate the appropriate system size (market), its cost, social and environmental impacts, etc., in the remaining metropolitan areas, and to aggregate the results. If the case study locales were selected by some disciplined process (such as described in the preceding sections) so that each is representative of a fairly homogeneous group of metropolitan areas (the groups being mutually exclusive and exhaustive of the total set of metropolitan areas considered), the most appropriate procedure is extrapolating case study results from each case study area to the other metropolitan areas in its group and then aggregating results over all groups. The process of extrapolation presents conceptual difficulties whereas the process of aggregation is comparatively trivial, and only the first warrants detailed discussion.

The present state of the art of market research, requirements analysis, and national benefit-cost analysis for urban systems is relatively primitive. The most common procedure appears to be based on stratifying the total set of metropolitan areas by one or two variables (typically metropolitan area population, or population plus a second variable such as density) and then to extrapolate the results (e.g., the required number of transit vehicles) in direct proportion to the population of the case study area and the other areas in its stratified group [for examples, see Kassoff and Gendell (42) or Graves and Rechel (28)]. It will be recognized that a decision to extrapolate case study results in direct proportion to population or any other single metropolitan area characteristic carries with it the assumption that no other variables need be or should be considered as influencing system utilization, costs, environmental impacts, etc.

An alternative approach, part of the research framework described in this paper, is to estimate the influence of several metropolitan area characteristics (variables), rather than population size alone, in the extrapolation of case study results. Differentials in the size, costs, and impacts of the new system between a case study area and other metropolitan areas in its group are estimated on the basis of knowledge of the differences in their metropolitan area characteristics and the sensitivity of system size, cost, and impacts to those metropolitan area characteristics. Differences in the characteristics between the case study locale and other metropolitan areas (intra-group variance) are described via a factor analytic process similar to that outlined earlier. Sensitivity analyses are made with respect to several metropolitan area characteristics as a part of the case study process.

This approach is tantamount to assuming that, within a relatively homogeneous group of urban areas, the system size, cost, or impact (each of which is considered as a vector, i.e., composed of an array of numbers) can be expressed as a continuous and differentiable function over a space defined from the metropolitan area characteristics, with the partial derivatives of the function developed via the sensitivity analyses. In comparison, the currently employed procedure of scaling system size, cost, and impacts in direct proportion to metropolitan area population represents a special and restrictive case of the alternative approach suggested here, with all but one of the partial derivatives (sensitivities) being considered to be null.

For the case of 80 metropolitan areas classified into 9 groups, factor analyses were performed on data sets composed of the original variables and the metropolitan areas in groups 3 through 9. (All 53 variables were included in the factor analysis for group 3; however, one variable—the percentage of work trips by rail transit—was excluded from the analyses for groups 4 through 9 due to zero variance. Honolulu, a statistical outlyer, was excluded from analysis of group 4.) The methodology of the factor analyses is similar to that discussed and referenced previously except that in each factor analysis here, the set of observations is restricted to those metropolitan areas comprising each group, and the process is repeated for each group. Group 1, the New York Consolidated Area, and Group 2, composed of the Chicago and Los Angeles areas, were not subject to these analyses.

Summary results of these intra-group factor analyses are given in Figure 9. As before, factors are listed in rank order by the amount of variance for which they account and are identified in terms of the most significant factor-variable correlations. Those metropolitan areas are noted that have particularly high positive or high negative (i.e., low) scores on the factors.

The intra-group factor analyses provide an analytic framework for the extension of the case study results. As before, one may give an interpretation to the factors in terms of which variables are principally involved, but here one is interested in using such interpretations as guidelines for sensitivity analysis. Thus, for group 7, factor 1 is highly correlated with size variables such as population and factor 2 with variables

Figure 9. Results of intra-group factor analyses.

FACTOR	PERCENT VARIANCE ACCOUNTED FOR	OUTSTANDING FACTOR LOADINGS		OUTSTANDING FACTOR SCORES	
		COEFFICIENT	VARIABLE	AREAS WITH HIGHEST SCORES	AREAS WITH LOWEST SCORES
GROUP 3					
1	32.3	+0.98	PROJ. MEAN HOUSEHOLD INCOME	WASHINGTON	
		+0.98	CONCENTRATION OF POOR IN CENTRAL CITY		
		+0.95	MEDIAN HOUSING VALUE		
		+0.93	% WHITE COLLAR		
		+0.92	PROJ. % AFFLUENT HOUSEHOLDS		
		+0.91	SERVICE RECEIPTS / CAPITA		
		+0.89	% WORKERS COMMUTING TO CENTRAL CITY		
		+0.89	PROJ. PRINCIPAL ARTERIALS DVMT / CAPITA		
		-------	-------		
		+0.83	PERSONS / HOUSEHOLD		
		+0.82	PROJ. % POP. <18 YRS.		
		-0.82	PROJ. % POOR HOUSEHOLDS		
		-0.77	NONWORKER-WORKER RATIO		
		-0.76	RETAIL ESTABLISHMENTS / CAPITA		
		-0.76	AVG. EMPLOYEES / MFG. ESTABL.		
		-------	-------		
		(0.72)	(NEXT HIGHEST LOADING)		
2	22.8	+0.95	PER CAPITA INCOME GROWTH	PHILADELPHIA BOSTON	DETROIT
		+0.92	% CENTRAL CITY WORKERS USING TRANSIT		
		+0.91	POP. DENSITY IN CENTRAL CITY		
		-------	-------		
		-0.86	PROJ. % DVMT ON PRINCIPAL ARTERIALS		
		+0.85	TOTAL TRANSIT VEHICLES		
		+0.83	No. OF CENTRAL CITIES		
		+0.81	% WORKERS USING RAIL		
		+0.79	FRINGE WORKERS USING TRANSIT		
		-------	-------		
		(0.72)	(NEXT HIGHEST LOADING)		
3	20.0	+0.94	% FRINGE COMMUTING	PITTSBURGH BOSTON	BALTIMORE
		-0.90	% NON-WHITE		
		-------	-------		
		-0.82	% POP. IN CENTRAL CITY		
		-0.80	PER CAPITA INCOME		
		-0.80	% CHANGE-PRINCIPAL ARTERIAL DVMT		
		+0.78	% FRINGE HOUSEHOLDS WITH NO AUTO		
		+0.74	% WORKERS WALKING		
		-0.70	POP. GROWTH FACTOR		
		-------	-------		
		(0.63)	(NEXT HIGHEST LOADING)		
4	15.3	+0.92	AREA	DETROIT	BALTIMORE
		+0.92	POPULATION		
		+0.91	PROJ. PRINCIPAL ARTERIAL DVMT		
		+0.86	PROJ. PRINCIPAL ARTERIAL DVMT / ROUTE MILE		
		-------	-------		
		-0.75	RADIUS OF DEVELOPMENT		
		-------	-------		
GROUP 4					
1	18.7	+0.96	TOTAL TRANSIT VEHICLES	NEW ORLEANS ATLANTA	
		+0.90	POPULATION		
		-0.87	% SINGLE-UNIT HOUSING		
		-------	-------		
		+0.82	MEDIAN HOUSING VALUE		
		+0.79	% CENTRAL CITY WORKERS USING TRANSIT		
		+0.78	AREA		
		+0.76	% WHITE COLLAR		
		+0.74	PROJ. PRINCIPAL ARTERIAL DVMT		
		-------	-------		
		(0.61)	(NEXT HIGHEST LOADING)		
2	13.6	+0.93	PERSONS / HOUSEHOLD	NORFOLK	
		+0.80	PROJ. MEAN HOUSEHOLD INCOME		
		-0.76	% POP. >64 YRS.		
		-------	-------		
		+0.69	% GROUP QUARTER HOUSING		
		+0.68	PROJ. % AFFLUENT HOUSEHOLDS		
		-0.68	% SALES IN CBD		
		+0.66	% POP. <18 YRS.		
		-------	-------		
		(0.61)	(NEXT HIGHEST LOADING)		
3	13.5	+0.91	% MARRIED WOMEN WORKING	CHARLOTTE	
		-0.90	NONWORKER-WORKER RATIO		
		-0.82	POP. DENSITY IN FRINGE		
		-------	-------		
		-0.74	% FRINGE WORKERS USING TRANSIT		
		+0.71	PROJ. PRINCIPAL ARTERIAL DVMT / CAPITA		
		+0.66	SERVICE RECEIPTS / CAPITA		
		-------	-------		
		(0.53)	(NEXT HIGHEST LOADING)		

Figure 9. Continued.

FACTOR	PERCENT VARIANCE ACCOUNTED FOR	OUTSTANDING FACTOR LOADINGS		OUTSTANDING FACTOR SCORES	
		COEFFICIENT	VARIABLE	AREAS WITH HIGHEST SCORES	AREAS WITH LOWEST SCORES
GROUP 4 (contd.)					
4	12.5	+0.86 +0.84 +0.82 +0.76 ------- (0.67)	% COMMUTING TO CENTRAL CITY % FRINGE COMMUTING CONCENTRATION OF POOR IN CENTRAL CITY % CHANGE IN CBD SALES ------- (NEXT HIGHEST LOADING)	KNOXVILLE	CHARLOTTE MOBILE
5	12.3	+0.90 ------- -0.76 +0.71 +0.69 ------- (0.64)	PROJ. INCREASE IN PRINCIPAL ARTERIAL RT.MI. ------- PER CAPITA INCOME GROWTH % CHANGE-PRINCIPAL ARTERIAL DVMT POP. GROWTH FACTOR ------- (NEXT HIGHEST LOADING)	JACKSONVILLE LOUISVILLE	KNOXVILLE
6	11.4	-0.84 +0.82 ------- +0.74 +0.67 -0.65 ------- (0.50)	PROJ. % POOR HOUSEHOLDS PROJ. % DVMT ON FREEWAYS ------- PROJ. RT. MI. - FWYS. AUTOS / FAMILY % CENTRAL CITY HOUSEHOLDS WITH NO AUTO ------- (NEXT HIGHEST LOADING)	ATLANTA	NEW ORLEANS
7	6.9	+0.83 ------- (0.54)	MEAN JAN. TEMP. ------- (NEXT HIGHEST LOADING)	JACKSONVILLE	NORFOLK LOUISVILLE
GROUP 5					
1	17.8	+0.91 +0.90 +0.85 -0.83 ------- -0.74 +0.69 -0.67 +0.66 -0.66 +0.65 ------- (0.60)	PROJ. % POOR HOUSEHOLDS MEAN JAN. TEMP. % SINGLE-UNIT HOUSING % WORKERS WALKING ------- PERSONS / HOUSEHOLD PROJ. PRINCIPAL ARTERIAL DVMT / CAPITA AGE OF CENTRAL CITY AUTOS / FAMILY PER CAPITA INCOME % WHITE COLLAR ------- (NEXT HIGHEST LOADING)		SPRINGFIELD PROVIDENCE
2	14.7	+0.93 -0.88 +0.84 ------- +0.76 ------- (0.67)	% GROUP QUARTER HOUSING % CHANGE IN CBD SALES NONWORKER-WORKER RATIO ------- % COMMUTING TO CENTRAL CITY ------- (NEXT HIGHEST LOADING)	TACOMA	TULSA SEATTLE
3	14.4	-0.88 +0.83 ------- +0.73 +0.71 +0.67 ------- (0.58)	% SALES IN CBD No. INC. CITIES ------- PROJ. INCREASE IN PRINCIPAL ARTERIAL RT. MI. AREA CONCENTRATION OF POOR IN CENTRAL CITY ------- (NEXT HIGHEST LOADING)	KANSAS CITY OKLAHOMA CITY	TULSA
4	13.5	+0.85 ------- +0.75 -0.73 -0.70 -0.69 ------- (0.63)	% CHANGE - PRINCIPAL ARTERIAL DVMT ------- RETAIL STORES / CAPITA TOTAL TRANSIT VEHICLES EMPLOYEES / MFG. ESTABL. % CENTRAL CITY WORKERS USING TRANSIT ------- (NEXT HIGHEST LOADING)	OKLAHOMA CITY TULSA PROVIDENCE	SEATTLE
5	12.6	+0.92 ------- +0.70 +0.68 ------- (0.64)	PROJ. % DVMT ON PRINCIPAL ARTERIALS ------- PROJ. PRINCIPAL ARTERIAL DVMT % HOUSING SOUND ------- (NEXT HIGHEST LOADING)	DENVER	TULSA
6	12.5	+0.90 +0.85 ------- -0.73 -0.70 ------- (0.65)	% FRINGE COMMUTING % POP. > 64 YRS. ------- % NON-WHITE % POP. in CENTRAL CITY ------- (NEXT HIGHEST LOADING)	PROVIDENCE PORTLAND	INDIANAPOLIS

Figure 9. Continued.

FACTOR	PERCENT VARIANCE ACCOUNTED FOR	OUTSTANDING FACTOR LOADINGS		OUTSTANDING FACTOR SCORES	
		COEFFICIENT	VARIABLE	AREAS WITH HIGHEST SCORES	AREAS WITH LOWEST SCORES
GROUP 6					
1	17.0	+0.95 +0.95 +0.93 +0.91 +0.90 +0.87 ------- (0.65)	POPULATION TOTAL TRANSIT VEHICLES No. INC. CITIES AREA PROJ. PRINCIPAL ARTERIAL DVMT PROJ. RT. MI. - FWYS. ------- (NEXT HIGHEST LOADING)	CLEVELAND	
2	13.1	-0.91 -0.84 +0.82 -0.77 ------- +0.69 -0.67 +0.66 ------- (0.57)	PROJ. PRINCIPAL ARTERIAL DVMT/CAPITA MEAN JAN. TEMP. % WORKERS WALKING % SINGLE - UNIT HOUSING ------- % POP. > 64 YRS. % NON-WHITE RETAIL STORES / CAPITA ------- (NEXT HIGHEST LOADING)	ALBANY	RICHMOND SACRAMENTO
3	11.4	-0.88 +0.80 +0.80 -0.80 ------- +0.71 ------- (0.61)	PROJ. % POOR HOUSEHOLDS PROJ. % AFFLUENT HOUSEHOLDS PROJ. MEAN HOUSEHOLD INCOME PER CAPITA INCOME GROWTH ------- PER CAPITA INCOME ------- (NEXT HIGHEST LOADING)	BRIDGEPORT HARTFORD ROCHESTER AKRON	
4	8.9	+0.91 +0.88 ------- (0.63)	CONCENTRATION OF POOR IN CENTRAL CITY % CENTRAL CITY HOUSEHOLDS WITH NO AUTO ------- (NEXT HIGHEST LOADING)	WILMINGTON	
5	8.5	+0.88 ------- +0.77 +0.73 ------- (0.53)	% GROUP QUARTER HOUSING ------- POP. GROWTH FACTOR % SALES IN CBD ------- (NEXT HIGHEST LOADING)	WORCESTER	
6	8.3	+0.85 ------- (0.53)	AUTOS / FAMILY ------- (NEXT HIGHEST LOADING)	SALT LAKE CITY	
7	7.5	+0.90 +0.81 ------- (0.47)	PROJ. INCREASE IN PRINCIPAL ARTERIAL RT. MI. POP. DENSITY IN FRINGE ------- (NEXT HIGHEST LOADING)	BUFFALO	
8	6.1	+0.86 ------- +0.67 ------- (0.61)	SERVICE RECEIPTS / CAPITA ------- % WHITE COLLAR ------- (NEXT HIGHEST LOADING)	ALBANY	WILMINGTON WORCESTER
9	5.4	-0.75 ------- (0.56)	PROJ. % DVMT ON FWYS. ------- (NEXT HIGHEST LOADING)	BUFFALO	
GROUP 7					
1	23.1	+0.97 +0.94 +0.92 +0.92 -0.90 +0.88 ------- +0.78 -0.77 +0.75 +0.74 +0.69 ------- (0.59)	% CENTRAL CITY HOUSEHOLDS WITH NO AUTO TOTAL TRANSIT VEHICLES POP. DENSITY IN CENTRAL CITY % CENTRAL CITY WORKERS USING TRANSIT % SINGLE - UNIT HOUSING AGE OF CENTRAL CITY ------- POPULATION RADIUS OF DEVELOPMENT No. INC. CITIES % FRINGE WORKERS USING TRANSIT PROJ. PRINCIPAL ARTERIAL DVMT ------- (NEXT HIGHEST LOADING)	SAN FRANCISCO	
2	22.2	+0.94 +0.92 -0.91 ------- +0.86 -0.86 +0.83 +0.81 +0.80 ------- (0.71)	PROJ. % AFFLUENT HOUSEHOLDS % HOUSING SOUND PROJ. % POOR HOUSEHOLDS ------- PROJ. MEAN HOUSEHOLD INCOME PER CAPITA INCOME GROWTH MEDIAN HOUSING VALUE AUTOS / FAMILY PER CAPITA INCOME ------- (NEXT HIGHEST LOADING)	SAN JOSE	SAN ANTONIO

Figure 9. Continued.

FACTOR	PERCENT VARIANCE ACCOUNTED FOR	OUTSTANDING FACTOR LOADINGS		OUTSTANDING FACTOR SCORES	
		COEFFICIENT	VARIABLE	AREAS WITH HIGHEST SCORES	AREAS WITH LOWEST SCORES
GROUP 7 (contd.)					
3	15.5	+0.81	PROJ. RT. MI. - FWYS.	DALLAS	BEAUMONT
		-0.80	% REVERSE COMMUTING		
		-------	-------		
		+0.76	PROJ. PRINCIPAL ARTERIAL DVMT / CAPITA		
		+0.74	AREA		
		+0.72	% MARRIED WOMEN WORKING		
		-------	-------		
		(0.65)	(NEXT HIGHEST LOADING)		
4	9.7	-0.91	No. CENTRAL CITIES	EL PASO SAN JOSE	SAN BERNARDINO
		-------	-------		
		-0.77	% POP. > 64 YRS.		
		-------	-------		
		(0.67)	(NEXT HIGHEST LOADING)		
5	9.4	+0.93	% GROUP QUARTER HOUSING	SAN DIEGO	BEAUMONT FT. WORTH
		-------	-------		
		-0.75	RETAIL STORES / CAPITA		
		-------	-------		
		(0.65)	(NEXT HIGHEST LOADING)		
6	7.8	-0.81	% FRINGE HOUSEHOLDS WITH NO AUTO	SAN DIEGO SAN ANTONIO	EL PASO
		+0.78	MEAN JAN. TEMP.		
		+0.77	PROJ. INCREASE IN PRINCIPAL ARTERIAL RT.MI.		
		-------	-------		
		(0.66)	(NEXT HIGHEST LOADING)		
GROUP 8					
1	35.4	+1.00	POPULATION	MIAMI	
		+0.98	PROJ. PRINCIPAL ARTERIAL DVMT		
		+0.97	PROJ. % DVMT ON PRINCIPAL ARTERIALS		
		-0.96	% CHANGE-PRINCIPAL ARTERIAL DVMT		
		+0.94	PROJ. RT. MI. - FWYS.		
		+0.92	AREA		
		-------	-------		
		+0.89	TOTAL TRANSIT VEHICLES		
		+0.86	POP. DENSITY IN FRINGE		
		-------	-------		
		(0.79)	(NEXT HIGHEST LOADING)		
2	30.0	+0.96	% MARRIED WOMEN WORKING		TAMPA
		-0.95	% SALES IN CBD		
		-0.95	% POP. IN CENTRAL CITY		
		-0.90	NONWORKER - WORKER RATIO		
		+0.89	% NON - WHITE		
		-------	-------		
		+0.84	MEDIAN HOUSING VALUE		
		+0.82	PER CAPITA INCOME		
		-0.81	No. CENTRAL CITIES		
		-------	-------		
		(0.76)	(NEXT HIGHEST LOADING)		
3	18.8	-0.95	No. INC. CITIES	ORLANDO	
		+0.91	PERSONS / HOUSEHOLD		
		-------	-------		
		-0.83	PROJ. % DVMT ON FWYS.		
		+0.82	% POP. < 18 YRS.		
		+0.81	% COMMUTING TO CENTRAL CITY		
		-------	-------		
		(0.77)	(NEXT HIGHEST LOADING)		

Figure 9. Continued.

FACTOR	PERCENT VARIANCE ACCOUNTED FOR	OUTSTANDING FACTOR LOADINGS		OUTSTANDING FACTOR SCORES	
		COEFFICIENT	VARIABLE	AREAS WITH HIGHEST SCORES	AREAS WITH LOWEST SCORES
GROUP 9					
1	19.4	+0.98	TOTAL TRANSIT VEHICLES	MINNEAPOLIS	
		+0.97	POPULATION		
		+0.97	PROJ. INCREASE IN PRINCIPAL ARTERIAL RT.MI.		
		+0.95	AREA		
		+0.95	PROJ. RT. MI. - FWYS.		
		+0.94	No. INC. CITIES		
		+0.91	PROJ. PRINCIPAL ARTERIAL DVMT		
		-------	--		
		(0.68)	(NEXT HIGHEST LOADING)		
2	19.2	-0.88	% FRINGE COMMUTING	ALBUQUERQUE	DULUTH
		+0.83	PROJ. PRINCIPAL ARTERIAL DVMT/CAPITA	NEWPORT NEWS	UTICA
				TUCSON	
		-------	--		
		-0.78	% POP. > 64 YRS.		
		-0.77	AGE OF CENTRAL CITY		
		+0.75	MEAN JAN. TEMP.		
		-0.73	% CENTRAL CITY HOUSEHOLDS WITH NO AUTO		
		+0.72	PROJ. PRINCIPAL ARTERIAL DVMT/ ROUTE MILE		
		+0.70	% HOUSING SOUND		
		-0.69	% WORKERS WALKING		
		+0.68	% POP. < 18 YRS.		
		+0.67	% SINGLE - UNIT HOUSING		
		-0.64	% FRINGE WORKERS USING TRANSIT		
		-------	--		
		(0.55)	(NEXT HIGHEST LOADING)		
3	12.1	+0.81	POP. DENSITY IN FRINGE	LANSING	DULUTH
		+0.81	% COMMUTING TO CENTRAL CITY	FLINT	TUCSON
				YOUNGSTOWN	WICHITA
		-------	--		
		-0.76	% POP. IN CENTRAL CITY		
		-0.76	PROJ. % POOR HOUSEHOLDS		
		+0.73	PROJ. % AFFLUENT HOUSEHOLDS		
		-------	--		
		(0.65)	(NEXT HIGHEST LOADING)		
4	11.6	-0.90	PER CAPITA INCOME GROWTH	WICHITA	NEWPORT NEWS
		-------	--		
		-0.72	PERSONS / HOUSEHOLD		
		-------	--		
		(0.66)	(NEXT HIGHEST LOADING)		
5	10.6	-0.81	AUTOS / FAMILY	NEWPORT NEWS	ALBUQUERQUE
		+0.81	AVG. EMPL. / MFG. EST.	FLINT	TUCSON
		-------	--		
		-0.74	% WHITE COLLAR		
		-0.74	SERVICE RECEIPTS / CAPITA		
		+0.70	% NON - WHITE		
		-------	--		
		(0.59)	(NEXT HIGHEST LOADING)		
6	8.2	-0.86	NONWORKER - WORKER RATIO	MADISON	YOUNGSTOWN
		+0.82	% MARRIED WOMEN WORKING		DULUTH
					TUCSON
		-------	--		
		(0.55)	(NEXT HIGHEST LOADING)		

relevant to the affluence of the community. Because the metropolitan areas comprising group 7 are thus differentiated in terms of variables related to affluence, such variables should be employed in extending system size, cost, and impacts from the case study results to the remaining metropolitan areas in group 7.

Those variables, or consistent sets of variables, that may appropriately be considered for inclusion in the case study sensitivity analyses (and thus in the process of extrapolating case study results) are identified in Figure 10 relevant to the various groups and factors. One criterion for inclusion is that the variable should be heavily loaded onto the indicated factors; a second criterion is that assumed changes in a variable should be meaningful in the context of the transportation planning process. Thus, while an assumed variation in nonworker-to-worker ratio might be interpreted in terms of revised distributions of travel by peak hours and trip types, the effects of an assumed change in mean January temperature would be more difficult to handle in the planning process, and the latter variable is not included in the list of Figure 10.

The information in Figure 10 is one possible set of guidelines for the structuring of case studies and sensitivity analyses. Thus, in the example for group 7, appropriate and consistent assumptions would be made concerning changes in the affluence-related variables (percent housing sound, median housing value, per capita income, projected mean household income, and projected percentages of both poor and affluent households). The assumed new variables would be loaded onto the 6 factors identified through the factor analysis process for group 7 such that the true case study area and the assumed more affluent version of the case study area are 2 distinct points in the 6-dimensional space defined by the factors (and with the imposed deviation within that space primarily along the direction of factor 2). Consistent adjustments would then be estimated in trip generation rates, modal split effects, right-of-way acquisition costs, perceived value of time, etc., in the transportation planning and evaluation process so as to yield modified estimates of system size, cost, and impacts. This process would be repeated for additional sets of variables (so as to produce deviations along other directions in the factor space and to result in additional estimates of size, cost, and impacts), as planning resources may permit and with priority directed toward factors of higher rank.

The desired sensitivity measurements would then be estimated as partial derivatives of the functions (system size, cost, impacts) at the point defined by the case study area

Figure 10. Variables for inclusion in case study sensitivity analyses.

VARIABLE	RANK ORDER OF FACTOR							ASSOCIATED VARIABLE TYPE*
	GROUP 3	GROUP 4	GROUP 5	GROUP 6	GROUP 7	GROUP 8	GROUP 9	
POPULATION	4	1	-	1	1	1	1	SIZE (VAR. NO. 1,2,3,5,45)
PROJ. MEAN HOUSEHOLD INCOME	1	2	-	3	2	-	-	AFFLUENCE (15,18,19,21,22,23)
PROJ. % POOR HOUSEHOLDS	1	-	1	3	2	-	3	AFFLUENCE (15,18,19,21,22,23)
% NON-WHITE	3	-	6	2	-	2	5	-
% CENTRAL CITY HOUSEHOLDS WITH NO AUTO	3	6	-	4	1	-	2	-
% POP. > 64 YEARS	-	2	6	2	4	-	2	LIFE CYCLE (12,13,14)
PERSONS/HOUSEHOLD	1	2	-	-	-	3	4	LIFE CYCLE (12,13,14)
POP. DENSITY IN CENTRAL CITY	2	-	-	-	1	-	-	DENSITY-TRANSIT USE (9,16,34,35,38)
% CENTRAL CITY WORKERS USING TRANSIT	2	1	4	-	1	-	-	DENSITY-TRANSIT USE (9,16,34,35,38)
NONWORKER-WORKER RATIO	-	3	2	-	-	2	6	LABOR FORCE PARTICIPATION (25,26)
% MARRIED WOMEN WORKING	1	3	-	-	3	2	6	LABOR FORCE PARTICIPATION (25,26)
% GROUP QUARTER HOUSING	-	2	2	5	5	-	-	-
POP. GROWTH FACTOR	3	5	-	5	-	-	3	GROWTH RATE (7,46)
% CHANGE IN PRINCIPAL ARTERIAL DVMT	3	5	4	-	-	1	-	GROWTH RATE (7,46)
% COMMUTING TO CENTRAL CITY	1	4	2	-	-	3	3	
% FRINGE COMMUTING	3	4	6	-	-	-	2	

* - VARIABLES, IN GENERAL, WITH SIMILAR LOADING VALUES. SEE FIGURE 9 FOR SPECIFIC RELATIONSHIPS ON FACTORS. SEE FIGURE 2 FOR INDEX TO VARIABLES

in the directions defined by the orthogonal factors. The estimation of system size, costs, and impacts in the additional metropolitan areas in group 7 would then follow through the knowledge of the location of those metropolitan areas relative to the case study area in the factor space (based on known values of the variables and the factor loadings) and the estimated value of the partial derivatives of system size, cost, and impacts.

The foregoing process of case studies, sensitivity analyses, and extrapolation of results would be accomplished for each of the groups 3 through 9. For the three metropolitan areas comprising groups 1 and 2 (i.e., New York, Chicago, and Los Angeles), it is suggested that individual case studies be performed if the system under study is considered applicable to those locales. Overall costs and impacts, and the likely market for the new system, are then estimated by summation over all groups; Canty and Golob (18) discuss the methodology of such aggregation processes.

DIRECTIONS FOR FURTHER RESEARCH

The research framework discussed in this paper contains features that are new to the urban transportation systems requirements analysis, planning, and evaluation process, including

1. A procedure, and selected results, for the classification of metropolitan areas into groups, each of which is relatively homogeneous in regard to a multiplicity of metropolitan area characteristics relevant to a perceived transportation need (rather than with respect to just 1 or 2 such characteristics), plus a companion procedure for the identification of the most representative metropolitan areas within each group as preferred locales for case studies; and
2. A procedure, in outline form with statistical guidelines, for the extension (extrapolation) of case study results to other metropolitan areas, taking into account the influence of a number of metropolitan area characteristics.

Although the classification and extrapolation procedures are compatible and complementary, each is of value independent of the other. Thus, metropolitan areas could be stratified on the basis of size alone, with case study results being extrapolated on the basis of several characteristics as in procedure 2 above. Also, metropolitan areas could be classified into homogeneous groups as in procedure 1 above and results extrapolated on the basis of a single variable (e.g., population size). The latter approach has much appeal in terms of minimizing level of effort, inasmuch as the classification procedure needs to be performed only once for each type of application (e.g., urban arterial transportation) while the extrapolation process must be repeated for each and every case study (i.e., each combination of metropolitan area group, system requirement, and system design).

The approach most often used currently, where metropolitan areas are stratified by a single variable—population size—and where case study results are simply scaled to other metropolitan areas on the basis of population, is much less likely to yield valid results. The fact that each group is made as homogeneous as possible with regard to population size and not with regard to other factors minimizes the usefulness of population size as an extrapolating factor. When metropolitan areas are classified, as in procedure 1 above, into groups that are relatively homogeneous with regard to a host of variables, extrapolation of case study results on the basis of size should become more valid.

These considerations lead to the following directions for further research:

1. The procedure for classification of metropolitan areas into homogeneous groups could be repeated for additional urban transportation applications (including transportation for the young, old, poor, handicapped, and other mobility-deprived members of urban society, and medical, education, and housing system studies) and with appropriately different data bases (different variables and possibly levels of urban structure other than the metropolitan scale).
2. A consensus could be reached among governmental, university, and industrial research groups on a consistent classification of metropolitan areas in order to maxi-

mize the usefulness of data bases and to integrate the results of numerous ongoing system requirements analysis, design, and evaluation studies in transportation and other urban systems.

3. Planning groups concerned with the task of estimating overall markets or costs-benefits-impacts of new system development and implementation based on analyses and demonstrations in case study areas should consider the processes outlined in this paper as a basis for case study selection and extrapolation of results.

4. The procedure outlined in this paper for the conduct of sensitivity analyses and the extrapolation of case study results could be performed, at various levels of complexity (i.e., for 1, 2, 3, or more sets of variables) in order to analyze and evaluate the cost-effectiveness of the procedure, that is, the necessary level of effort versus the degree of difference in the results (estimated system size, cost, and impacts).

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